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AN OVERVIEW OF MATERIALS SCIENCE AND ENGINEERING IN JAPAN.(U)

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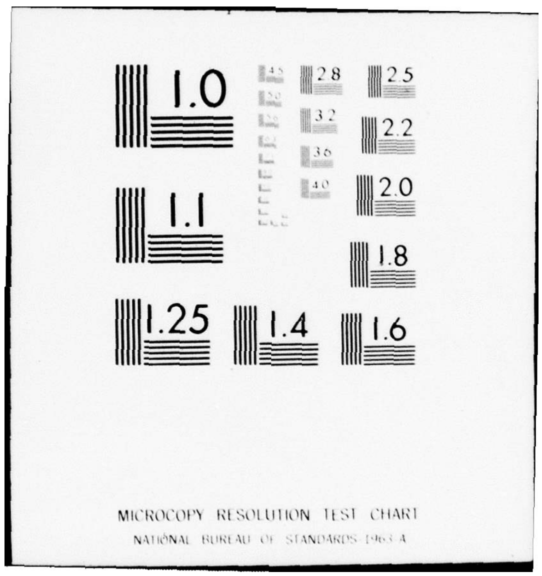
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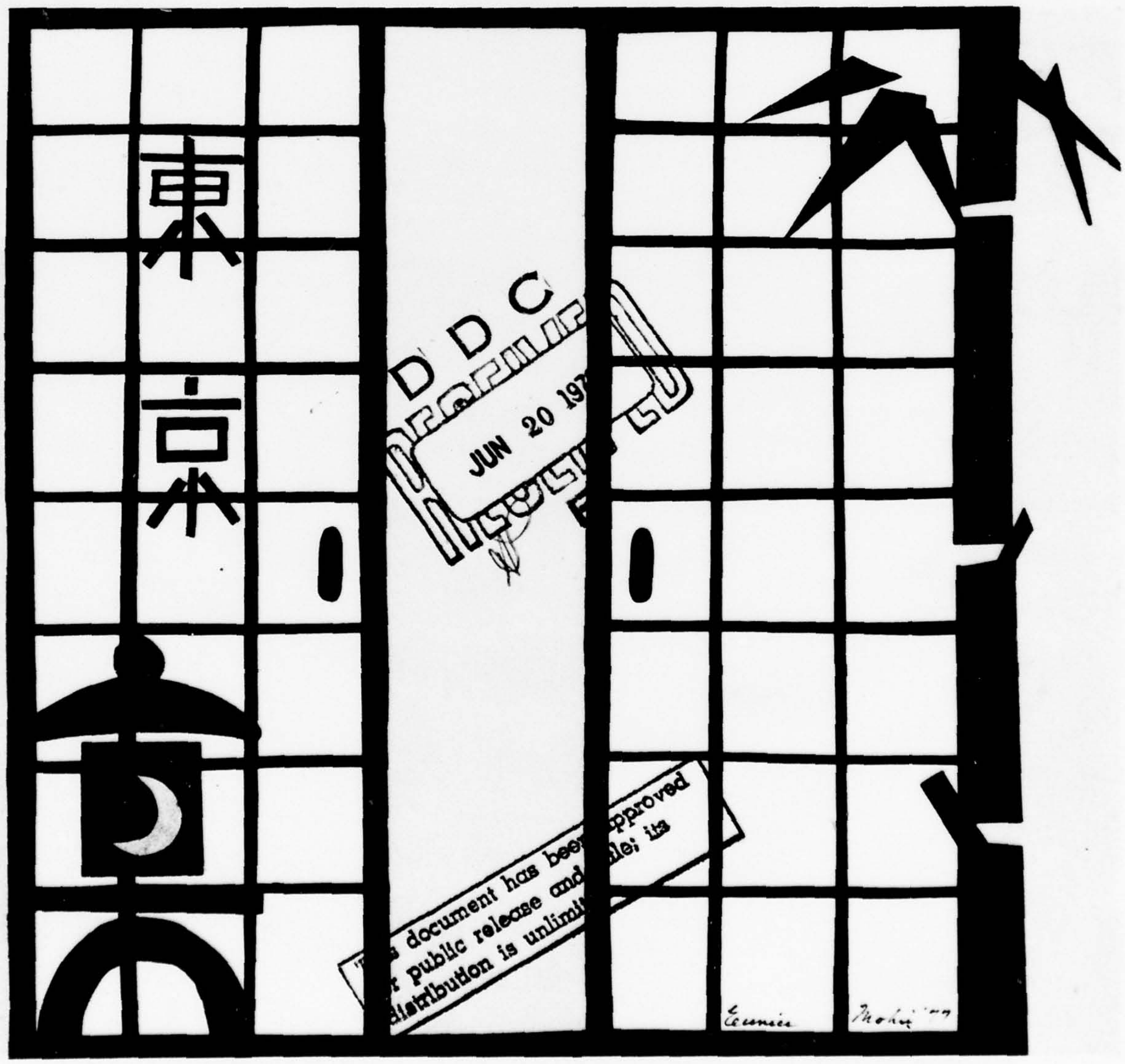
# AN OVERVIEW OF MATERIALS SCIENCE AND ENGINEERING IN JAPAN

1977

116p.

GEORGE SANDOZ



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In 1977 a tour of Japan was organized to foster scientific communications between the Office of Naval Research and the Naval Research Laboratory, and the industrial and academic materials research communities of Japan. An effort was made to visit key laboratories and industries involved in metals production (steel, cast iron, aluminum, copper, titanium), in transportation (ships, aircraft, rail, automotive), in energy production

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20. and use (oil, electric, industrial chemicals, nuclear and chemical energy) and in construction (off-shore platforms, oil and gas pipelines, buildings, machinery). The universities visited were chosen on the basis of research interests, available contacts, and prominence in materials research.

The results of the tour are given in this report.

## ABSTRACT

In 1977 a tour of Japan was organized to foster scientific communications between the Office of Naval Research and the Naval Research Laboratory and the industrial and academic materials research communities of Japan. An effort was made to visit key laboratories and industries involved in metals production (steel, cast iron, aluminum, copper, titanium), in transportation (ships, aircraft, rail, automotive), in energy production and use (oil, electric, industrial chemicals, nuclear and chemical energy) and in construction (off-shore platforms, oil and gas pipelines, buildings, machinery). The universities visited were chosen on the basis of research interests, available contacts, and prominence in materials research.

The results of the tour are given in this report.

# CONTENTS

**THE COVER:** is the artist's concept of being outside looking in, symbolically depicting a foreigner's view of Japan and the Far East. It was done in kirie (a Japanese "cut and paste" form of collage) by Eunice Mohri, a member of the staff of ONR Tokyo.

## AN OVERVIEW OF MATERIALS SCIENCE AND ENGINEERING IN JAPAN

## INTRODUCTION

The visits described here were intended to provide an exchange of technical information in the materials and structures area between ONR and industrial, institutional, academic and to an extent, governmental organizations in Japan. The tour began on January 12, 1977 and terminated on April 30, 1977. Visits were numerous and widespread, but only major cities on the islands of Honshu and Kyushu could be covered in the time available. The Japanese contacts were made through searches of the literature, recommendations from United States technical colleagues and through personal acquaintances within Japan developed through years of discussions and correspondence in connection with research projects, published papers and technical presentations. The ONR Tokyo Office, ONR Headquarters Office, Naval Research Laboratory and many ONR contractors also provided suggestions for visits.

The industries contacted were in the metals production and fabrication area (steel, cast iron, aluminum, titanium, copper) the transportation area (automobiles, rail, aircraft, ships) the energy area (nuclear, fossil fuel, geothermal, electric utilities) and the construction industry (off-shore platforms, oil and gas pipelines, buildings, machinery). The universities and institutes were involved in almost all areas of materials research from basic physical metallurgy and metal physics to the development of weld procedures and the processing of ceramics. The specific organizations visited are listed in the Table of Contents.

In almost all cases the visits were welcomed enthusiastically by the Japanese organizations. There were no awkward incidents and apparently no problems developed from the presence of a Navy representative, even among the students. This was very reassuring because in the initial contacts a few of the Japanese were apprehensive about the visits. One university professor was so concerned about possible incidents, for example, that a proposed visit to his university was never consummated. This professor was incidentally a personal acquaintance who was very anxious to arrange a private meeting. Another scheduled visit to the Japanese Defense Agency was cancelled following a surprise last minute requirement that all questions be submitted in advance and in writing.

As visits were arranged there was usually a request for presentations on ONR-NRL activities. These presentations were tailored with respect to technical interests and size of the audience (the audiences varied from a mere handful to more than a hundred at institutional and technical society gatherings; major addresses were given at Nagoya University, Osaka University and Tohoku University). Most of the talks were organized within the general framework given in the Appendix.

The courtesy and hospitality of the Japanese have been widely acclaimed, but one cannot help being surprised and delighted on a first visit. Beyond the fabulous treatment and genuine friendliness from the people involved in the formal visits, there were numerous encounters with total strangers who were just magnificent in their kindness and helpfulness.

A trip to Furukawa Aluminum Ltd. in Nikko, for example, required the first long train ride. About a half hour out of Tokyo vendors began to pass through the aisles to distribute a number of delicious snacks and beverages. As they arrived at the writer's seat a nearby man began to distribute many of these edibles. Since no money exchanged hands, it was assumed to be part of the service which comes with the ticket. Having enjoyed this excellent "feature" of Japanese train service, it was a shock to learn later that in fact the writer had adventitiously joined a party of Japanese on an excursion, and that his good neighbor had paid for all the refreshments! Of course, out of the writer's thoughtlessness and naivity, the generous Japanese companion received not even a "thank you." Perhaps he will read this and come to know the warm gratitude which lingers.

This courtesy and concern shown to the foreign traveller is perhaps born of centuries of relative isolation and the natural curiosity about strangers which this creates, plus a long tradition of gracious customs and good manners among the Japanese people themselves. Wherever the hospitality originates, one notes sadly that the progress of Westernization seems to proceed relentlessly, and that this, coupled with a burgeoning number of visitors, appears to be slowly eroding these charming Japanese customs. One detects for example, a slight difference between the young and the older citizens.

Another reason for the civil behavior, good manners and cheerful tolerance among the Japanese people is perhaps that Japan enjoys a unity in race and cultural background. Moreover, the very crowded conditions in Japan may have nurtured out of sheer necessity a system of relationships which preserve peace of mind. This is highly visible in the respect for privacy. In several instances, for example, lunches were served by Japanese girls on company premises (women's liberation is barely launched in Japan). The serving process required numerous entrances into and out of the dining area, usually a conference room. The point is that every entrance and exit involved the opening or closing of the doors to the room, and every entrance produced a prior knock on the door. This was quite amusing and touching in cases where numerous dishes were served.

The unity of the Japanese people generated from isolation, racial and cultural similarities and ancient traditions may in part also relate to the disaster of World War II—the fight and the defeat. In several cases spectacular industrial successes seem to derive from meeting the challenges which the early post-war experiences imposed as an absolute condition for survival.* One example was seen at Hitachi Metals Ltd. in Kitakyushu. Immediately after the war with all its damage this malleable iron manufacturer was unable to obtain the customary raw materials. The iron, fuel, slags, ferroalloys, etc. were hopelessly erratic in composition and in metallurgical characteristics. This is a disastrous situation in malleable iron manufacture because only small variations in composition or the unsuspected presence of trace elements can wholly alter the annealing and casting characteristics which must be controlled for a satisfactory product. The Japanese answer? Get to work. Hitachi Metals began technical investigations and research studies to learn how to deal with the new problems. They also devoured all the information they could get from the technical literature, particularly European and American. They attended numerous technical conferences and meetings overseas. Gradually a series of company reports were generated which pointed to the solution of specific problems. The 30 year technical output of this one small company, which was reviewed on site, is most impressive. Today, Hitachi Metals boasts new and modern facilities, advanced techniques and a knowledgeable staff. The company can compete with any company in the world.

This is one example of how the Japanese compete so well economically and industrially. One aspect of this success has been stated—a willingness to work hard. This willingness is partly a response to the challenges of defeat in war as has also been stated, but there are deeper ancient motivations. Japan is an island without resources, without the capacity to feed itself, teeming with people. These very conditions were doubtless an influence in the expansionist policies which culminated in Pearl Harbor. With the economic and other burdens of defeat, and having been frustrated in the attempt to expand, Japan was forced to look to its own wits and the largess of the United States for its survival.

The willingness to work is evidenced everywhere in Japan, but especially in the educational system. It is heartbreaking to see how young children are forced to compete in examinations which, if passed, lead eventually to admission to the most prestigious preparatory schools and universities. Admission to the right university almost assures success; failure precludes that a chosen career can be followed in most cases. Parents make great sacrifices to provide special tutoring and instruction for their children to enhance the chances for passing the examinations. Failure is taken hard. It has been reported that 800 Japanese children age 5 to 19 killed themselves this year because of the heavy homework or failure in examinations.

Within the universities there is also strong competition, and what appears to be unquestioned subordination to the leadership. Students study hard. Associate professors work hard. This is traditional, and beyond what is necessary to assure advancement; that is, there is a pervading loyalty and devotion to the immediate superior as well as to the system in general which spurs the intensity of efforts.

The same general tone is seen in industrial research activities. In industry, loyalty to the company is a further motivation since the individual ordinarily spends his career with a single company. One senses the Japanese worker is driven by the expectations of his family, his fellows, his company and perhaps his country with an intensity unfamiliar to Americans. This perhaps accounts also for the near absence of street crime.

In addition to the willingness of the Japanese to try hard, there is also the willingness to live cheaper. This is especially noticed in the housing area where there is just no comparison to what is considered acceptable in America. Top professors and industrial executives with world-wide recognition live in very modest houses or apartments in Japan. This situation worsens with time and the disappearance of building sites. Many Japanese families were observed to share their parents homes, wholly unable to purchase a home of their own as prices have burgeoned. Even one car is a luxury. Part of this is of course due to the compactness of the islands which imposes a special premium on any possessions which require space or land. Other valuable goods, such as fine cameras, are widely possessed. Still, the impression is that in Japan people work longer to obtain fewer material goods.

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*Other writers have challenged the opinion that Japanese engineering companies do well in stiff competition (see Chemical and Engineering News, September 5, 1977)

As for the contributions of the United States to the well being of Japan, the most obvious is the immunity from the burdens of defense. Other assistance has been given in the form of tolerance in permitting Japanese products to flow relatively unimpeded into the United States markets.* A somewhat less obvious contribution has been technical assistance. For some 30 years there has been a flow of Japanese to the United States to visit industries and to study with prominent scholars in the finest universities. During the visits in Japan it was very noticeable that a high proportion of key technical persons had either visited extensively in the United States or Europe or had actually studied extensively abroad to earn an advanced degree or done postgraduate work.

Thus there is a highly trained cadre of technical experts in Japan who have been trained abroad. It is apparent that the technical expertise and technology of the United States have been exported at a very reasonable price. This is no criticism of the Japanese who have only sought to prosper under difficult conditions, within our rules and within the bounds of fair play as we have defined these bounds.

The writer was told that over the past decade or so, as basic research funds in the United States have evaporated, many basic scientists (in materials areas) who were trained in the United States have returned to Japan where they are doing the type of work which no longer attracts support here. This work is being supported by the Ministry of Education and other government agencies in the form of small but unrestricted annual grants. The spectre arises of Japan (and other countries) capturing the lead in fundamental research areas where the United States has for many years been out front. The long range effects cannot be seen clearly, but the United States may be saving very little money in comparison to the risks involved.

The success of the Japanese is therefore seen as the product of intense effort, unity in culture and goals and help, intentional or otherwise, from the United States and Europe. Under these circumstances it is doubtful that the United States could compete economically without the advantages of abundant natural resources, space and perhaps an edge in very high technology.

In this connection there is an important point to be made in favor of the Japanese technical community, which has been under fire recently in the American press. *In all of the technical exchanges which were* made in this tour, the Japanese appeared to be honest, forthright and sincere. There was no evidence of anything deceitful or sinister or underhanded or dishonest or treacherous at any time. As a matter of fact the Japanese appear to be very anxious to cooperate in a variety of technology transfer arrangements.* It is as if at last Japan can see itself becoming an equal partner, and takes pleasure in this.

To the mind of the writer, then, there is no profit or substance in searching for unprincipled methods or motives in the Japanese technological world. Technical organizations in the United States are at least as mischievous.

In one way Japan is a sad place to visit in that the crowding, depleted resources, heavy industrialization, decline of agricultural areas, pollution of the waters, land and air and the generally declining level of material self sufficiency could preview the United States to come; the same road is being traveled. Still, there is hope, for Japan is wide awake to the dangers. One sees new interest in green space, natural areas, and pollution control systems, and there are fierce struggles within Japan between the forces of commerce and those concerned with environmental management. Because Japan has been hurt earliest, she will perhaps also be first to find the solutions.

The sections which follow describe individual visits. Some of the thoughts which have been expressed here will appear again in these descriptions, if only between the lines. Hopefully, the affection of the writer for Japan and the Japanese people and his sincere gratitude for the chance to form these new friendships will also come through.

Finally, for those patient readers who have reached this point, the writer should acknowledge that he is strictly a 90 day wonder with respect to Japan, painfully aware that the impressions described are based on limited experiences. As a matter of fact, the writer suspects that a major qualification in being selected for the tour was an undisputed claim to total ignorance of Japan, thus assuring an open mind and freedom from any preconceived notions. This major qualification was probably only slightly abraded* by the experiences recorded in this report.

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*The reverse flow appears to be highly restricted, except for perhaps raw materials and some agricultural products. The relative number of American or European automobiles, television sets, appliances, etc. seen in Japan is nearly zilch. On being queried about the sparsity of American cars, the reply is often that American vehicles are too large for Japan's roads. But American subcompacts and many European cars are as small as Japanese cars but are seen no more frequently. Similarly, it would be unheard of for a Japanese industry to import steel products from the United States.

*See for example references to Dr. T. Ikeno (Nippon Steel Corporation), p. 58; Dr. K. Terai (Kawasaki Heavy Industries), p. 85; Drs. Y. Nishio, R. Ebara and T. Daikoku (Mitsubishi Heavy Industries), p. 91 and 92.

*The Japanese have trouble with words like this. One company brochure boasted of experiments on "abrasion" cooling. It took some discussion before it was ascertained that "ablation" cooling was intended. What fun!

## HIROSHIMA UNIVERSITY

Hiroshima University is eighth largest among government supported Japanese universities. Although it was not established until 1949, some elements date back to as early as 1902. There are nine faculties at present including law and medicine. Of interest to the materials community are the Faculty of Science, which includes a Materials Science Department, and the Faculty of Engineering which includes a number of departments with interests in materials and materials performance. There are also several Research Institutes, including a Laboratory of Crystal Physics which is attached to the Faculty of Science. The Faculty of Engineering has recently been reorganized into four divisions: mechanical engineering, electrical engineering, chemical engineering and structural engineering. Doctoral programs in engineering have also been started.

On this visit Professor K. Nakasa and H. Takei of the Faculty of Engineering were visited. These professors are working in the areas of fatigue and fracture. A few highlights of the discussions follow:

1) 500° F embrittlement - the professors have shown that 500° F embrittlement shows up in $K_c$* (crack initiation) and $K_c$ parameters but that the plane strain parameter $K_{Ic}$ is insensitive. Thus plastic deformation is required at the notch or crack tip for 500° F embrittlement to be observed. Of equal interest, dimple rupture is the fracture process in both embrittled and non-embrittled specimens, and therefore an intergranular process does not necessarily accompany 500° F embrittlement (See JJIM *37*, 754, 1973).

2) Sheet thickness effects on fracture toughness of high-strength steels - Studies of the effects of specimen thickness B on the fracture toughness parameter $K_c$ and on shear lip thickness $B_{SL}$ were made on several steels of varying tensile strength. The value of $K_c$ increases with thickness in the range of small specimen thickness where slant fracture occurs. At intermediate thickness, where mixed slant and flat fracture regions are observed, $K_c$ decreases with increasing thickness. Greater specimen thickness, where flat fracture predominates, produces gradually decreasing $K_c$ until the value of $K_{Ic}$ is approached. Shear lip thickness $B_{SL}$ decreases with specimen thickness over the intermediate region of mixed slant-flat fracture.

On the basis of the results Nakasa and Takei propose an approximate relation $B_{SL}/B = \alpha\beta_c{}^m$, where B is specimen thickness, $B_{SL}$ is shear lip thickness, $\beta_c$ is relative plastic zone size, m is an exponent (value 0.6 ~ 1.0) independent of material and $\alpha$ is a coefficient dependent on the work hardening exponent. The relative plastic zone size $\beta_c$ is given by $K_c{}^2/B\sigma_y^2$ where $\sigma_y$ is yield strength and the coefficient $\alpha$ is given by $0.0016/_n1.6$. The work is described in JISI, *62*, 1523, 1976.

3) Effects of mechanical and environmental effects on fatigue life - Several variables on fatigue have been studied. For example, the effects of small repeating stress on the delayed fracture crack initiation in high strength Ni-Cr-Mo steel (4340 type, 50 Rc) has been of interest. It is considered that very small repeating stresses (large R value) may produce fundamentally different effects than larger repeating stresses superimposed on the static load. Very small repeating stress may have little effect on static fatigue, and may produce effects similar to a change in temperature or environment. On the other hand, larger amplitude repeating stress superimposes fatigue and delayed fracture phenomena and the interaction in corrosion fatigue must be considered. In short Nakasa and Takei are attempting to use superimposed alternating stresses of various amplitude and frequency in static fatigue tests to deduce mechanisms for the effects of corrodents and hydrogen. Two papers (JJIM, 40, 744, 1976 and Eng. Fracture Mech, submitted March 1977) present data on the effects of superimposed stress and varying frequency on fatigue strength of notched specimens and on crack incubation time, crack growth rate and $K_{Iscc}$ of precracked specimens. The superimposed stresses decrease fatigue life in the notched specimens. The incubation time (time to initiate crack growth) and $K_{Iscc}$ in precracked specimens are decreased by the repeating load as the range of $\Delta K$ or the frequency increases. The crack propagation rate is decreased by the superposition of increasing alternating load but there are minima in the curve of frequency versus da/dt. The investigators attribute the decreased incubation time and $K_{Iscc}$ value to the effects of the repeating load and increasing frequency in promoting corrosion reactions. Surface films rupture at the crack tip, which in turn increase the supply and adsorption of hydrogen.

The decrease in crack propagation rate is explained as a net reduction in hydrogen concentration at the position of highest triaxial tensile stress. The area of highest triaxial stress moves inward from the surface with increasing $\Delta K$, and hydrogen must diffuse further from the surface at the crack tip. When the value of $\Delta K$ is large, hydrogen, cannot diffuse to the region of maximum stress before the stress cycle reverses. It is also suggested that the generation of compressive residual stress or a change of microstructure near the crack tip caused by the alternating load may suppress the entrance and diffusion of hydrogen.

The interaction of delayed failure and the initiation and propagation of fatigue cracks in Ni-Cr-Mo steel were discussed with reference to a recent paper (Trans JIM *17* 726, 1976). Nakasa and Takei (with T. Asamoto) develop an expression for fatigue crack growth rate in water which sums the fatigue crack propagation rate in air and the crack propagation during static fatigue in water. Thus,

$$\left(\frac{da}{dN}\right)_w = \frac{da}{dN} + \beta \frac{\frac{da}{dt}}{f}$$

$$\text{where } \frac{da}{dN} = c_1 \ \Delta K^{m_1}$$

$$\text{and } \frac{da}{dt} = c_2 \ K_D^{\ m_2}$$

In these expressions $\Delta K$ is the stress intensity range, $K_D$ is the stress intensity in delayed failure (static fatigue), f is frequency and $\beta$ is an addition coefficient.

The value of $\beta$ found by the Hiroshima University investigators is apparently 0.3 rather than the value of 1.0 which Wei and Landes had proposed earlier (Mat. Res. Std., *9*, 25, 1969). The value of $\beta$ is related also, according to the Japanese investigators, to the interaction of hydrogen atoms and the cyclic change of triaxial stress field.

Nakasa and Takei have recently studied the effects of temperature on the frequency dependence of crack propagation rate in delayed failure under cyclic load. The paper is intended for publication in Engineering Fracture Mechanics.

Another recent fatigue investigation involves the effect of fatigue accumulation on delayed failure crack initiation in high strength steel. The steel is again the 4340 Ni-Cr-Mo type, tempered at either 200°C or 400°C. Bend specimens have been used in the notched condition, and pulsating stresses of various amplitudes and frequencies have been applied to study the effects of fatigue accumulation on subsequent static fatigue test results. It has been found that specimens tempered at 200°C show a decrease in crack initiation time in delayed failure with increases in fatigue amplitude and accumulation. The critical stress for such initiation, however, is not affected. Specimens tempered at 400°C show both reduced time for initiation and in critical stress with fatigue accumulation. For further detail, see JJIM *39*, 735, 1975.

The discussions with Nakasa and Takei convince one that first class work is conducted at Hiroshima University. A lengthy visit would likely have been well worthwhile. When one recalls that the holocaust of some 30 years ago wiped out this school physically, the progress which has been made is astonishing.

## KOBE MERCANTILE MARINE UNIVERSITY

Following a visit to Kawasaki Heavy Industries (Dr. K. Terai, host), the writer was contacted by Mr. A. Iwata of Kawasaki Heavy Industries and Professor Y. Saji of Kobe Mercantile Marine University concerning some experiments they are conducting on a ship propulsion scheme. The work is being done at the Mercantile Marine University, with Iwata working on a spare or release-time basis. The investigators requested an on-site visit, and this was done.

Basically, the propulsion device involves turning the ship and sea into an electric motor. A magnetic field is supplied using superconducting circuits, and an electric current passed through the saltwater produces a force which propels the ship. The chief advantage is of course that noise from a propeller is eliminated. Hull seals are also eliminated. Disadvantages include highly detectable magnetic and electric fields and poor efficiency.

The experimental setup at the Mercantile Marine University includes a working model. About the size of three bread baskets, it produces a force of 5 grams. It also releases copious quantities of gas generated electrolytically in the water and at the surface from the liquid helium required to produce the superconducting magnet.

According to the investigators, the efficiency is potentially much greater in a large scale model, and they are seeking the necessary support for this work. The construction of the present working model and the calculations indicating an efficiency increase with size are apparently the chief contribution of Iwata and Saji; the basic idea of the propulsion system was admittedly described earlier by USA investigators (and so referenced by Iwata and Saji).

## KYOTO UNIVERSITY

Kyoto University was founded in 1897 and a College of Science and Engineering was one of the four colleges which composed the university at that time. In following years many other colleges were formed and Kyoto University is of course well-known today throughout the world. On this occasion the Department of Metal Science and Technology and the Department of Metallurgy were visited. Principal host was Assistant Professor Paul Shingu, of the Department of Metal Science and Technology. Dr. Shingu is a graduate of Northwestern University and is in the Foundry Technology Laboratory (of all places) directed by Professor R. Ozaki. Other groups in the Department of Metal Science and Technology are the Lattice Defects and Crystal Plasticity Laboratory (Professor J. Takamura), the Structural Metallurgy Laboratory (Professor M. Adachi) the Science of Steels Laboratory (Professor I. Tamura), the Metal Physics Laboratory (Professor Y. Nakamura) and the Welding Engineering Laboratory (Professor M. Mizuno). The juxtaposition of basic metallurgy studies groups with the "practical" groups associated with foundry and welding is an intriguing feature of the Department of Metal Science and Technology.

The Department of Metallurgy is composed of the Iron Metallurgy Laboratory (Professor T. Mori), the Nonferrous Metallurgy Laboratory (Professor J. Moriyama), the Electrometallurgy Laboratory (Professor H. Majima) the Science of Metallic Materials Laboratory) Professor Y. Murakami, the Foundry Metallurgy Laboratory (Assistant Professor Y. Kawano) and the Process Metallurgy Laboratory (Professor Y. Kondo).

It is obvious that the groups in the two metals departments are often complementary and perhaps even overlapping (the Navy reorganizers would have great fun here), but a great deal of interaction and cooperation was observed. The present organization is working.

One current activity of the Foundry Technology Laboratory (P. Ozaki, P. Shingu and K. Kabayashi) is on the details of crystal growth and solidification in the eutectic and near-eutectic compositions of the Al-Si system. In hypereutectic alloys the plate-like primary *silicon crystals* grow by the so called TPRE (twin plane re-entrant edges) mechanism. The silicon crystals in sodium treated melts appear to be spherical and are composed of several pyramidal grains with tops at the center of the sphere. Many have a twin relation to each other. The sodium enriched regions are located at the boundaries of the pyramidal silicon grains. The external surfaces of the spherical primary crystals exhibit regular crystal facets, usually parallel to {111} planes.

The crystallographic relationship between the primary silicon crystal and aluminum crystal nucleated heterogeneously on the silicon surface in hypereutectic Al-Si alloys is apparently random, but Shingu and others have shown that the orientations may be clarified simply by consideration of the twinning in the primary silicon crystals. The epitaxial relationships between silicon and aluminum crystals in untreated alloys and in sodium-treated alloys are different.

Silicon crystals usually nucleate on the surface of aluminum with little undercooling, but aluminum crystals are difficult to nucleate on the surface of silicon crystals. An explanation is offered in terms of relative interfacial energies.

There is a shift of the aluminum solidus in the Al-Si system resulting from sodium additions. Slightly hypereutectic Al-Si alloy treated with sodium shows primary crystals of aluminum rather than silicon. This shift in eutectic composition is explained in terms of thermodynamic considerations rather than the poisoning of heterogeneous nucleation sites by sodium as advanced previously by other investigators. Further details on this work may be seen in Jr. Materials Science *11*, 399, 1976, *10*, 290, 1975; Scripta Metallurgica *10*, 525, 1976 and Trans JIM, *17*, 545, 1976.

Shingu and his colleagues have also studied and apparently discovered the first iron-carbon amorphous metal and in particular amorphous cast iron. Shingu and Ozaki have made numerical calculations on solidification rate for splat-cooling, and the relative importance of such factors as splat temperature, substrate temperature, thermal contact between splat and substrate and splat thickness. These calculations indicated that improvements in splat-cooling procedures could be made and this was confirmed by the production of amorphous structures in near-eutectic iron-carbon splat-cooled material. A gun method of splat-cooling in vacuum was used. An important innovation was the protection of the substrate silver plate from the adsorption of gas. Before cooling the substrate, its surface was covered by soft rubber to avoid deposition of residual gases. Immediately prior to splat cooling, the rubber cover was removed by a magnetic device located within the vacuum chamber.

Shingu's group is continuing to study the conditions to obtain the amorphous state by continuous cooling. There are essentially two possible controlling processes: 1) the movement of the solid-liquid interface is limited by atomic transport and arrangement processes and 2) the solid-liquid interface velocity is limited by the external gradients which can be developed. Shingu has estimated the degree of kinetic undercooling which can be obtained. A limiting condition of cooling is seen when the cooling rate is so large that the crystal growth cannot cover the whole sample body before it is cooled to a temperature so low that the growth rate of the crystal is negligible.

This work on amorphous alloys is described in some detail in the literature (see Scripta Metallurgica, *8*, 1317, 1974, Materials Science and Engineering, *23*, 183, 1976 and Met. Trans., 6A, 33, 1975). Presentations were also made to the Second International Conference on Rapidly Quenched Metals, MIT, 1975 and to the Joint United States-Japan Seminar on Solidification of Metals and Alloys, Tokyo, January 17, 1977.

Shingu is currently studying the properties of amorphous metals including density changes upon annealing and the variation of viscosity with temperature. Amorphous metals get very viscous near the recrystallization point, Tg. The activation energy is high because viscous movement is involved upon deformation of amorphous metals at high temperatures. There is no lattice diffusion; hence crystal growth is impeded.

Shingu is also studying the solidification of seawater, taking into account not only the thermal gradients but also the concentration and distribution of salt. Because of changes in composition, the temperature of solidification changes. A paper was presented on this subject to the Joint United States-Japan Seminar on Solidification of Metals and Alloys, Tokyo, January 17, 1977, entitled "An Analysis of the Solidification Rate of a Binary Eutectic System." The experiments described were based on observations of solidification along and within a glass tube filled with saltwater and cooled at one end with liquid nitrogen.

Discussions of studies on reinforced composites were held with Dr. Shojiro Ochiai of the Science of Metallic Materials Laboratory. Composite materials may be degraded by the interfacial chemical reactions which may occur between matrix and fiber; therefore, Ochiai and his colleagues are studying the effects of interfacial conditions on the mechanical properties of composites. Included in these studies are the effects of surface roughness, coatings, etc. It has been found from deformation experiments on Mo/Cu - Cr composites and W/Cu composites that the tensile strength is lower than calculated from the rule of mixtures, probably because of damage to the solid solution at Mo fiber interfaces or from reduced ductility of W fibers.

It has been observed that in W/Cu-Cr composites the W fibers break in the elastic region, and the tensile strength and elongation is less than for W/Cu composites. This is because of a notch effect in tungsten fiber caused by the fracture of a W-Cr solid solution layer at the fiber-matrix interface. Such stronger bonding can produce poor notch resistance of the composite also. The effects of interfacial reactions on deformation and fracture behavior of composites depend on the size and ductility of the fiber.

Coatings can improve interfacial shear strength. It is interesting that the shear strength at an interface can be substantial even when the tensile strength is near zero. This is accounted for by the effects of interlocking with surface irregularities.

Coatings on tungsten fibers of carbon, carbonitride and nickel produce strengthening. When $V_f$ (fiber volume fraction) is less than Vmin (minimum fiber $V_f$ to reinforce the matrix material), there is, under strain, fracture of the fibers in the composite to continually shorter lengths until the length $lc/_2$ is reached (lc is the critical length given by $lc/d = \sigma_f/2_\tau$, $\tau$ being the shear strength at the interface). Hence the values of the critical aspect ratio and shear stress at the interface can be obtained. The values of critical aspect ratio and shear stress depend on $V_f$ and the interfacial conditions. An external load may transfer to the fibers even with zero interface bonding because of the frictional forces arising out of the compression stress resulting from differences in contractions and deformation between fibers and matrix.

The work of Ochiai, Murakami and others on fiber composites is summarized in several papers (see Trans. JIM, *16*, 463, 1975, *16*, 345, 1975, 17, 649, 1976; JIM *37*, 208, 1973, *37*, 579, 1973; Metal Science, *9*, 535, 1975, *10*, 401, 1976). Work has also been done on in-situ composites as in the unidirectionally solidified quasi-binary Al-S ($Cu_2Mg_2Al_5$) eutectic. This work relates solidification rate to structure and mechanical properties (see Trans. JIM, *15*, 66, 1974).

The Science of Metallic Materials Laboratory has also been studying stress corrosion cracking in aluminum alloys. One such study has been on microstructural effects on SCC of Al-Zn-Mg alloys. Murakami and colleagues state that the SCC susceptibility is controlled by the size and distribution of grain boundary precipitates, in turn dependent upon the grain boundary structure. Bicrystals with twist angles smaller than several degrees displayed excellent SCC resistance regardless of heat treatment conditions. The width of precipitate free zone (PFZ) and matrix precipitates were minor influences on SCC. The presence of species which may influence electrochemical behavior are suspected to be important in addition to the microstructural influences. See Proc. International Light Metals Conference, Leoben-Wien, Germany, 1975.

The Science of Metallic Materials Laboratory in cooperation with the Foundry Metallurgy Laboratory (Kawano) has also studied the stability of cementite in iron-carbon alloys and in cast irons. One approach has been observation of the effects of impact on the formation of graphite at elevated temperatures in iron - 4.24 carbon alloys (< 0.1 Si). A critical level of deformation (about 70 percent) was observed beyond which graphitization at 1000°C occurred very rapidly. Flake graphite formed along the direction of plastic flow. Unless the critical deformation level for graphitization is reached, annealing at 1000°C produces only changes in structure after deformation, and no graphitization. The investigators suggest that this proves the rate of growth of graphite is controlled by the rate of solution of cementite. The effect of impact deformation is to break down the covalent bonds in cementite. The general background is given in Bulletin JIM, *11*, 903, 1972. The impact work is, however, still in manuscript form.

Professor T. Maki described some current activities of the Science of Steels Laboratory. One interest is in two phase iron alloys with the second phase displaying some ductility. The strength and ductility of such alloys as contrasted to single phase alloys is related to microstructure. Thus the variables are grain size, volume fraction of second phase, and differences in tensile properties between the matrix and second phase. Such variables are controlled by composition and heat treatment. Alloys which have been studied are in the Fe-Cr-Ni, Fe-Ni-C and Fe-C systems.

The more important findings on ($\alpha$-$\gamma$ alloys) are that two phase alloys may show better combinations of strength and elongation, probably because the grain size of the two phase alloys is generally smaller. The tendency to coarsen is also reduced. The effect of grain size is the same for single phase and two phase alloys, and follows the Petch relationship. A parameter C is introduced which is simply the ratio of the 0.2 percent yield strength of the harder phase to the softer phase. With C less than a value of 3 the law of mixtures applies: but at higher values the law is not predictive. The investigators have developed these observations into some rather complex theoretical analyses of two phase alloys. Details may be seen in Trans. JIM, *13*, 283, 1973; Materials Science and Engineering, *24*, 85, 1976 and in Proc. of 1974 Symposium on Mechanical Behavior of Materials, Kyoto, 1974.

Another interest of the above group is in the strength and ductility of austenitic Fe-Ni and Fe-Cr-Ni alloys as influenced by strain-induced martensitic transformations (TRIP steels). The important point is that all alloys involving TRIP type martensitic formations show high elongation, and an optimum elongation occurs with an optimum rate of martensite formation. The martensite suppresses necking because of the continuous and large increase in strain hardening exponents. In addition microcrack crack initiation and growth is suppressed because of the relief of local stress as martensite forms. The work is presented in greater detail in Trans ISIJ, *10*, 163, 1970; Proceedings of Conference on the Strength of Metals and Alloys, *3*, 900, Pacific Grove, California, 1970 and Int. Symposium on Improved Ductility and Toughness, Iron and Steel Institute of Japan and Climax Molybdenum Development Company Ltd. (Japan), Kyoto, 1971.

Dr. Maki, who incidentally did post-doctorate work with Professor Wayman at University of Illinois in 1976, also discussed some current work on amorphous metals. In particular there is interest in what structure develops in amorphous metals upon aging. The studies are beginning with Ni-Co-Si-B alloy. There is also interest in high speed steel which has been rapidly quenched as by roller quenching. The rapidly quenched high speed steel is not amorphous but there is great interest in what kind of carbides precipitate as compared to those in normally treated high speed steel. The possibility of improved wear resistance and mechanical properties is visualized.

The materials activities at Kyoto University are of course far more extensive than could be covered in one short visit. However, the excellence of the work going on could be appreciated. To give a broader view of the activities going on, listings of the 1976 research activities of the Departments of Metal Science and Technology and Metallurgy are appended to this report.

## APPENDIX

## RESEARCH ACTIVITIES IN DEPARTMENT OF METAL SCIENCE AND TECHNOLOGY

*Lattice Defects and Crystal Plasticity Laboratory*

Professor: J. Takamura
Assistant Professor: K. Furukawa
Assistant: F. Nakamura
Assistant: N. Narita

1) Vacancy-Solute Interactions in Dilute Alloys
2) NMR Studies in Dilute Alloys
3) Deformation Twinning and the Stacking Fault Energy in FCC Metal and Alloy Crystals
4) Radiation Damage of FCC Metals
5) Positron Annihilation in Metals

*Structural Metallurgy Laboratory*

Professor: M. Adachi
Assistant: S. Kikuchi
Assistant: J. Takada

1) Deformation Mechanism of Al and its Alloys at Elevated Temperature
2) Deformation Mechanism of Cu and its Alloys at Elevated Temperature
3) Mechanism of Superplasticity
4) Mechanism of Dispersion Strengthening

*Science of Steels Laboratory*

Professor: I. Tamura
Assistant Professor: T. Maki
Assistant: S. Fujiwara

1) Martensitic Transformation and Morphology of Ferrous Martensite
2) Thermo-Mechanical Treatment and Transformation-Induced Plasticity of Steels
3) Relation between Metallographic Morphology and Fracture of Steels
4) Precipitation Behaviours (including Spinodal Decomposition) and their Strengthening Effects in Steels
5) Structure and Mechanical Properties of Rapid Freezed Steels
6) Strength and Ductility of Steels with Duplex Structure of Two Phases

*Foundry Technology Laboratory*

Professor: R. Ozaki
Assistant Professor: H. Shingu
Assistant: T. Sawamoto
Assistant: K. Kobayashi

1) Crystallographic Studies on the Nucleation and Growth of Metal Crystals
2) Studies on the Metallic Amorphous Structures and their Formation and Stability
3) Studies on the Nucleation of Eutectic Solidification Reaction
4) Studies on the Influences of Annealing Environments on the Graphitization of White Cast Iron
5) Studies on the Heat and Solute Distribution during Solidification of Ingots
6) Structures of Metals and Alloys Splat Cooled from Liquid State

*Metal Physics Laboratory*

Professor: Y. Nakamura
Assistant Professor: T. Tsuchida
Assistant: M. Shiga
Assistant: K. Sumiyama

1) Magnetic Properties of Invar Alloys
2) Magnetovolume Effects in Magnetic Alloys
3) Magnetic Properties of Rare Earth Intermetallic Compounds with Cubic Laves Phase
4) NMR Studies of Transition Metal Silicides and Sulphides
5) Mossbauer Studies of Magnetic Alloys

*Welding Engineering Laboratory*

Professor: M. Mizuno
Assistant: A. Otsuki
Assistant: Y. Tomii

1) Relation of Welding Conditions to Porosity in Weld Metal
2) Investigation of Hot-Cracking in Medium Strength Aluminum Alloys
3) Age Hardening of Welds in Medium Strength Al-Zn-Mg Alloys
4) Embrittlement of Solid Metals by Liquid Metals
5) Decarburization Mechanism in Low Alloy Steel Welds

# RESEARCH ACTIVITIES IN DEPARTMENT OF METALLURGY

*Iron Metallurgy Laboratory*

Professor: T. Mori
Assistant Professor: E. Ichise
Lecturer: A. Morooka
Assistant: M. Iwase

1) Studies on emf Measurements by Means of Solid Electrolyte
2) Activity Measurements of Iron Alloys by Knudsen Cell-Mass Spectrometry
3) Deoxidation of Liquid Iron by Complex Deoxidizers
4) Fundamental Studies on Gaseous Desulphurization from Slags

*Nonferrous Metallurgy Laboratory*

Professor: J. Moriyama
Assistant Professor: K. Ono
Assistant: T. Oishi

1) Thermodynamic Studies on Sulphides by CaF Solid Electrolyte Galvanic Cells
2) Thermodynamic Studies on the Systems of Nb-Mo-C-O, Nb-W-C-O and Nb-Ti-C-O
3) Studies on Phase Relationships and Thermodynamics in the Cu-Fe-O-SiO System at Elevated Temperature

*Electrometallurgy Laboratory*

Professor: H. Majima
Assistant Professor: M. Kurachi
Assistant: K. Matsuda
Assistant: Y. Awakura

1) Leaching Mechanisms of Metal Sulphides and Metal Oxides
2) Recovery of Metals from Aqueous Solutions
3) Electrorefining and Electrowinning of Metals at High Current Density
4) Electrocrystallization and Electrochemical Dissolution of the Alloys Containing Intermetallic Compounds
5) Thermodynamics of Concentrated Aqueous Solutions Based on the Hydrated Crystals
6) Waste Water Treatment in Metallurgical Industries

*Science of Metallic Materials Laboratory*

Professor: Y. Murakami
Assistant Professor: K. Osamura
Assistant: S. Yamamoto

1) Studies on Ageing Phenomena in Alloys Mainly by X-ray Diffuse Scattering Method, Transmission Electron Microscopy, and Mossbauer Effect Measurement
2) Transport Phenomena in Alloys
3) Preparation of III-V Compounds and their Thermodynamic and Physical Properties
4) Fibre-reinforced Composite Materials
5) Stress-Corrosion Cracking in Aluminum Alloys

*Foundry Metallurgy Laboratory*

Assistant Professor: Y. Kawano
Assistant: N. Inoyama

1) Studies on Formation and Structures of Spheroidal Graphite in Iron-Carbon Alloys
2) Relationship between the Physical, Thermodynamic Properties of Cast Iron Melt, the Graphitization or Graphite Form of Cast Iron and the Impurities in Raw Materials
3) Solidification Mechanisms of the Spheroidal, Eutectic, Flake Graphite Cast Irons and White Cast Iron
4) Mechanism of the Graphitization of Cementite in the Cast Iron
5) Temperature Dependence and Magnetic Properties of the Spheroidal Graphite Cast Iron
6) Working Environment of the Foundry Shop and the Layout on Grouping the Small Foundry Shops

*Process Metallurgy Laboratory*

Professor: Y. Kondo
Assistant Professor: Z. Asai
Assistant: Y. Maru
Assistant: A. Tanabe

1) Kinetics of Fluidized Bed Roasting of Zinc Sulfide
2) Kinetics of Oxidation of Iron Sulfide
3) Modelling Studies on the Flash Smelting Process
4) Studies on the Segregation Process of Lateritic Nickel Ores
5) Studies on the Natural Convection and Mass Transfer of Cu Ion near the Vertical Copper Cathode Surface
6) Studies on the Air Oxidation of Fe Ion

## KYUSHU INSTITUTE OF TECHNOLOGY

Kyushu Institute of Technology in Tobata, Kitakyushu, was founded some sixty years ago as a private school and became a National University in 1949. The goal of the school is to produce "gentlemen proficient in technology", and the professors encountered on this visit were certainly just that.

The principal host was Professor T. Owadano, an old "pen pal" from the days of cast iron graphitization studies at NRL. His special interest has been the kinetics of second stage graphitization of black heart malleable (Imono, *46*, 110, 1974; *45*, 193, 1973; *46*, 834, 1974), spheroidal graphite ductile iron (Imono, *44*, 36, 1972; *45*, 21, 1973; *46*, 4, 1974; *46*, 110, 1974; *47*, 313, 1975; *48*, 563, 1976; Trans. JIM, *16*, 663, 1975) and gray cast iron (Imono *46*, 537, 1974). The principal findings of these investigations are as follows:

1) The second stage graphitization rates from both austenite and from pearlite (direct and indirect graphitization reactions) are dependent on the rate of diffusion of carbon through ferrite, according to Owadano, and the rates of the two reactions are about the same in the same black heart malleable cast iron.

2) The graphite nodule number per unit volume is related to the number per unit area by the expression $N_v = (\pi/6 V_g)^{1/2} (\alpha N_A)^{3/2}$, where $V_g$ is the volume fraction of graphite in the iron and $\alpha$ is a factor dependent on the distribution nodules. The value of $\alpha^{3/2}$ varies between 1 and 1.4. The expression applies to both spheroidal graphite and malleable cast irons.

3) The time to ferritize a cast iron is inversely proportional to the nodule number, $Nv^{2/3}$ or $N_A$. The effect of nodule number in spheroidal cast irons becomes less as the temperature of graphitization is lowered. In all cases increased Si concentration increases the rate of reaction.

4) Forging of spheroidal graphite irons increases the rate of isothermal ferritization, presumably by increasing the graphite surface area per unit volume of iron. This appears to contradict the earlier conclusion that diffusion through ferrite is controlling.

5) Isothermal ferritization in gray cast irons is slower than in spheroidal iron or in black heart malleable. Owadano attributes this to the effects of composition.

6) The growth rate of ferrite during second stage graphitization increases with Mn and Si content. However, the rate decreases as the Mn concentration in spheroidal and black heart malleable exceeds about 0.2 percent. Apparently a fixed sulfur content is assumed.

7) Ferritization in spheroidal cast iron varies with the Si and Mn present and upon the linear cooling rate. The ferritization by the direct graphitization of austenite is proportional to the degree of undercooling.

8) In isothermal austenization of spheroidal iron, increasing the temperature and graphite nodule number increases the rate.

Stress relief in ductile iron depends on the annealing temperature and time rather than on the magnitude of the initial stress, according to Owadano (see Jr. Japan Foundrymens Soc. *31*, 1, 1959). The residual stress in castings may be reduced by use of self-chilling fins (JJFS, *33*, 1, 1961). The generation of residual stresses in bronze castings has also been studied (JJFS, *33*, 1, 1961). Another paper (JJFS, *39*, 1, 1967) affirms that annealing temperature and time, not initial stress, are controlling for stress relief in cast steel, gray cast iron and ductile cast iron. The effects of chemical composition of iron castings on residual stress generation is considered in JJFS *32*, 1, 1960. Silicon reduces residual stress up to a level of 3.8 percent. Phosphorus increases residual stress slightly.

Owadano has also studied solid-liquid diffusion in the Fe-Al, Al-Cu and Al-Zn systems. Such diffusion takes place when, for example, iron is dipped into liquid aluminum.

A current study on the wear of cast iron involves use of an electron beam to remelt spots on the surface, thus producing a punctiform array of hardened spots. Studies of the fracture toughness of gray cast iron and other irons are also underway. Thus determinations of $J_{Ic}$ and $K_{Ic}$ are being made. These new studies are strengthened by Owadano's knowledge gained during a sabbatical leave at Lehigh University in 1963-64. Owadano contributed to the Second International Symposium on the Metallurgy of Cast Iron at Geneva in 1974, and is otherwise recognized internationally.

Discussions were held also with Professor S. Mukae who is involved in welding metallurgy. The major interest of Mukae, who studied in the Civil Engineering Department at University of Illinois during the 1967-68 school year, is in the heat affected zone (HAZ) of welds in steel and aluminum alloys, and how the grain size in these HAZ zones can be reduced or controlled. The belief is that the strength and fracture toughness of welds is largely determined by the microstructure and in particular the grain size of the weld metal and HAZ zones. One approach is the addition of Ti, Zr and Nb metal to the base steel. There is no study of electron beam welding at this time.

Professor K. Takahashi is interested in the fundamentals of fatigue, in particular the dislocation structure induced by fatigue. He is studying cell formation in Al, Cu and Fe-3 Si alloy during bending fatigue. For general background see JSME, *16*, 161, 1973.

The visit concluded with a conversation with Dr. M. Konomi, President of the Kyushu Institute of Technology. Dr. Konomi stated that he was pleased that a representative of ONR had visited KIT and that he hoped such interchanges would become customary.

## KYUSHU UNIVERSITY

The Departments of Materials Science and Technology, Nuclear Engineering and Iron and Steel Metallurgy at Kyushu University in Fukuoka are certainly centers of excellence for materials research and engineering. Professor T. Eguchi of the Materials Science and Engineering Department was principal host on this visit. Eguchi heads a group (KOZA) studying the physics of metals and alloys. The group was formerly attached to the Department of Iron and Steel Metallurgy, but in May 1976 there was a move to the new department. In addition to Eguchi, there are in the group Associate Professor K. Oki, Research Associate Y. Tomokiyo and graduate students.

Professor Eguchi is an interesting person with a curious background for a materials specialist. He began as a theoretical physicist and spent the years 1954 and 1955 as a Senior Scientist at the Institute for Atomic Research at the Iowa State University at Ames, studying mesons and high energy physics. At about the same time he worked with Professor Fry of the University of Chicago. During earlier years he was an exchange graduate student (1950-1952) and an exchange Assistant Professor (1951-1952) at Iowa State. After returning to Japan he moved into solid state physics and from there to theoretical metallurgy and finally experimental metallurgy. This dismal slide (from a physicist's eyes) was prompted by governmental and managerial pressures for less theoretical physics and more "practical" research. But Eguchi seems content and his physics background strengthens his work in metallurgy.

One of Eguchi's joys is a new high voltage electron microscope (JEM-1000). This microscopic reaches 1.5 million volts controllable in 17 steps at $10^{-6}$ torr with a stability of $10^{-6}$. The JEOL microscope is stable with respect to voltage, current and mechanics, and lattice images of two angstroms can be seen. In addition, stress and temperature are controllable on the various microscope stages. A cold stage is available to -120°C and a hot stage to 1000°C. A "supercold" tiltable stage reaches temperature of 20°K, and permits the specimen to be stressed simultaneously. A system is being planned which will reach 2°-4°K; this will be used for superconductivity experiments in which the magnetic flux can also be observed. The microscope is controlled by Professor Eguchi, but is at present used by many departments involved in sixteen projects. Although microscope and building (at approximate $1 million cost) were installed as recently as October 1976, several investigations have been completed and several papers were scheduled for the Kyoto International Conference of High Energy Electron Microscopy August 1977. Two papers were also scheduled for the Conference on Order-Disorder in Solids in Paris, July, 1977.

A brief description of some projects currently underway which involve use of the microscope follow:

1) Nb-Zr - attempts are being made to correlate the boundaries between different phases with radiation damage.

2) Fe-Al - Studies of ordering and spinodal decomposition are being made.

3) Cu-Co and Cu-Al - phase transformations, short range ordering and precipitation processes are being studied.

4) Critical voltage effects in Cu-Al and Cu-Au alloys - at certain wave lengths of the electrons, some spots and lines disappear. This is related to the Fourier component of the periodic potential in metals and alloys. It is hoped to determine this Fourier component of periodic potential by observing the voltage produced by the electron microscope where the spots and lines vanish. The critical voltage effect is used to determine the structure factor. The Fourier component, incidentally, is dependent on alloy composition. The microscope permits voltage to be changed essentially continuously.

5) Correlations between magnetic domain boundary structure and the normal structure (lattice defects, precipitates, etc.). This work is being done on Cu-Mn-Al alloys.

6) Study of hydrogen embrittlement mechanisms in metals.

7) Study of radiation damage in iron and iron alloys.

8) Plasticity mechanisms in metal crystals radiated by electrons.

9) Aging mechanisms in dental alloys.

Many of these projects are supported by the Ministry of Education, which also bought the new microscope.

The work of Eguchi's KOZA involves generally studies of atomic arrangements and rearrangements in binary alloys of Fe, Co, Cu and Al. The alloys of Fe with Co are compared, for example, with the alloys of Fe and Al; thus alloys of iron with a strongly ferromagnetic metal (Co) are compared to alloys of Fe with a non-magnetic metal (Al). The effects of long range order on these alloys is the other variable.

Similarly, alloys of Cu with a strongly magnetic metal (Co) are compared to alloys of Cu with a non-magnetic metal (Al), and the effects of short-range order and precipitation are observed. The purpose of these experiments is to correlate atomic arrangements with magnetic properties.

It has been found that in Cu-Co alloys Co atoms enter solid solution at 700°C but precipitate at room temperature, which causes the alloy to become magnetic. The size distribution of Co particles can be estimated from the magnetic properties, but the electron microscope is favored to make direct measurements to support theoretical analyses.

In Cu-Al alloys the electrical resistance, specific heat, lattice constant and hardness vary with short-range order. Again X-ray analysis of short range order is done, but the electron, microscope provides direct observation.

The tools most used by Eguchi's KOZA are:

(1) electron diffraction
(2) Mossbauer spectroscopy for magnetic analysis
(3) Sensitive magnetometer (made in-house)
(4) high accuracy measurement of electrical resistivity
(5) specific heat measurement
(6) electron microscope observations at 250 KV and 1250 KV and
(7) computer analysis

Further details on these studies are given in several publications. See trans. JIM *12*, 390, 1971; *14*, 8, 1973; *14*, 91, 1973; *15*, *39*, 1974; *15*, 143, 1974; *15*, 338, 1974, *16*, 489, 1975 and *18*, 87, 1977. Also see Japanese Journal of App. Physics, *12*, 1522, 1973 and *13*, 753, 1974. One paper on ferromagnetism and ordering in Fe-Co alloys is published in IEEE Trans on Magnetics, 1968. All references cited are in English.

Professor Youichi Tokunaga of the Department of Iron and Steel Metallurgy is trying to develop new maraging steels with ultra-high strength. The precipitation reactions are being monitored using measurements of specific heat, internal friction, hardness and dilatometry. Repetitive low temperature aging is the approach at present, and maraging steels with 200 $Kg/mm^2$ have been produced. The basis of this work is described in ISIJ, *33*, 254, 1969, *34*, 234, 1970, *37*, 1330, 1973 and in Trans. JIM, 12, 250, 1971.

Tokunaga and his associates have also studied powder metallurgy problems involving abnormal brittleness of high density sintered iron (see Journal Japan Society of Powder and Powder Metallurgy, *16*, (1969), 266. It was observed that sintered iron powder specimens under impact stress rupture easily at the grain boundaries at the unique density of 7.0 $g/cm^3$ (a minimum in energy absorption of Charpy specimens is observed at this density). Tokunaga concludes that the 7.0 $g/cm^3$ dip may be caused by oxygen at the grain boundaries of commercially pure iron powder. The anamolous behavior is subdued if carbon is added.

Professor Hideo Yoshinaga is an interesting and rather unusual case of a transfer from one university (Tohoku University) to another (Kyushu University) at a mature stage of his career. He described work done at both institutions. One area of research is the dislocation dynamics of solute hardened metals at high temperatures. Yoshinaga argues that there is a plastic instability at intermediate temperatures. The solute atom atmosphere around a moving dislocation, which produces a dragging stress, may decrease in size and density as the velocity of the dislocation increases. This may produce serrated flow. The earlier work is described in Philosophical Magazine, *23*, 1351, 1971.

Another of Yoshinaga's studies involves the deformation mechanisms in hexagonal materials. The main difference between hexagonal metals and cubic metals is the basal slip process. A metal cannot deform homogeneously through basal slip alone; therefore, the plastic deformation in polycrystalline metals should be limited. However, in practice hexagonal metals deform in unlimited amounts at high temperature. Therefore, another slip mechanisms is suspected. To investigate this, Yoshinaga stressed single crystals in compression normal to the basal plane (no basal slip). At low temperatures only twin deformation was seen, but at higher temperature slip on pyramidal planes was observed, and this was seen as proof of a change in mechanism with temperature. This work is described in greater detail in Materials Science and Engineering *12*, 255, 1973; Acta Met. *21*, 845, 1973 and Trans. JIM, *17*, 102, Feb. 1976 and *17*, 559, Sept. 1976.

Studies of the thinning of the Group Va metals V, Nb and Ta have shown that there is no hydrogen pick-up from electrochemical and chemical thinning. Spark cutting in kerosene produces no hydrogen pick-up in V and Nb, but Ta picks up as much as 1000 ppm. Wet wheel cutting introduces several ppm of hydrogen into all three metals. Electrolytic thinning of V single crystals may precipitate hydrides. This work is described in Trans JIM, *17*, 551, 1976.

Currently Yoshinaga is surveying the mechanisms of deformation in metals and alloys. The basic question is whether there is a fundamental difference in the deformation of pure metals as contrasted to solid solutions. Yoshinaga concludes that there is a difference at high temperature, although this is widely disputed (esp. by Nix at Stanford). Yoshinaga reports that the flow resistance of pure metals is determined by the internal stresses, that the dislocations move discontinuously in free flight. In solid solutions the dislocations glide through viscous motion. At present there is an attempt to prove this experimentally by comparison of flow velocity just after stress relaxation. In free flight motion (pure metals) the flow velocity should respond to stress relaxation, but in viscous motion (solid solutions) the flow velocity should remain unchanged.

A project is beginning on the development of high temperature ceramic-metal alloys through powder metallurgy. For example, composite materials of 50-50 TiC-Mo are under study for possible applications in heat exchangers for high temperature gas-cooled reactors. The service temperature would be 1000°C which is beyond the limit of normal refractory materials.

Professor Y. Hayashi is associated with the Surface Chemistry of Metals Section of the Department of Iron and Steel Metallurgy and he is engaged in studies of corrosion and hydrogen embrittlement. The specific projects are described below:

(1) Mechanical properties of iron and steel as affected by hydrogen in solution - by straining specimens during hydrogen charging, it has been shown that the flow stress may rise or fall. Stress relaxation may be observed and there may be increased plastic deformation. Even in the elastic region high charging rates of hydrogen may produce plastic deformation (in pure iron and iron-chromium alloys). Examinations by electron microscopy show a hydrogen-rich zone at the grain boundaries, predominantly on one side of the grain.

(2) Electrochemical evolution of hydrogen on steel surfaces and entrance into the steel - this is primarily a study of the effects of poisons such as As in $H_2SO_4$ electrolyte. The presence of arsenic increases the rate of hydrogen permeation by a factor of 20 at the same current.

Hayashi has concluded that a thin layer of amorphous arsenic is deposited on the iron surface. Hydrogen is adsorbed on the arsenic surface and then enters the iron; the arsenic is a stepping stone. At sufficient potential, $AsH_3$ gas is formed.

(3) Interaction of hydrogen with stacking faults in nickel base alloys - the stacking fault energy of Ni and Ni-Cu alloys is decreased by hydrogen in solution, because the electrons of hydrogen go into the d-band.

(4) Hydrogen permeation - the interest is in the effects of alloying elements on permeation of hydrogen in dilute solutions. Trapping of hydrogen decreases diffusivity and increases solubility. Order-disorder transformations affect the hydrogen permeation in the alloys Fe Al, $Fe_3$ Al, $Ni_3$ Fe and $Ni_3$ Mn. Ordering increases permeation rates in $Fe_3$ Al and $Ni_3$ Fe, but the reverse effect is seen with $Ni_3$ Mn.

All of the work described by Hayashi is incomplete and has not yet been published.

Professor K. Matsuda who heads the Casting and Welding Section of the Department of Iron and Steel Metallurgy was away on the day of the visit, but conversations were held with Associate Professor Keisaku "Cast Iron" Ohge. One current study is on solidification. Fluid flow is one interest in this area, with experiments underway on the fluid flow of aluminum alloys in a rotating magnetic field. Directional solidification and eutectic growth in high-chromium cast irons are also of interest. Current experiments involve interrupted solidification with subsequent study of the distribution of elements near the liquid-solid interface. Analyses are being done with the electron microprobe and other microanalytical techniques.

The alloys under study contain 15 to 30 percent Cr in pure Fe-Cr-C alloys. The alloys are hypoeutectic, containing about 3.4 percent C. The freezing range varies with the concentration of chromium. In addition to studies of segregation at the solidification front, the distribution of Cr in the eutectic cells is under study.

The purpose of studying the high-Cr cast irons is to develop better wear and abrasion resistant irons. The irons develop high hardness, and an improved ductility is being sought without lowering hardness. The belief is that this can be done by control of the eutectic and matrix structure.

The thermal fatigue properties of the high-Cr irons are also of interest, and studies of crack growth by thermal fatigue are underway. There are also torsion tests at temperature to 1000°C being conducted in another department.

Professor Sadakichi Kitajima of the Material Science and Nuclear Engineering Faculties is prominent in studies of plasticity, stress corrosion cracking and surface effects. His work on the corrosion fatigue of austenitic stainless steel shows that a square stress wave is less injurious than a saw-tooth stress wave. This is viewed as evidence that the corrosive effects are most severe under increasing stress where there is a continuous formation of new slip bands and therefrom fresh and clean metal surface.

Kitajima believes that microscopic strain rate is controlled mainly by the rate of slip-band formation rather than the velocity of dislocations. To test this he has studied single crystals of copper irradiated with neutrons to prevent movement of dislocations. He then deformed the copper crystals at various strain rates and found a direct correlation between the deformation rate and the number of slip bands produced. Thus the dislocation velocity model is suspect because dislocations were not moving in this case. According to Kitajima it is the moving dislocation density which is the controlling factor, not the dislocation velocity. This work to clarify the role of dislocation density on crystal plasticity is continuing.

Kitajima and his colleagues have developed an interesting means of producing highly perfect copper crystals (see Jr. Crystal Growth 24/25 (1974) 521-526). The method involves successive 30 minute thermal cycles between 1050°C and 850°C. This reduces the number of dislocations without forming new sub-boundaries and old sub-boundaries are also broken up. Crystals with dislocation densities of $1 \times 10^{[illegible]}/m^2$ have now been produced.

The production of highly perfect single crystals of copper is useful in studies to determine surface effects on mechanical behavior. Surface dislocations are more mobile than dislocations in the interior. Even before yield surface dislocations elongate and prevent the motion of dislocations from an interior source. An edge dislocation emerging on the surface is more mobile than screw dislocations. Surface dislocations pinned by oxide, however, are immobile and the yield force is determined by the pin force of $Cu_2O$. This work is discussed in part in the Proceedings of the Conference on Surface Effects in Crystal Plasticity, September, 1975 at the NATO Advanced Study Institute in Germany.

Kitajima was well aware of the work on surface effects of Dr. I. Kramer of NSRDC-Annapolis and was most complimentary.

The final discussions were with Associate Professor C. Kinoshita, a brilliant scientist under Kitajima and a former student of Eguchi. Kinoshita is studying the mechanisms of radiation damage, especially the kinetic behavior of point defects produced by irradiation. It is desired to measure the energies of formation and migration of vacancies in concentrated alloys, but this is difficult. The high voltage electron microscope (HVEM) may introduce radiation damage itself so it is not useful to determine order parameters. The critical voltage effect gives the structure parameter but not the order parameter. Kinoshita uses the thickness fringe because the extinction of dislocations is dependent on the order parameter. The order parameter of $Fe_3Al$ is reported to be influenced by high voltage electrons only, and the order parameter of $Cu_3Au$ by electrons at all voltages.

Kinoshita is applying these methods to determine the rate of disorder as a function of orientation, accelerating voltage and order.

Another area of Kinoshita's work involves fusion reactor materials in the Nb-Zr system. Zirconium forms in the alloys through transformation. The studies have shown so far that the Nb-Zr phase diagram is very sensitive to the presence of oxygen. The studies benefit from some excellent experimental equipment and skills. For example an ultra-high vacuum system reaches $10^{-10}$ torr and specimens may be annealed at 1000°C at $10^{-9}$ torr.

Resistivity measurements may be made to an accuracy of $10^{-5}$ ohms at elevated temperatures.

In summary, there are many highly skilled, competent and hard working individuals engaged in materials science and engineering at Kyushu University. The strength in basic aspects of metallurgy and solid state physics is unsurpassed.

## NAGOYA UNIVERSITY

Nagoya University is one of the leading technical universities in science and engineering. Formerly Nagoya Imperial University, the school was renamed Nagoya University in 1947, and reorganized in 1949 under a so-called new educational system. In addition to science and engineering there are postgraduate schools of Letters, Education, Law, Economics, Medicine and Agriculture. At present there are also four Research Institutes in Environmental Medicine, Atmospherics, Plasma Physics and Water Research. An Institute in Aeronautical Medicine was abolished in 1945 after only two years' existence, obviously a casualty of the war. The industrial and center city of Nagoya has been largely rebuilt since the war and Nagoya University has also mostly been built during the post-war period.

Within the Department of Metallurgical Engineering, there are several research-teaching units. They are Metal Physics, Non-Ferrous Metallurgy, Ferrous Metallurgy, Chemical Metallurgy, Welding Metallurgy, Metal Casting, Analytical Chemistry, Metallic Materials, Process Engineering Metallurgy, Reaction Engineering, Solid State Physics, Plastic Working of Metals and Strength of Metals. Three of these units were visited - Welding Metallurgy, Metal Physics and Strength of Metals. A lecture on "Stress-Corrosion Cracking in Some High Strength Steels" was presented to a student faculty assembly.

Professor Isao Masumoto is the well-known leader of the Welding Metallurgy Group and Laboratory. The group investigates welding technology with emphasis on the relation of mechanical properties to metallurgical structure. As one example of the work, methods have been devised to improve the fatigue strength of welded joints. Galvanized joints (after welding) should be quenched to improve aging characteristics and the residual stress pattern. The function of plastic (epoxy resin) coatings of welds in improving resistance to fatigue has been shown to be the exclusion of moisture and oxygen from the atmosphere.

Professor Masumoto and his colleagues have also done some important research on the avoidance of hot-cracking in weld metal and in the welded joint of steels. The important finding is that the weld metal should solidify within the delta ferrite region of the phase diagram peritectic, to avoid sulfur grain boundary segregation. Thus there are limits to the amounts of C, S, and Ni (and to the Cr in austenitic steels) in order to avoid hot cracking. The threshold values have been specified by Masumoto in many articles over the past decade.

Masumoto and colleagues have also published widely on electroslag welding (IIW Doc XII-J-8-71), and $CO_2$ Arc Welding (Welding Journal Res Sup. July, 1958, IIW Doc. XII-B-135-73). Research on underwater welding of steel and electroslag welding of aluminum has also been undertaken.

Recently computer programs for the critical parameters for welding by electron beam, $CO_2$ and submerged arc welding processes have been studied. Another area of current interest is the transfer of such metals as Ca, La and Mg in the arc from the metal wire in MIG and Ar-$CO_2$ weld processes. This metal transfer can influence the ease of welding and the properties of the welds. The refrigeration of welds to improve properties is also an important study of continuing interest.

In the study of strength of metals, Professor A. Otsuka concentrates primarily in fracture and fatigue. His studies on fracture are based on the COD concept coupled with metallurgical observations. The problem addressed is the fibrous fracture initiation in the mixed mode loading condition. The fracture initiation from a precrack in low and medium strength steel occurs by fibrous cracking at high temperatures and by cleavage cracking at low temperatures. The transition temperature is greatly influenced by the degree of plastic constraint.

Otsuka and his colleagues define the transition temperature Ti as the transition in fracture mode which is accompanied by a large change in toughness. A steel should always be used at temperatures above Ti.

At temperatures higher than Ti, the COD (crack opening displacement) at fracture initiation ($\delta i$) becomes almost constant, showing little sensitivity to temperature, specimen geometry or loading rate. At temperatures below Ti, $\delta i$ is sensitive to these factors. Therefore Otsuka defines the fracture toughness of low and medium strength steel by Ti and $\delta i$. The transition temperature Ti is dependent on specimen size, loading rate, etc., and is therefore not a material constant. The crack opening displacement, $\delta i$, is a material constant however, and may therefore be useful in material strength-toughness regimes where fracture mechanics cannot be used.

At the maximum values of Ti, plane strain conditions are reached. Otsuka has developed an expression which defines the critical value of Ti for plane strain, as follows:

$$a, b, W-a > 0.4 \frac{\delta_i E}{\sigma_Y R}$$

where a is crack length, W is specimen width, E is Young's modulus, $\sigma_Y$ is yield strength and R is the ratio of yield strength to ultimate tensile strength. The ratio of maximum tensile strength to maximum shear strength ($\sigma_Y max / \tau max$) is also at a maximum when plane strain is reached.

Otsuka measures with SEM a value of "stretch zone depth" (SZD) which is a maximum at the point of static fracture. The value of SZD is directly proportional to COD up to the Ti temperature above which the notch tip COD increases rapidly while the plastic COD, which is proportional to SZD, becomes constant.

These results appear to be important in the application of quantitative analytical techniques to steels which are not normally tractable to fracture mechanics techniques. The work of Otsuka's group seems to offer the means of measuring a material constant, δi, which can be a useful toughness index as well as a means of determining the value of Ti where plane strain is obtained. Further details on this work is given in Engineering Fracture Mechanics, Vol 7, p. 419, 1975 and in a paper by A. Otsuka, T. Miyata and S. Nishimura entitled "Fracture Toughness and the Transition in Fracture Initiation Mode in Low and Medium Strength Steel" which was delivered at the International Conference on Fracture Mechanics and Technology in Hong Kong, March 1977.

Otsuka and his group have also studied the initiation of fatigue crack growth in mixed mode conditions (see Engineering Fracture Mechanics, vol 7, p. 429, 1975). Precracked low-carbon steel specimens were used, with the notches introduced at both surface and center, and at various angles to the applied fatigue stress. It is concluded that the fatigue crack growth is fractographically divided into two modes, shear and tensile (the fractographs were not sensitive to notch acuity). The critical condition for fatigue crack growth is given by the local tensile stress and shearing stress at the notch tip, which relate to the stress intensity factors $K_I$ and $K_{II}$. Under plane loading conditions this criterion is generally applicable.

The Metal Physics Group under Professor T. Imura is very active in high voltage electron microscopy (HVEM). In situ dynamic thermal and mechanical effects (dislocation movements) have been observed. This work of Imura is widely known, and no attempt to provide details will be undertaken here. For those interested, the following papers of Imura and coauthors are recommended: a) "In-Situ Dynamic Experiments on Plastic Deformation in HVEM," Fourth International Congress, Toulouse, 1975, and b) "In-Situ Dynamic Observations of Dislocation Behavior in Metals and Alloys by High Voltage Electron Microscopy" Memoirs of Faculty of Engineering, Nagoya University, Vo. 28, No. 1, May, 1976. Imura also is serving as co-chairman and program chairman of the Fifth International Conference on High Voltage Microscopy in Kyoto, Japan, August 29-September 1, 1977, sponsored by the Japanese Society of Electron Microscopy.

Associate Professor N. Yukawa is developing interesting high-temperature in-situ composites based on the monovariant eutectic line in the Ni-Cr-C system and the Co-Cr-C system. The hope is to obtain both fiber and dispersion strengthening. An alloy composed of 39 Cr-2C-22Ni-34 Co - and 3 Al has been made. The eta $Cr_7C_3$ phase and a strong gamma matrix are expected to provide high temperature strength and the oxidation and corrosion resistance should be provided by the Cr. Preliminary tests show that the structure is entirely stable for 30 hours at 900°C. Yukawa feels the alloy will be stable to over 1000°C, but this has not yet been proven. An ultimate use in gas turbine components is visualized. At the time of the meeting, Yukawa had not decided where to publish the work.

Imura with T. Masumoto of Tohoku University and Y. Yoshiro of Nagoya Institute of Technology reported on the "Structure and Stability of a Splat-Cooled Fe-P-C Alloy" at the Second International Conference on Rapidly Quenched Metals at MIT in November 1975 (published in Materials Science and Engineering, *23* (1976) 169-172). The alloy (80 Fe-13P-7C) was found to have a significantly higher recrystallization temperature (from the amorphous state) after irradiation with electrons of 100 keV to 1000 keV up to a total dose of about $10^{23}$ electrons/$cm^2$ in the HVEM. This could have practical implications.

In general, Nagoya University appears to be first class by every standard. Each of the three groups visited in Metallurgical Engineering proved to be very strong and it is sincerely regretted that there was not time to visit the other groups.

## OSAKA UNIVERSITY

The Departments of Materials Science, Metallurgy, Welding Engineering and the Welding Research Institute at Osaka University, Suita City Campus, complement each other and rather effectively impact the most fundamental metallurgical research investigations on practical metallurgical engineering problems. In this two day period the materials groups (Koza's) dealing with iron and steel (Professor S. Nenno) and metallography (Professor T. Yamane) were visited in the Department of Metallurgy. Professor Y. Mukai's group dealing with stress-corrosion and corrosion fatigue and Professor Y. Kikuta's group which is interested in hydrogen embrittlement and cracking were visited in the Department of Welding Engineering. Professor Fujita was also visited at the world-famous Research Center for Ultra-High Voltage Electron Microscopy in the Materials Science Department. A talk outlining some ONR-NRL research in materials science and engineering, with emphasis on welding, was delivered to the Welding Research Institute. Professor N. Iwamoto who directs the Institute was host.

Professor Nenno's group is studying 1) phase transformations in alloys, 2) structures and mechanical properties of intermetallic compounds and 3) martensitic transformation and shape memory.

The reverse shape memory (RSM) effect is associated with martensitic transformation and has been observed 1) in beta-brass alloys such as Ni-Ti, Ni-Al, Cu-Zn, Cu-Al-Zn and Cu-Al-Mn and 2) iron-base alloys such as Fe-Mn and Fe-Ni. The RSM effect occurs as these alloys are deformed severely below Ms (or Md). Subsequent heating and cooling then produces spontaneous, reversible and repeatable shape changes in both types of alloys. According to Nenno and his colleagues, deformation induces a stress field into the material which in turn controls the growth directions of the martensitic crystals. Under severe strain these martensites deform by variant-to-variant transformations and upon heating (above $A_s$) the resultant variants transform to the parent phase, restoring the original shape. This work is described by Nenno and others in a series of papers which continue from 1971 to the present time (See *Scripta Metallurgica 5*, 663, 1971; *8*, 1055, 1974; *8*, 1363, 1974; *9*, 887, 1975; *9*, 941, 1975). Also *Met. Trans. 2*, 1487, 1971; *Proc. First JIM International Symposium of* "New Aspects of Martensitic Transformation", Kobe, 1976; *Jr. Less Common Metals*, 50, 223, 1976. One of Nenno's colleagues, T. Saburi, will work at the University of Illinois during 1977 with Professor C. Wayman, who is also expert on shape memory effects (see *Met. Trans.*, V. 6A, 29, 1975).

With respect to intermetallic compounds, such as $Ni_3(Al, W)$, there is keen interest in the observation that the yield strength increases markedly with temperature. This phenomenon, which has also been observed in $Ni_3Si$, $Co_3Ti$, $Ni_3Ga$ and $Ni_3Ge$, has been recognized and used in the design of high temperature nickel-base superalloys, but the fundamentals are not well understood. Nenno and his group have conducted compression tests on single crystals of $Ni_3(Al, W)$ to determine the temperature and orientation dependence, and they have found that at low temperatures [111] < 110 > slips operate whereas at high temperatures [100] < 110 > slips operate. The positive temperature dependence of the yield strength occurs only over the temperature range of the [111] < 110 > slips. The peak strength transition temperature between the two slip systems is orientation dependent relative to the compression axis. The critical resolved shear stress of the primary (111) [101] slip also increases as the stress component of the (010) [101] cross slip increases; similar effects are observed with $Ni_3Ga$ and $Ni_3Ge$. The rate of strength increase with temperature becomes larger as the compression axis approaches the [111] orientation. According to Nenno the probability of the screw dislocations on the {111} slip plane decreases as the deformation temperature increases. The reasons for this reduced mobility are a subject of current investigations. It has been noted that stacking fault energy (SFE) correlates with the difficulty of cross slip. Papers which describe this and related work in greater detail are published in *Scripta Metallurgica* (*10*, 879, 1976; *10*, 1081, 1976), *Japanese Jr. Applied Physics* (*11*, 437, 1972; *13*, 1461, 1974; *14*, 703, 1976; *16*, 267, 1977) and in *Jr. of Physical Society of Japan* (*32*, 694, 1972; *35*, 1386, 1973; *36*, 1330, 1974).

The group of Professor T. Yamane is interested in 1) fiber reinforced materials, 2) internal friction studies, 3) diffusion in metals and 4) radiation damage in metals. During the initial conversations Yamane noted his extensive work on the physical metallurgy of titanium alloys which terminated about seven years ago, apparently a casualty of the Japanese administrative decision-making process but also the result of Yamane's dissociation from his former employer, Hitachi Shipbuilding and Engineering Co., Ltd., where the titanium work was done.

More recently Yamane and others have specialized in studies of neutron irradiation effects on iron alloys. Of interest is the study of the response of N and C atoms to irradiation, through internal friction measurements. This work has resulted in a long series of papers. The thrust is that C and/or N atoms are trapped by defects produced by neutron irradiation, and released upon annealing at various temperatures. Annealing may take place stepwise with temperature, signaling various events in the release process. The annealing temperatures required for release vary with the composition of the alloy. For instance, carbide stabilizing elements such as Cr and Mo inhibit release of C and N from the radiation-produced C-N-vacancy complexes. The commercial pressure vessel steels ASTM 542 and ASTM A533B have been included in the investigations. Further details may be seen in *Jr. of Nuclear Science and Technology* (*9*, 598, 1972; *10*, 587, 1973; *10*, 556, 1973; *10*, 705, 1973; *11*, 99, 1974; *11*, 114, 1974; *12*, 519, 1975; *12*, 634, 1975). An award for best paper of the year was received in 1976 from the Atomic Energy Society of Japan.

In the field of fiber reinforced materials Yamane's group has studied primarily copper reinforced with W, Mo or Fe fibers. Areas of special interest have been the use of internal friction measurements to study the rolling and annealing characteristics of copper reinforced with Mo and W fibers and the relationships between the mechanical properties and interfacial reaction of composites containing W or Mo fibers in a matrix of copper or copper alloyed with Ni or Mn. The presence of Ni or Mn promotes a reaction zone which may be observed in the microscope and which is tractable to analytical determinations with the electron beam microprobe.

The studies indicate that with respect to strength there is an optimum 5 to 10 microns thickness of reaction zone. These studies are summarized in several papers (see *Proc. 1971 International Conference on Mechanical Behavior of Materials* or Vol. 5, *Soc. Of Materials Science*, 220, 1972; *Met. Trans.*, 1250, 1974; *Trans. JIM* 13, 160, 1972; *Trans JIM 17*, 25, 1976). A somewhat related paper dealing with superplastic deformation in the presence of cross section inhomogeneities appears in *Met. Trans.*, 2159, 1975.

In the Department of Welding Engineering there are continuing studies on the hydrogen embrittlement of base metal and weldments. The researchers employ metallographic and fractographic observations, acoustic emmission and internal friction measurements to study hydrogen diffusion and interactions with defects and impurities other than hydrogen.

The work has shown that hydrogen does interact with dislocations and does precipitate at dislocation sites. Plastic strain intensifies the effect of hydrogen and plastic zones attract hydrogen. Kikuta and coworkers see the concentration of hydrogen near crack tips as the indirect result of dislocation multiplication rather than the result of stress concentration. The conclusions are supported by finite element analyses and computer simulations. The substance of this work is described in papers published by the *International Congress on Hydrogen in Metals*, Paris, 1972, pages 144 and 293, IIW Doc. IX-837-73, IIW Doc II-A-327-73; Trans. ISIJ *15*, 87, 1975, Trans ISIJ *15*, 503, 1975; *Nuclear Metallurgy 20*, part 2, p. 789.

Discussions were also held with Professors Y. Mukai, M. Watanabe and others in the Welding Engineering Department. These investigators have been studying corrosion fatigue (stainless steel and structural steel) and stress corrosion by $H_2S$ (in high strength steels). There were no startling findings reported, but several solid papers have been written (see Technology Reports of Osaka University, *14*, No. 602, 609, 1964; *22*, No. 1040, 155, 1972; *24*, No. 1202, 487, 1974).

Of perhaps greater current interest are some studies in the fracture mechanics of stress corrosion cracking in austenitic stainless steel which Professor Mukai is conducting in collaboration with M. Murata. Using specimens which feature increasing, decreasing or constant stress intensity, the investigators show that substantial differences are seen in plots of da/dt vs. K. If K is decreasing there is a smooth transition between regions I, II and III. In the cases of increasing or constant K, however, there is an abrupt drop in da/dt with increasing K as the boundary between regions I and II is exceeded. Within region II the value of da/dt is fairly constant, but a steady increase occurs again as region III is reached. The investigators at this point associate the "jog" with crack branching. The work is not yet published.

The Welding Engineering Department boasts some massive welding equipment. there is, for example, an electron beam welder of 100 KW and 100 KV accelerating voltage. Welds from 30 to 50 cm. can be made in one pass. New equipment is being obtained which will permit a 300 KV accelerating voltage, and there are plans for a 1000 KW electron beam welder which will weld up to one meter thick.

There is also a 48 KW hydrogen plasma welder and plans for a 100 KW plasma welder which would be the largest in the world.

The Welding Research Institute at Osaka University is distinct from the Department of Welding Engineering. The major contact, Professor N. Iwamoto, and his colleagues have written many research papers over the last three years. Two papers cover oxide inclusions formed in steels by the deoxidizing elements Al, Si, Mn, Ti, V, Nb, Zn and Cr. (See Trans. JWRI, *3*, 41, 1974 and *4*, 23, 1975). The different types of inclusions and their morphologies which these deoxidizing elements produce in steel is reviewed.

Iwamoto has also written a series of five papers on slags. First, the basicity of slag is reviewed with respect to concept and effects on solubility of gases such as oxygen, nitrogen and water vapor (Trans. JWRI *3*, 89, 1974). A second paper considers the role of $CaF_2$ in slag and considers the effects of fluorine ions on the Si-O-Si bonds (Trans. JWRI, *4*, 91, 1975). It is apparently uncertain at this time whether or not fluorine ions break the Si-O-Si bond.

Iwamoto summarizes the structural theory of oxide melts in a third paper (Trans. JWRI, *4*, 127, 1975). There is still much uncertainty about the structure of the species in molten slags. The meaning of the amorphous state as applied to slags is not clear.

The behavior of amphoteric metal ions such as aluminum and titanium in slag is also described (Trans. JWRI *5*, 87, 1976). Again, there is much uncertainty, particularly in the case of titanium, although it is a general view that the ratio of metal to oxide as distributed between metal melt and slag is related to the basicity of the slag. It is therefore remarkable that the rolls of common additives to fluxes such as $Al_2O_3$, $TiO_2$ and $CaF_2$ are so poorly understood.

In the fifth paper on slags (Trans. JWRI *5*, B5, 1976) Iwamoto considers gas solubility in slags. It is claimed that there is a strong correlation between the state of aluminum ions in slag and the solubility of gas (water vapor and nitrogen). The role of titanium is not yet resolved.

Because of the interest in amorphous phases in slags, X-ray diffraction studies on amorphous materials are currently active (Trans JWRI, *5*, 7, 1976). Determinations of radial distribution functions for $Na_2O$-$Si_2O_2$-$GeO_2$ glasses were used to infer structure.

A final interest which was discussed with Iwamoto was pressure welding of aluminum to titanium (Trans. JWRI, *5*, 63, 1976) and diffusion welding of mild steel to aluminum (Trans. JWRI, *4*, 67, 1975). There has been collaboration with Tokyo Shibaura Electric Co., Ltd., and with Teikoku Piston Ring, Inc., in this work. The results have shown that iron and aluminum form a diffusion bond with $Fe_2Al_5$ at the interface. With a silver interlayer, $Fe_2Al_5$ forms at the mild steel side. With a nickel interlayer, $Al_3Ni_2$ and $Al_3Ni$ form on the aluminum side. Best strength requires a nickel interlayer and vacuum diffusion.

With respect to pressure welding, aluminum is readily pressure welded in air to titanium if the titanium is coated with aluminum by hot dipping prior to welding. The compound $Al_3Ti$ appears at the interface.

The final visit at Osaka University was with Professor Hiroshi Fujita, Director of the Research Center for Ultra-High Voltage Electron Microscopy. The pride of the Center is the 3MV electron microscope which is 10 meters high and weighs 70 tons. Magnification is obtainable from 1000 to 300,000 times with a resolution of about two angstroms. For experimental purposes, several *in-situ* devices are available. Thus metallurgical specimens may be stressed continuously or alternately and at the same time be cooled to the temperature of liquid nitrogen or heated to as high as 1000°C. For studies of superconductivity, a liquid helium device cools to under 4°K; the effects of lattice imperfections on the critical field are of current interest. To study ceramics an electron beam heating device may boost temperatures to 2000°C.

An unusual environmental cell is also available to study biological and metallurgical phenomena as related to the environment. Biological specimens may be viewed *in vivo*. Solid-liquid and solid-gas physical and chemical reactions may be observed. Thus there is a current use of the cell to study hydrogen embrittlement mechanisms.

According to Professor Fujita the principal advantage of the high voltage is that greater specimen thickness can be used. This is important because there are threshold thicknesses below which such material characteristics as dislocation density and recrystallization temperature differ from the bulk material. The high voltage is essential for observation of elements with atomic number over 30.

On the basis of such thickness effect studies, Fujita has concluded that the high strength of whiskers results from their minute thickness. In such thin fibers, dislocations escape at the surface. Whiskers would not be required if the metal could be thinned another way.

The microscope of Fujita has also been used to study sintering phenomena. It has been shown that small particles play an important role in reducing sintering temperature.

Other applications of the microscope are described by Fujita in several recent papers. For applications in materials science see *Japan Jr. of App. Physics, 11*, 1522, 1972 and *Proc. of the Fourth International Congress on High Voltage Microscopy*, Toulouse, 1975, pages 233, 237 and 345. For studies on deformation see *Jr. Phys. Soc. of Japan, 40*, 1976, pages 792 and 1103. A paper on diffusion phenomena appears in *Jr. Phys. Soc. of Japan, 37*, 986, 1974. The universal environmental cell and its applications in metallurgy is described in *Japan Jr. of App. Physics, 15*, 2221, 1976. The High Voltage Electron Microscope Center has been described also by Dr. Leslie S.G. Kovasznay of ONR Tokyo, who visited Fujita earlier (see *ONR Tokyo Scientific Bulletin*, Vol. 1, No. 2, October to December 1976, p. 27).

The overall impression of Osaka University is entirely favorable. The University is involved in diverse disciplines with a spectrum of activities from theoretical to wholly practical. The extremely gifted and well educated investigators work in sufficient proximity that the strength of science is brought to bear on significant problems.

# TOHOKU UNIVERSITY

In 1907 Tohoku University was founded at Sendai, Japan. The Faculty of Engineering was established in 1919 and the same year the Research Institute for Iron, Steel and Other Metals was founded as a part of Tohoku University. A Department of Metallurgy was formed in 1924, the largest such department in Japan. The department covered both chemical and physical metallurgy; the latter subject area was just beginning to grow in the world at that time. A Research Institute of Mineral Dressing and Metallurgy was formed as part of the University in 1941, the Department of Materials Science in 1960 and the Department of Metal Processing in 1965. A Research Institute for Strength and Fracture of Metals was established in 1964.

The present setup is that the three materials departments (Metallurgy, Materials Science and Metal Processing) are administered as a single unit with professors teaching sometimes in more than one department. Likewise, students in the three departments take common courses and specialize only in the final years. Graduate degrees through the doctorate are offered. At the graduate school level, members of the research institutes such as the Research Institute for Iron, Steel and Other Metals become active in the direction of research and in teaching. The total enrollment of the three departments is somewhat over 200, with about 35 working in graduate school for the doctorate and 50 for the masters degree.

Visits to the Department of Metallurgy, Materials Science and Metal Processing are reported here, and visits to the Research Institute for Iron, Steel and Other Metals and the Research Institute for Strength and Fracture of metals are described in other articles in this report.

For the Departments of Metallurgy, Materials Science and Metal Processing the principal host was Professor Karashima who is well-known for work on the strength of metals and in fact heads the Strength of Metals Group which includes also Drs. H. Oikawa and T. Watanabe. Studies of this group include (1) low temperature deformation of Cu and Zn bicrystals, (2) deformation of $\alpha$-iron single crystals, (3) deformation of Al-Mg alloys and Al-Mg single crystals at high temperature, (4) high temperature creep of Fe-Mo and Fe-Si alloys, and (5) grain boundary sliding and fracture. Before describing his own work, Karashima outlined briefly some activities of other materials groups, as follows:

1) Structural Materials (H. Sato, N. Nemoto, S. Uemura, J. Echigoya) - heat treatment of ferrous and non-ferrous alloys, ductility of high-strength alloys, physical and mechanical properties of vacuum-deposited alloy films, heat-resisting alloys, high-voltage-electron microscopic studies of phase transformations of metallic materials such as $Ni_3Al$, structure of precipitates and intermetallic compounds.

2) Special Materials (H. Kaneko, M. Homma, H. Tanaka, J. Ikeuchi) - Fe-Cr-Mo hard-magnet alloys, rare-earth hard-magnetic materials such as $R_2Co_{17}$ and $SmCo_{17}$, new magnetic alloys for recording, new high-permeability alloys, high-manganese heat-resisting alloys such as Fe-15Mn-15Cr alloy for engine valves.

3) Physical Metallurgy (T. Nishizawa, T. Sakuma, A. Chiba, M. Hasebe) - structure and mobility of phase interfaces, diffusion-couple multiphase interfaces, phase transformations and interface mobility, electron microscopy of phase transformations, thermodynamics of phase equilibria, effects of magnetic field on phase equilibria in iron alloys.

4) Chemistry of Metals (K. Igaki, Y. Noda, S. Ito, T. Kagatani, K. Nishimura) - preparation of ultra-pure metals such as Fe and Al, non-stoichiometric chalcogenides of transition metals, (e.g., Co-Se), preparation and properties of binary and ternary II-VI compounds such as ZnSe, structure and property control of amorphous semiconductors and liquid crystals.

5) Metal Physics (K. Hirano, Y. Onodera, S. Fujikawa, Y. Iijima) - diffusion of hydrogen in iron and nickel, diffusion of transition metal impurities in aluminum, electromigration of carbon in iron, thermal diffusion in Al-Ge alloys, spinodal decomposition, splat-spinodal decomposition, splat-quenched aluminum alloys.

6) Foundry Engineering (G. Ohira, A. Watanabe, T. Sato, T. Ohide) - solidification of aluminum alloys and cast iron, properties of malleable cast iron, wear and friction of alloys, high temperature oxidation scales, oxidation of metal-carbon alloys.

7) Welding Engineering (T. Kobayashi, T. Kuwana, Y. Kikuchi, R. Kiguchi) - nitrogen absorption during arc welding, chemical reactions during arc welding and electroslag welding, effects of nitrogen in

aluminum welding, effects of alloying elements on metal transfer in the arc space, welding in high pressure atmospheres, welding cracks in low-alloy steels, non-shielded arc welding of steel.

8) Interface Science of Metals (W. Suetaka, A. Hatta, M. Ito) - molecular orientations in thin films on bulk metal surfaces, nucleation and growth of organic crystals on metal surfaces, electronic high-sensitivity reflection spectroscopy, infrared spectra of adsorbed species on metals, mechanisms of organic corrosion inhibitors.

9) Powder Metallurgy (Y. Masuda, R. Watanabe, J. Takekawa, E. Otsuki) - sintering, densification mechanisms, grain growth in sintered metals, sintering of sub-micron particles, mechanical properties of WC-Co and TiC-Ni hard alloys.

10) Plastic Working of Metals (H. Takahaski, T. Marakami, N. Okamura) - extrusion through stepped dies in plane strain, open die forging, semi-closed die forging, indentation and piercing.

11) Mechanical Metallurgy (H. Shimada, M. Chiba, K. Shimizu, M. Obata) - mechanical behavior of metals under biaxial stress, photoelastic stress analysis of shells and plates, effects of grain boundaries, notches, size effects and grain size on yield behavior, strength of non-homogeneous materials, mechanical behavior of aluminum bicrystals and deformation of the bicrystals at elevated temperature, high-speed photoelastic methods.

Professor Karashima next described recent work on the effects of deformation temperature and orientation on the Bauschinger effect in polycrystaline and single-crystal aluminum, respectively. It was pointed out that one must be careful in reading the literature to determine which Bauschinger strain parameters are used. Some authors use $\beta_1$ and others $\beta_{0.1}$ or $\beta_{0.5}$. Karashima concludes that the Bauschinger effect decreases with increasing temperature, and that this is explained by the change in dislocation structures with deformation temperature. With respect to orientation Karashima and his collaborators notice that the Bauschinger effect is smaller in crystals oriented for a single glide than in crystals oriented for multiple glides; that is, the Bauschinger effect decreases with increasing Schimid factor. This is in accordance with the notion that the Bauschinger effect is produced by elastic interactions among dislocations which are introduced during prestraining. Further details may be seen in Trans. JIM *17*, 414, 1976 and *18*, 25, 1977 and in Materials Science and Engineering, *20*, 267, 1975. Karashima and his colleagues have also studied the effects of magnetic characteristics or Curie temperature on creep. Studying Fe-Mo, Fe-Co, Fe-Si and Ni-Co alloys, it has been found that the steady-state creep rate versus temperature curve shows a discontinuity at the Curie temperature, Tc; the creep rates in the ferromagnetic temperature region are lower than expected. These studies, which were confined to temperatures above 0.5 Tm (melting point), indicate that the creep discontinuity reflects the effects of ferromagnetism on diffusion. Similar results were obtained with fcc and bcc metals and alloys. This work is described in greater detail in Met. Trans, *2*, 1359, 1971, Scripta Metallurgica, *5*, 825, 1971 and Trans. AIME, *242*, 1703, 1968.

In more recent studies Karashima has collaborated in a study of testing mode on deformation behavior in first-stage creep and in tensile tests. Primary creep curves on Fe-Mo $\alpha$-iron alloys (Class I alloys) at 1074 and 1124K could be classed in four types, and similar classes could be specified in the conventional stress-strain curves. Hence, the results from one test can predict the performance in the other, and the first stage creep behavior can be estimated from the tensile test at room temperature. This work has been summarized in a paper submitted to Materials Science and Engineering, 1977.

A paper, with Karashima as coauthor, has been written on the grain boundary sliding in zinc bicrystals. The paper was presented to the Fourth International Conference on Strength of Metals and Alloys, Nancy, France, 1976. The work treats the mechanisms of sliding, emphasizing grain boundary structure, orientation and crystal deformation in addition to dislocation models. The amount of sliding increases with tilt angle, but minima are seen at angles which produce a good match. Thus grain boundary sliding does not occur when a good match in tilt angle and twist boundary is obtained; in such cases fracture may be intergranular but is more likely to become transgranular. Twist boundaries provide a better match than tilt boundaries so sliding is more difficult.

In other work with T. Watanabe, Karashima shows that environmental effects may relate to grain boundary structure and segregation of impurities may amplify these effects. Thus it was shown in one instance that silicon segregation increased with tilt angle and that the silicon concentration was greater in air than in vacuum (at elevated temperature). The investigators state that the concentration at grain boundaries is dependent on tilt angle but not twist angle.

Following the discussions with Karashima, investigators in the various other groups were visited. Professor M. Nemoto is studying plasticity of $Ni_3Al$ using the 1 MV HVEM and a tensile stage at 600°C. Observations are on dislocation movements in relation to grain size. The relation of grain size effects to superplasticity is sought. In previous work with H. Sato, Nemoto had studied the structure and strength of fine-grained copper and silver prepared by vacuum deposition. The grain size could be held to 2000 angstroms in the as-deposited state but grain size increased with annealing. The Hall-Petch relation predicted the strength changes satisfactorily. See Trans JIM, *12*, 1971.

Professor M. Homma, H. Kaneko and K. Suzuki have been developing hard magnet alloys for some years, mostly in the Fe-Cr-Co system. Fairly recent developments have produced a hard magnetic material almost equal to Alnico V in energy product which is also easily forged and rolled. The recent improvements result from judicious additions of Nb and Al to the basic Fe-Cr-Co alloys which may contain from 20-30 percent Cr and 15 to 23 percent Co plus smaller concentrations of various other elements such as V and Ti. According to Homma, there is much interest in the United States, notably at General Electric and Bell Telephone. Kaneko was scheduled to lecture on the new alloys in the United States during 1977. In addition, Homma was scheduled to lecture at Dresden on this subject in November 1977.

Currently Homma and others are attempting to produce high-permeability materials such as the famous Fe-9Si-5Al Sendust alloy in a forgeable and ductile form. No results were given. There are also efforts to develop the rare-earth hard-magnet alloys of the type $R_2Co_{17}$. Already an alloy developing 30 megagauss-oersted has been found. This is tops in the world according to Homma and there is already international interest.

Background material on these subjects may be seen in Trans JIM, *9*, 124, 1968; *AIP Conference Proceedings No. 29, Magnetism and Magnetic Materials*, 620, 1975; *AIP Conference Proceedings No. 5, Magnetism and Magnetic Materials*, 1088, 1971; IEEE Trans on Magnetics, Vol. *Mag-11*, 1440, 1975; *34th Ann. Proc. Electron Microscopy Soc. America*, 606, 1976 (G.W. Barley, Editor); IEEE Trans. in Magnetics, Vol. *Mag-12*, 977, 1976.

Professor W. Suetaka and his colleagues perform studies on the interface science of metals. A brief description of these activities follows:

1) Adsorption of simple molecules on clean metal surfaces. Reflection IR spectra are used to identify the molecule and its orientation adsorbed on a metal surface.

2) In-situ observations of intermediates formed on metal electrodes. Using laser beam excitation, Raman spectra and the Raman resonance effect are used for analyses at the metal surface, at potentials controlled by a potentiostat. Concentrations as low as $10^{-5}$ mol/liter can be detected. The results are applicable to the design of catalysts.

3) Molecular orientation in thin films on metal surfaces. One example of the above activities is the study of adhesion. Consider aluminum coated with the polymer *α-cyanoacrylate. The aluminum* as electropolished gives one IR spectra (Type B), the anodized aluminum surface another (Type A). The structure of the polymeric layer depends on the type of underlying surface, Type B or Type A. The reason is that the Type B surface is smooth so that linear growth of the polymers is possible, whereas the anodized surface is rough so that numerous intersections occur as the polymer chains grow.

The same type of research is being done on lubricants. Linear chain hydrocarbons are found to form a prismatic structure on a smooth metal surface at low temperatures. This structure is favorable for good lubrication, but it is gradually disoriented and destroyed with increasing temperature. Additives such as carboxylic acid of the same chain length as the hydrocarbon lubricant assist maintenance of the oriented structure to higher temperature, but the effects of additives diminish with decreasing chain length. Also a bulky molecule such as isostearic acid disorients the lubricant even at low temperature and experiments with different metal substrates (iron, copper and gold) show a change in orientation with metal species. Thus many variables are being studied using experimental techniques to better understand and improve lubricants, adhesives, corrosion inhibitors, etc.

Further background and detail on the surface studies are found in Chemistry Society of Japan Chemistry Newsletters, 113, 1975; 189, 1973; Fourth European Symposium on Corrosion Inhibitors, Ferrara, Italy (82th Manifestation of the European Federation of Corrosion), 67, 1975; Journal of Phys. Chem. *79*, 1190, 1975; Surface Science *62*, 308, 1977 and Bulletin. Chem. Soc. of Japan, *48*, 2428 and 1512, 1975. A paper on the effects of additives in lubricants is in preparation.

Professor Ken-ichi Hirano of the Metal Physics Group discussed some experiments on the electromigration of carbon in iron. Homogeneous specimens are used which contain about 0.01 percent radioactive carbon. Electric currents (DC) are passed through the specimens at various temperatures between 500 and 1000°C. Typical current densities range between 90 and 900 amperes per /cm².

Over a period of time (not specified) the carbon segregates toward the cathode end of the specimen; a difference of about 30 percent in carbon concentration is commonly observed. The forces on the carbon atoms from the flow of electrons can be calculated and from this the electronic structure of the carbon in solution can be deduced.

The principal findings are that carbon has a true charge number of about zero, from which it is concluded that the carbon ion is subjected not to the electrostatic force but to the drag force from the current carriers during electromigration. The determination that the carbon has zero charge number is based on the observation that the drift velocity in $\alpha$-iron is proportional to the electric current density and that therefore the effective charge number is independent of electric current density. The effective charge number decreases with increasing temperature. The magnetic transformation of $\alpha$-iron affects the effective charge number in a way which can be explained by the contribution of the spin-disorder resistivity. The studies on electromigration have potential application in the purification of iron.

Grain boundaries also move by electromigration and studies of such movement in aluminum have been made. The practical interest is in thin-film conductors and the open-circuit failure of integrated circuits which involve grain boundary diffusion. Other investigators are studying the growth of aluminum single crystals by electromigration techniques. Some details on the electromigration studies were scheduled to be published in J. of Applied Physics, April, 1977. See also Thin Solid Films, *25*, 353, 1975 (printed in Switzerland).

Professor Suto and others of the Structural Materials Group discussed an interesting study on comparisons of mechanical properties of age hardening alloys in the underaged and overaged states. Alloys were in the Fe-Cu, Fe-Cr, Fe-Ni-Cu, Fe-Ni-Mo-C, Fe-Co-Cr-W, Al-Si and Al-Ag systems. Underaging was found to improve ductility, lower the yield point and produce a larger strain hardening exponent, at the same tensile strength. Alloys with coherent precipitates fracture easier in the underaged condition.

Sato has also studied the crystallization of vapor-deposited amorphous copper-silicon alloys. Pure silicon crystallized at 550°C, but in Cu-Si alloys, silicon recrystallized at 450°C. The work of Sato may be seen in further detail in JIM, *39*, 792, 1975 and Trans. JIM *17*, 596, 1976.

Professor Y. Sawada and others in the Department of Metallurgy have studied stress corrosion cracking in Al-4%Cu alloys. The work has shown that the susceptibility of these alloys varies with aging structure and that the alloys with greatest susceptibility to stress-corrosion cracking show two pitting potentials corresponding to pitting either *at* grain boundaries or *within* grain bodies. The potential at the grain boundaries is critical for stress corrosion. Maximum susceptibility occurs with aging treatments which produce the maximum difference in the two potentials. Details may be seen in JJIM, *39*, 520, 1975 and Corrosion Science, *15*, 709, 1975.

Professor Goro Ohira and others of the Foundry Engineering Group have been studying directional solidification in eutectic cells in eutectic and hypereutectic mottled cast irons. Other studies are on the unidirectional solidification in the iron-graphite (Fe-4.65C, Fe-4.11C-1.77Si and Fe-4.02C-0.1S) and iron-cementite (Fe-4.28C-3.86Cr) systems. The results are interpreted in terms of solidification temperature gradient and composition. Some of the detailed results are given in Journal of Crystal Growth, *34*, 61, 1976, and Imono, *46*, 1054, 1974, *47*, 10, 1975. A study of the morphology of primary iron carbide as related to alloying elements is given in Imono, *47*, 562, 1975.

The general impression is that the departments of Metallurgy Materials Science, and Metal Processing at Tohoku University are extremely well-integrated, well-staffed and highly-productive. Professor H. Oikawa of the Department of Materials Science explained this: about ten years ago many Japanese came to study and work in the United States, because fellowships paid for by the United States were plentiful and the United States enjoyed a technical lead in most materials areas. Now, the people who came to the United States have returned to Japan, in part because the support in the United States has diminished. They are doing basic research work in Japan on non-directed university funds. Tohoku University, as one of the leading centers on materials research in Japan has quite naturally attracted the very best of the returned Japanese scholars.

# TOKYO INSTITUTE OF TECHNOLOGY

Tokyo Institute of Technology (Tokyo Kogyo Daigaku) characterizes itself as the leading institution of higher learning in the field of engineering and science in Japan. After a visit to both the O-okayama and Nagatsuta campuses, the writer would not venture to argue on their "we're number 1" proclamation. The discussions at the O-okayama campus were primarily with Tsutomu Mori, Professor in the Departments of Metallurgical Engineering and Materials Science and Engineering. Professor A. Sato, the Associate of Professor Mori, also participated actively.

Professors Mori and Sato are well known in the international metallurgical community and they both have resided in the United States for various periods, notably in connection with activities at Northwestern University. Professor Mori was a post-doctorate in the Civil Engineering Department at Northwestern University from 1959 through 1961. He was also in residence from 1965 through 1968 in the Materials Science Department. Most recently, he was at Northwestern for two months in 1975 during which period he produced an amazing four technical publications in collaboration with the Northwestern faculty. Another two-month trip to Northwestern is scheduled for the summer of 1977, and it will be interesting to see if this fantastic productivity continues. To complete the Northwestern University connection, Dr. Sato obtained his Ph.D. there in 1971. Professors Mori and Sato have two major current interests: 1) work hardening and recovery of dispersion hardened materials, and 2) stress effects on martensitic transformation and diffusional precipitation.

With respect to the first area, Mori stated that his early theoretical analyses have led him to his current experimental activities. Briefly, he produced a series of papers beginning in 1970 (Acta Met *18*: 939 (1970), Acta Met *20*: 297 (1972), Acta Met *21*: 571 (1973), Materials Science and Engineering, *26* 87 (1976)) in which he and his collaborators developed a theory of dispersion hardening which reconciles calculations of work hardening by continuum mechanics and dislocation theory. Previously dislocation theory met difficulty in handling elastic constants and particle morphology. The theoretical analyses of dispersion hardening were shown also to be applicable to fiber-containing material (Acta Met *21* 85 (1973)).

The first experimental work appeared in 1975 (Acta Met *23* 85 (1975)). This involved single crystal specimens of copper-containing silica particles (via internal oxidation). The study was of length change and softening by recovery during annealing at 200°C. The observations agreed with the theory.

At present the work seeks to explain the effects of dispersions of particles upon creep. Two students are involved, studying the systems Al-Si and Cu-$SiO_2$ + BeO. Ordinarily, metals are strengthened as a given amount of precipitate material is dispersed into smaller particles; however this may not be true at elevated temperatures. Mori and his colleagues have shown, for example, that softening during low temperature annealing is sensitive to particle size. A paper on this subject, "Effect of Particle Size on Low Temperature Softening of Work Hardened Copper-Silica Crystals," has been accepted for publication by Acta Metallurgica. Particles 280Å in diameter resulted in softening after 20 minutes at 42°C whereas 900Å diameter particles produced no softening. Therefore at low temperature small particles strengthen, but at high temperatures where creep is a problem large particles may be preferred.

The student studying the Al-Si system will be concerned with the effects of one precipitate, of variable particle size as produced by heat treatment. The other student, studying the Cu – $SiO_2$ + BeO system will be involved with a composite dispersion. These systems are produced by the internal oxidation of Cu-Si-Be alloys, which can be produced at the University. It also so happens that the $SiO_2$ particles grow upon annealing whereas the BeO particles are rather stable. Thus a material can be produced with two dispersions, one with particle size which is stable and the other with particle size which is variable and which can be controlled. Mori hopes to demonstrate that a material which is strong both at low temperatures (fine dispersion) and at elevated temperatures (coarse dispersion) can be produced. The alloys used in the experiments are, of course, selected to simplify the experimental problems. The principles evolved, however, should be applicable to the design of genuine refractory alloys.

Professor Mori's second area of current interest is the effects of stress on martensitic transformation and on diffusional precipitation. Interest in the latter process has focused about the Fe-N system. Iron-0.5 percent N alloys were prepared as single crystals. The crystals were quenched from 590°C to produce a solid solution, then aged at temperatures between room temperature and 100°C, either under stress of various magnitudes, or free of stress. It was found that the $\alpha$ $Fe_{16}N_2$ precipitate which forms becomes progressively finer and crystallographically oriented with increasing stress during aging. Stress in the [011] direction produces precipitate disks which are perpendicular to the stress if in tension but parallel to the stress if the stress is in compression. Residual stresses also influence precipitation. This work is described in detail in Kinzoku Gakkaishi, *V39* No. 6 (1975).

With respect to the effects of stress on martensite transformation, Mori has shown the existence of a temperature, $M_d$, which is different from the martensitic formation temperature $M_s$ which obtains in the absence of stress. Deformation of the metal above $M_d$ is by slip, below $M_d$ by transformation to martensite. According to Mori the process involves the motion of partial dislocations. Further details are given in a series of papers. See Acta Met *22* 313 (1974) and Acta Met *24* 853 (1976). A paper entitled "Contribution to the $\gamma$ - $\varepsilon$ Transformation of Stainless Steel Single Crystals," by A. Sato, Y. Sunaga and T. Mori has been accepted for publication by Acta Metallurgica.

The visit to the O-okayama campus concluded with a laboratory tour. The highlight was the new Hitachi H-700 200 KV transmission electron microscope, which features the routine attainment of 200 KV and thus offers better resolution.

The meetings at the Nagatsuta campus took place at the Research Laboratory of Precision Machinery and Electronics, one of the research institutes attached to the National Universities. The mission of this Laboratory is to study the basic theories in precision engineering and their application to industry. The Laboratory is organized to foster interdisciplinary interaction among precision machinery engineers, electronics engineers and metallurgists. Among the fourteen Divisions of the Laboratory, the writer visited two, the Materials Sciences Division with Professor Shigetomo Nunomura the principal contact, and the Heat Treatment Division with Professor Tomoo Suzuki the principal contact.

The visit began with a tour of the Nagatsuta campus and the Research Laboratory of Precision Machinery and Electronics in particular. There is an enormous amount of construction of rather impressive building underway at this new and only partially completed campus. The graduate school of the O-okayama Campus is scheduled to move to the Nagatsuta campus in 1977 and the Laboratory of Engineering Materials (another research institute) in 1978.

With the exception of the new electron microscope at the O-okayama Campus, the writer was shown little in the way of sophisticated equipment. In one completed building, for example, the hosts pointed to the spot (very clean and very ready) where the electron microscope will go, if and when the Ministry of Education comes up with the funds.

In the Heat Treatment Division (a refreshing departure from the vogue of inventing pretentious titles), Professor Suzuki discussed briefly a number of activities which are highlighted as follows:

1) Fiber Composites — one student is trying to strengthen polymers with glass and carbon fiber. The goal is light weight coupled with high modulus for aircraft application. No specific results were described.

2) *In-Situ* Composites — the interest is in the effects of thermal cycling on directionally solidified composites such as Al-$Ni_3Al$. Such cycling produces severe dimensional changes in aligned phases according to Suzuki. This may complicate the prospective use of such materials in high temperature applications involving thermal cycling. There is severe growth and twisting of the Al-$Ni_3Al$ composite, for example, after a few thousand 5-10 minute cycles from room temperature to 500°C. The work being done involves lower melting, experimentally tractable alloys, but the hope is that the fundamentals of controlling and understanding the dimensional instabilities which are developed will be applicable to the design of refractory directionally solidified composites.

3) Properties of $Ni_3Al$ — there is an interest in studying fundamentally the anomalous increases in hardness of this compound with increasing temperature. The hardness of this important phase ($\gamma'$) in high temperature alloys may increase by a factor of two or three between room temperature and 800°C. No specific results were described.

4) Hydrogen effects — the effects of hydrogen on properties such as electrical resistivity and upon $M_s$ temperature are being studied. An apparatus to charge gaseous hydrogen into specimens at 200 atmospheres and 800°C has been assembled. An internal quench tank is an added (and necessary) feature. Suzuki has published a paper, "Effect of Hydrogen on the $M_s$ Temperature in Fe-Ni and Fe-Ni-C," First Japan Institute of Metals International Symposium on New Aspects of Martensitic Transformation, Kobe, May 10-12, 1976 (Supplement to Trans. JIM, V 17 (1976). The paper is in collaboration with J.C. Shyne of the Division of Materials Research, National Science Foundation. This work, which shows that hydrogen decreases $M_s$ comparably to other interstitial solutes such as C or N, was done in part while both authors were at Stanford University.

In the Materials Science Division, Professor Nunomura discussed studies in fatigue crack growth rates of alloys. The goal is to relate the effects of metallurgical structure (as influenced by composition and heat treatment) and such mechanical factors as mean load, stress intensity factor range, periodic overload, etc. Nunomura is also attempting to determine fatigue threshold rapidly by a programmed decrease in $\Delta K$ (crack arrest). At the same time he denies the existence of a fatigue threshold, but the contradiction appears to be a matter of definition with respect to micro and macro observations. The experiments are currently being performed with 7075 Al specimens. Crack growth rate is monitored by a time-lapse photography method, which perhaps highlights the imbalance between equipment and buildings.

A novel approach to measure the plastic zone directly in certain steel alloys was also described. The trick is to stress or fatigue a precracked specimen in the temperature region between $M_s$ and $M_d$. The increased stress (strain) in the plastic zone promotes the transformation to martensite, and the martensite then serves to decorate the plastic zone. According to Nunomura the reverse plastic zone can also be delineated. This work has been summarized in a paper entitled "Direct Measurement of Plastic Zones in Side Grooved Fracture Toughness Specimens" to be presented at the Fourth International Congress on Fracture, Waterloo, Canada, June 19-24, 1977.

## THE UNIVERSITY OF TOKYO

The University of Tokyo is about 100 years old and was the first in Japan to orient itself toward the Western World. The first classes in science and technology were in fact taught by foreign professors who were employed to introduce these subjects which were not at that time advanced in Japan, at least compared to European technical levels. With this headstart, the University of Tokyo led the way toward westernization and apparently has educated many of the nation's leaders in government and industry. The standards of admission are extremely high and the examinations upon which entrance is based absolutely are referred to as pure "*hell.*"

As a matter of firm policy, the University of Tokyo remains outside of partisan politics. Members of the faculty serve as special advisors or on committees of agencies such as the Science and Technology Agency, Ministry of Education, Ministry of Transportation, Ministry of Construction and the Environmental Agency. The two professors visited, Professor Y. Asada and Professor K. Iida, are for example heavily engaged in research associated with pressure vessel technology and shipbuilding, and they interact directly with such organizations as the Power Reactor and Nuclear Fuel Corporation and the Ship Research Institute (both governmental organizations).

Professor Asada is associated with the Department of Mechanical Engineering and is pursuing several problems in high temperature low-cycle fatigue and on cyclic strain induced plasticity, strain induced creep and recovery. For example he is currently studying the effects of hold time and strain rate on low cycle fatigue of type 304 and type 316 stainless steels at 650°C. This temperature is of interest because it reflects the reactor temperatures where type 316 may be used as a cladding material. The test specimens of Asada are of the hour-glass type, 6 mm in diameter. The load cycle is triangular and involves both tension and compression, but the holding periods (of one to sixty minutes) are always during tension. Tests are conducted in a vacuum of $1 \times 10^{-6}$ torr.

One paper on their work will be presented by Asada and several collaborators before the 3rd International Conference on Pressure Vessel Technology to be held 19-22 April 1977 in Tokyo. Other papers have appeared previously (see Annual Report of the Engineering Research Institute *31* 91 (1972), Proceedings of the International Conference on Creep and Fatigue in Elevated Temperature Applications, Sept 1973, Sheffield, U.K. 1974).

Asada was most interested in the work of Shahinian and others at the Naval Research Laboratory. Shahinian has attacked similar problems but measures crack growth rates in precracked specimens. Asada has considered the effects of notches (Proceedings of the 2nd International Conference on Pressure Vessel Technology, San Antonio, Texas, 1973) but apparently leaves crack growth rates to others at this time. A colleague of Asada at University of Tokyo, Professor H. Okumura is, however, conducting fracture mechanics type tests with crack growth measured optically.

The work of Asada and others on plastic strain was presented in part before the International Conference on Creep and Fatigue in Elevated Temperature Applications, Philadelphia, 1973. A new paper on "Accumulation of Longitudinal Strain Under Cyclic Torsion" will be presented before the 4th International Conference on Fracture, 19-24 June, Waterloo, Canada. (It appears that Waterloo will become a Japanese enclave, to judge from the numbers planning to attend.)

The plasticity work of Asada is done on several rather intricate but well-conceived machines which provide torsion plus push-pull strain. By measuring the push-pull plus the torsional strains, the total strain can be determined and comparisons made with theory. A hollow cylindrically shaped specimen 42 mm in diameter is used (currently type 316 stainless) which costs $500.

Professor K. Iida is associated with the Department of Naval Architecture and this visit began with a tour of the laboratory. The laboratory features an assortment of machines designed to test specimens and components for fatigue resistance, brittle fracture resistance and general strength characteristics. One machine, for example, can apply 600 tons to brittle fracture specimens, thus allowing sections of several inches of thickness to be tested. There is also a 50-ton cyclic load bed to study high-cycle fatigue and another 50-ton bed to study low-cycle fatigue, under servo control. A 400-ton Amsler type loading machine for static loads was apparently the scene of Professor Kanazawa's famous double tension test developed some years ago. This test features a small tensile "ear" with crack starter notch machined from but still attached to the larger specimen to be tested for resistance to brittle fracture. The small "ear" serves to start a crack traveling into the larger section. The test, similar to the ESSO and Robertson tests, is very expensive but was useful in earlier investigations.

It was interesting to see some of the smaller fatigue machines and specimens which were duplicates of the fatigue machines used earlier by E. Lange of the Naval Research Laboratory to test unnotched specimens in low-cycle fatigue. Lange is well known to these investigators at University of Tokyo. These particular machines are being used to test welded joints of 9 percent nickel steel for pressure vessel carriers of LNG ($\approx$ -160°C, 1.5 psi gage). The Department of Naval Architecture is also studying acoustic emission as a means of following the processes of fracture. One test observed in progress involved a 4-point bend specimen. The acoustic emission sensors were being used to follow the plastic deformation and cracking processes.

Iida presented a tall stack of reports, many of them very current, which shows that he is a most prolific researcher. His high stature as evidenced by his invitations to serve on high level committees, boards, and international advisory and control or regulatory groups is very understandable. One of the subjects on which Iida has published extensively is on low-cycle fatigue, how cracks are initiated and grown by this process, and how this relates to design and fabrication processes, especially of large ships and pressure vessels. He has been interested in the related areas of the effects of notches and weld defects on fatigue crack initiation and propagation. The fatigue spectrum, or shape of the fatigue cycle, has also been investigated. Recently he has been working with Dr. M. Kawahara of Nippon Kokan Kabushiki Kaisha to develop an expression for the propagation rate of a fatigue crack from a surface flaw. This work (see report on visit to Nippon Kokan K.K.) attacks the problem of variation in crack front morphology depending on stress system (bending or tension) (see IIW Doc 13-802-76, IIW Doc 13-790-75, IIW Doc 13-801-76).

Iida and collaborators presented papers at the Third Acoustic Emission Symposium, Tokyo, 1976, describing acoustic emission during fibrous brittle fracture and during the low cycle fatigue of hemispherical pressure vessel models. One interesting finding was that in the case of brittle fracture not accompanied by a fibrous crack, there is almost no previous signal by acoustic emission, hence no way of detecting the initiation of brittle fracture. However most common structures do not fail in a completely brittle manner, and acoustic emission does signal the initial fracture processes in these cases.

Most recently, Iida presented a paper, "Comparison of Fatigue Strengths of Steels Under Deflection Controlled Bending and Strain Controlled Axial Load Cycling," at the 2nd International Conference on Mechanical Behavior of Materials, 16-20 August 1976, in Boston. A paper on "Low Cycle Fatigue Strength of Steels and Welds in Relation to Static Tensile Properties," is scheduled for presentation at the 4th International Conference on Fracture at Waterloo (where else?), 19-24 June 1977. This paper, in collaboration with E. Fujii of the Ship Research Institute in Mikota, claims to show that the total strain amplitude in reversed strain cycling can be predicted by static fracture ductility (RA) and ultimate tensile strength within an accuracy of 40 percent. The visible crack initiation life must also be known.

Both Iida and Asada were apologetic about the lack of modern equipment in their laboratories, particularly with respect to the computerized control of tests and data retrieval and analysis. However, the impression was that there is much in the way of human ingenuity at University of Tokyo now, which a flood of new machines might erode.

## YOKOHAMA NATIONAL UNIVERSITY

Several departments of the Yokohama National University faculty of engineering were visited on this occasion. The principal host was Professor S. Oki, who did much more than was expected or required for a satisfactory exchange. There was not much discussion of the history of this institution, but it was established that only master's degrees are conferred and that the school is in process of moving to an entirely new campus some 10-15 kilometers away. The move will be completed in 3 or 4 years. Meanwhile, the existing campus is somewhat run down and generally neglected insofar as cosmetic values are concerned.

Professor Oki described the KOZA system of Japan which is a research or professorial unit consisting of a professor, associate professor plus assistants or lecturers and graduate students. In a given university, each KOZA is granted an identical amount of money for research, although there are differences between technical departments and liberal arts departments. Of perhaps greater interest, there are significant differences in the money allotted (by the Ministry of Education) to KOZA's of different universities. Thus a KOZA at University of Tokyo receives more money than a KOZA at Yokohama University. One determining factor in this is the highest degree offered, and as stated earlier, Yokohama offers only the master's degree.

The usual presentation on activities of ONR and NRL was well received and there was considerable interest in how this system operates within the organization of the Defense Department. There is still some difficulty among the Japanese in visualizing a defense activity which is primarily a thrust at basic science.

Presentations and discussions followed among a number of professors at Yokohama National University. The students of Professor Y. Wada made a valiant effort to explain their work in the areas of hydrogen embrittlement and surface self-diffusion. With respect to hydrogen embrittlement, it was observed, in the case of pure iron, that increasing currents of cathodic charging produced a decrease in the flow stress of tensile specimens. On the other hand, increasing charging amperages on an HT-80 steel (0.09C, 0.24 Si, 0.82 Mn, 0.23 Cu, 0.97 Ni, 0.42 Cr, 0.42 Mo, 0.03 V, 0.002 B) produced a progressively increasing flow stress.

To explain these effects, specimens of an HT 60 steel were charged at 0.2, 1.0, 10, 40, and 100 $mA/cm^2$ during tensile testing. Specimens charged at 40 and 100 $mA/cm^2$ were apparently damaged. The "damage" incurred can be explained, according to Wada, only by the interaction between "active" hydrogen and dislocations.

The surface self-diffusion is studied by Wada and his students essentially by studying the rate of smoothing of grooved specimens as a function of temperature. The materials involved have been 17 percent Cr steel, pure Ni and 3 percent Al-Fe. Wada contends that the surface relaxation occurs by volume diffusion, surface diffusion and evaporation-condensation. He favors the mass transfer mechanism due to Mullins, who describes the solution for the smoothing of a sinusoidal metallic surface in vacuum.

Professor Oki described briefly his work on hot tearing and in particular the relation between cooling rate and thermal stress in castings during solidification and subsequent cooling (International Foundry Congress, Belgrade, Yugoslavia, 1969). Oki is preparing a paper on the theory of hot tearing for submission to the Japan Iron and Steel Institute entitled "Theoretical Study of Hot Tearing in Skin-Forming Solidification." He also described some very interesting recent work on the atomic model of crystallization. Basically, he puts many small steel balls on a plate subject to vibration, but one end of the plate is vibrated with greater amplitude than the other. By slowly decreasing the amplitude generally, he can show how crystals nucleate and grow. He can also model the processes of melting, by gradually increasing the vibration amplitude. This work has been described in IMONO (FOUNDRY), Vol. 48 No. 8, 1976.

Professor Asakura described work on control of corrosion which his group is doing in the Department of Safety Engineering. Safety and Environmental Engineering has become important in Japan in recent years, and in consequence this new department was created. Early efforts have been directed toward the development of a corrosion rate test meter which measures corrosion rate from polarization at a distance. There are also experiments designed to simulate pollution and the diffusion of pollutants in water. Both the pollutant and the detection of the pollutant are of interest. Future plans include tests of corrosion by pollutants in a stress environment.

Dr. K. Ando described his interesting work in the Laboratory for Materials for Energy Systems. He is interested in brittle fracture problems with pressure vessels and with large oil tankage vessels. He has developed a simplified and cheaper test to assess cold cracking after welding in high strength steel. He has also studied fatigue fracture toughness parameters and describes a fatigue fracture toughness parameter "$K_{fc}$" which always is lower than $K_{Ic}$. Both parameters decrease with decreasing temperature. The steels with which Ando is concerned are quite tough and slow crack growth is involved in fracture mechanics tests. He is therefore trying to develop use of the J-integral for such analyses.

Ando is also investigating the initiation of brittle fracture from the defects in welds such as lack of penetration. As a "hobby" he is also interested in the effect of temperature on fatigue crack growth rate and on the plastic zone size near the fatigue crack. Ando is a fully qualified Naval architect as well as a materials engineer. Important papers by Ando appear in 1) Tohoku University Thesis, 1969; 2) Proceedings of 2nd International Conference on Mechanical Properties, Boston, 1976; 3) Journal of Society of Materials Science, Japan, Vol. 25, No. 268, p. 97, 1976.

Professors T. Kamijo and K. Sekine are interested in deformations and annealing textures and upon the influence of texture on stress corrosion cracking of Al alloys in salt solutions. Variations in susceptibility with respect to preferred orientations have been observed. No crackstarter tests have been attempted. Pertinent papers are published in 1) Journal of Safety Engineering, Yokohama National University, Vol. 14, No. 2, 1975; 2) Transactions J.I.M., Vol. 12, No. 3, May 1971; and 3) Transactions J.I.M., Vol. 17, 1976.

Kamijo also states that the ductility of face centered cubic metals depends on the stacking fault energy, temperature and initial orientation. Kamijo has studied the longitudinal work hardening rate of Al, Cu, and Cu-Al alloys. The addition of Al to Cu decreases stacking fault energy and the frequency of deformation twins decreases.

Professor Iguchi is studying the non-stoichiometric states of transition metal oxides. He has returned only recently from the University of Bradford, near Leeds, where he studied for two years with R.J.D. Tilley. The work has resulted in one publication in the Transaction of the Philosophical Society of the Royal Society of London ("The Elastic Strain Energy of Crystallographic Shear Planes in Reduced Tungsten Trioxide"). The paper will appear in May 1977. A subsequent paper entitled "Strain Energy Between Parallel {001} Crystallographic Shear Planes in Reduced Tungsten Trioxides" will be submitted to Philosophical Magazine soon.

Iguchi's work is basically the calculation of the elastic strain energy due to crystallographic shear on planes lying upon the {102}, {103} and {001} planes. Calculating the cases of both isolated shear planes and for pairs of shear planes he is able to estimate the elastic strain energy per unit volume for crystals containing ordered arrays of crystallographic shear planes. Iguchi calculates that the magnitude of the elastic strain energy of the three planes is of the order {001} > {102} > {103}, and that at small crystallographic shear plane spacings the curves of elastic strain energy versus crystallographic shear plane separation takes the form of successive peaks and valleys. Iguchi claims to have shown experimentally that the elastic strain energy does indeed play a significant role in controlling the microstructure.

Dr. T. Endo, an associate of Professor Kamijo, described briefly some work on the effects of superimposed ultrasonic vibratory stress on static flow stress. Apparently Endo is seeing some mechanical effects as a result of superimposed ultrasonic vibration applied to specimens otherwise under routine tensile testing. The effects have been seen on a wide variety of metals and alloys (Al, Cd, Cu, Cu-7Al, Cu-Zn, mild steel, Mg, Mo, 17-4 PH, Pb, Ta, Zn and W). A decrease in static flow stress results to varying degrees in all of these materials when ultrasonic vibration is imposed. Effects on work hardening rate, hardness and fracture resistance (probably ductility) are observed in some instances but not in others. There are no effects of environment (air, $H_2O$, $CCl_4$) but frequency and temperature may have an effect. It was not entirely clear just which results are Endo's and which were results he obtained from the literature, but Endo is working in this area. The immediate goal is to determine the role of dislocations and whether a change in average dislocation density due to ultrasonic vibratory stress can explain the observations. Endo is working on Fe-3 Si alloy.

The general impression of Yokohama University is very favorable. One sees a faculty which is dispersed in age, but energetic and working hard. The students also are intense, serious and appear to be obtaining a sound education. As is common everywhere there were complaints over forced direction into practical problems.

# MITSUBISHI METAL RESEARCH INSTITUTE

The Mitsubishi Metal Research Institute is essentially the corporate research laboratory of Mitsubishi Metal Corporation. In 1976 the Metal Research Institute achieved status as an independent company, but it is evident that organizational ties remain.

Mitsubishi Metal Corporation is a giant conglomerate engaged in material activities which range from mining and raw material production to the science of metal alloy fabrication. The company specializes in nonferrous metals and the smelting and refining department produces metals and alloys of Cu, Pb, Zn, Au, Ag and Sn. The metal fabrication department produces a range of products from nonferrous metallurgical products to industrial machinery and even pigments. The Niigata plant produces, for example, sintered machine parts, oiless bearing alloys, metallic filters, sliding electrical contact alloys for trolleys and sintered magnetic Al-Ni-Co magnet alloys (Diamet and Diamax materials). The Okegawa plant produces corrosion and heat resistant Hastelloy, hard facing Haynes-Stellite alloy, high strength bronzes, Monel alloys, chromium-copper conductor material, precision castings, forgings, and silver brazing alloys. The Ooi plant produces tungsten carbide tools, rock drilling bits, diamond tools, dental drill alloys and face mill cutters. The company also produces and processes nuclear fuels and nuclear reactor alloys (for LWR, HTGR and FBR reactors). Zircalloy tubing is produced, for example, in Okegawa.

The Research Institute reflects these wide interests in its research activities. There are groups concerned with ore concentration, chemical and physical separation and purification. A material science group is involved with physical metallurgy, such as electron microscopy to study dislocation loops in creep deformed nickel-base alloys or the microstructure of hot isostatically pressed powders of superalloys. The metals and alloys group studies melting, casting and fabrication of alloys such as nuclear material for HTGR reactors and mold materials for continuous casting. This group also studies the joining of Co, Fe, Cu and Al base alloys by such means as electroslag welding and vacuum brazing. A group is also concerned with coatings and corrosion and stress corrosion of an assortment of alloys. The stress corrosion of nickel base alloys and stainless steels in fuel gases and in molten salts is an example. A powder metallurgy group works on problems of sinter-forging of powder metallurgy materials such as titanium and heat and corrosion resistant nickel-base alloys and friction materials (for disc brakes, railway brakes, etc.). This group also studies the details of wear and fracture processes in cemented carbide tool materials (TiC and WC in cobalt). Other groups work with fine ceramics such as Ni-Cu ferrites for magnetostrictive vibrators (which are claimed to operate well under high pressure), ultrapure materials and semiconductor materials such as GaAs. There are also studies of nuclear fuel and nuclear absorber materials, extractive metallurgy, pollution technology and analytical technologies.

A tour of the Metal Research Institute was conducted under the guidance of Dr. Y. Mae. The usual assortment of machinery for testing fatigue, impact and tensile strength was seen. There was also a machine to test wear and an Erichsen cup test to assess metal formability. A very extensive collection of corrosion and stress corrosion testing equipment was observed. For example there were numerous autoclaves for testing in high temperature—high pressure water and also loop-test facilities under high-temperature, high-pressure water conditions. Alloys under test are Hastelloy, Inconel, Monel and zircalloy. The specimens are mostly U-bend and smooth-tensile, in addition to the tube and pipe-flow tests.

Wet corrosion tests include the rotating disk type to study velocity effects, jet impingement tests to study erosion of Cu-base alloys (Al-bronzes) in seawater, salt spray tests (for Al alloys), stress corrosion tests (smooth specimens in moist air, ammonia and boiling 52 percent magnesium chloride) wet-dry cycle tests in seawater and an ultraviolet wet-dry-sunshine test chamber. There is also an ultrasonic cavitation test facility. As a finale to the tour, the Shimadzu SMX-50 X-ray diffraction stress analyser was shown. The machinery was bulky compared to the equipment developed by Cohen and James at Northwestern University under ONR contract.

In technical discussions, Dr. H. Doi, Director of the Powder Metallurgy Division described some work (with Y. Shimaniki and M. Masui) on variations of the composition of the $\gamma'$ phase in the Ni-base superalloy Udimet 520 with aging temperature. At 800°C there is an arresting of coarsening of the $\gamma'$ phase at about 50 hours. This is not observed at higher or lower temperatures. Doi explains this as a depletion of Al and Ti in the Cr-rich region around the particles which occurs at 800°C and 50 hours (see Scripta Met *10* 805 (1976)).

Dr. Y. Mae described studies on the effects of temperature and cross rolling on Ti-Al-2.5Sn and Ti-6Al-4V alloys. The experiments involved straight and cross rolling in the beta range followed by either straight or cross rolling in the alpha + beta range. The effects on the tensile properties, hardness anisotropy and texture were examined. The conclusion was that the most uniform properties are obtained by cross rolling in the alpha + beta range, irrespective of the initial working procedure in the beta range.

Dr. Mae has also described a method of preventing edge cracking during the rolling of aluminum alloys, by attaching a more ductile material to the edges of the slab before rolling (Jr. Light Metals *26* No. 6, 1976).

Important papers by Dr. H. Doi and others have appeared in Proceedings of the 1976 Powder Metallurgy Conference, sponsored by the Metal Powder Industries Federation and the American Powder Metallurgy Institute. In one paper the strengthening of cermet binder phase through precipitation of intermetallic compounds is described. The strengthening through ultrafine grain carbide generation is promising for the eventual application of cermets in machining operations now requiring high-speed steels. The fine-grain cermet would resist wear and reduce the tendency of the tool to weld to the metal being machined. In the other paper, hot forging of powder metal products without the usual intermediate sintering step is proposed.

The two most interesting observations made during the visit concerned items which could not be discussed in detail, for understandable reasons. First, there are tests going on of Zn-base and Al-base sacrificial anode materials. Obviously, these developments are intended for a highly competitive market, and the details of composition and structure are under study to enable the company to compete successfully. Secondly, there has been a development of Cr-base alloys which is most attractive. These Cr-base alloys are resistant to both nitric and hydrochloric acids. They can be hot-forged and hot-rolled up to 30 percent. It appears therefore that a new class of alloys has been developed which may be very useful for certain applications, and may have real importance to the U.S. Navy despite problems with chromium availability.

## THE NATIONAL RESEARCH INSTITUTE FOR METALS

The National Research Institute for Metals (NRIM) is essentially an in-house laboratory for the Science and Technology Agency of Japan, which provides 90 percent of the support (approximately $10 million per year). The remaining sponsorship comes from other governmental agencies such as the Ministry of International Trade and Industry and the Agency for Environmental Protection. A few tasks are handled under contract for industries, but this is done indirectly through various governmental agencies.

NRIM was established in 1956 and is organized into five groups, each containing three divisions. The primary functions of these groups are as follows:

1. Materials Group (1) — metal physics involving both ferrous and non-ferrous metals.
2. Materials Group (2) — responds to national projects, and involves electronics materials, nuclear materials and high strength materials. Project areas involve breeder and hot-water reactors, fusion, nuclear fuels, space, deep-sea diving, high speed transportation, MHD.
3. Process Metallurgy Group — metallurgical chemistry and process metallurgy and development. Projects involve improving extraction and refining processes. As an example, work is underway on the continuous electrolytic refining of Cu, Zn and Ni.
4. Metal Processing Group — welding, foundry practice, powder metallurgy and one division concerned with corrosion control.
5. Strength Group — a host of activities including NDT, composite materials, the basic approaches to increasing metal strength. Fatigue and creep properties are included.

Materials Group (2) is scheduled to move to Tsukuba New Town for Research and Education by about 1979. Earlier construction at the new site provided a building for testing superconducting materials (1975) and a laboratory for testing materials at high temperatures in special atmospheres (1976).

This visit began with a description of the organizational features and research philosophy of NRIM by the Director, Dr. Toru Araki. Following this there were tours of the Fatigue Testing Division and Creep Testing Division (Strength Group) and the Welding Division (Metal Processing Group). Discussions were also held with various members of the High Strength Materials Division (Materials Group (2)) and the Ferrous Materials Division (Materials Group (1)). For about an hour and a half a group was convened to hear the writer describe materials activities at ONR and NRL. The visit was frustrating in one sense; too many interesting projects are underway to visit in a day and it was necessary to probe haphazardly. An adequate review would take a number of days.

The Welding Division is engaged in a wide variety of activities and is generally well equipped. One study is underway to relate the controllable parameters in electron beam welding to weld defects, especially in deep penetration welds. Materials under study are semikilled steel and Al-Sn-Mg alloys. The defects of interest are penetration irregularities, porosity, spike formation, and the cracking which may occur at an assortment of boundaries (fusion line, near blow-holes, bead line etc.). The controllable variables include changes in the electron beam gun, vibration, change of feeder material, etc.

There is also some interesting work going on in underwater welding. A pressure chamber is available for tests of the plasma arc weld process. Pressures equivalent to a water depth of 300 meters (31 kg/cm$^2$) can be duplicated. According to Dr. Michio Inagaki, who conducted the tour, plasma arc welding is especially attractive in deep water (100-300 meters). Stick welding and GTA welding are satisfactory up to 100 meters, but problems with arc stability are encountered at greater depths.

NRIM developed a controlled pressure system for butt welding of pressure tubing for atomic energy plants. Gas pressure in the tube is controlled to provide a delicate balance between surface tension, gravitational forces and arc force during this TIG welding operation. This equipment has now been produced commercially by Mitsubishi Electric Corporation under the trade name "Melomotic."

A tensile restraint cracking test machine of 1000 tons capacity is in use also at NRIM (and in fact was developed by NRIM to investigate the cold cracking of welds by hydrogen). A sustained load is the major feature, and rather massive tests can be conducted. The data are plotted as typical static fatigue data —

mean tensile stress in the weld versus time of sustained load. The time-to-failure and threshold features of the curves are used to show such effects as weld temperature, preheat and postheat.

A machine designated as "Weld Thermorestor" was shown which is used to simulate weld thermal cycling, stress or strain during welding, and other welding conditions in a controlled atmosphere, which may include hydrogen, moisture and argon. A high frequency heating system is used. The machine can be controlled to simulate a variety of thermal cycles and can produce constant load or constant strain. This machine, also developed by NRIM, is available commercially now, and at least one has been sold in the United States (University of Michigan, according to Inagaki). The Welding Division also has equipment for the plasma jet spray coating of such materials as alumina and zirconia on Ni and Mo to improve resistance to heat and wear. No results were presented.

The Creep Testing Division is conducting the most extensive collection of data on commonly used engineering alloys in the world. There are literally 1100 creep test machines collecting data on 3500 individual specimens. The philosophy is not only to collect representative creep data on the various high temperature alloys but to establish the statistical spread of properties between different parts of a heat, between different heats, and between heats made in different companies. All industrial high temperature alloys plus several new alloys each year are tested at a variety of temperatures, so far in air. Tests have been run for times as long as 60,000 hours (8 years), and even longer tests are under way. Temperatures range to 1200°C depending on intended service temperature. One investigation was described: A study was made of the effects on stress-rupture of differences in cross sectional shape among specimens of identical cross sectional area. The results indicate that material inhomogeneity is a larger effect than the shape factor.

The Fatigue Division is also applying the massive assault approach to the prediction and control of fatigue cracking in commercial alloys. Special emphasis is on 1) fatigue strength at elevated temperatures, 2) fatigue strength of welded members and 3) statistical variations in fatigue strength. Again literally thousands of specimens are tested to assess the probability of cycles to failure at various frequencies and temperatures. The S-N curves produced show the confidence limits to the designer who may then exercise the desired degree of conservatism as related to cost and structural performance. Various types of machines are used including rotating beam, push-pull and reverse torsion. One push-pull machine is capable of 150 ton. Another machine permits combined axial and torsion tests. Both high and low cycle fatigue tests are used to evaluate alloys at temperatures to 800°C. High cycle fatigue tests run to 100 million cycles.

In one investigation with austenitic stainless steel the plastic strain range was plotted versus cycles to failure at various temperatures. The steel failed intergranularly at low strain range but transgranularly with larger plastic strain range.

The High Strength Materials Division interests as outlined by Dr. Y. Kawabe are in the development of both high strength and ultra high strength steels. Six general areas were described as follows:

1) Low alloy steel development in the high strength range. Examples are 4340 and H-11.

2) Fatigue behavior of high strength steel in the marine environment (for the present, however, tests are conducted only in air).

3) Steels for deep-diving submersibles. The Japan deep sea rescue vehicle under design was originally intended to reach 6000 meters, and steels such as the U.S. Steel 10 Ni - 8 Co steel were of interest. Problems in dealing with the heavy section related to reproducibility, stress corrosion cracking, fatigue and fracture toughness encouraged a revision of the goal to 1000 meters. For the latter goal, steels similar to HY-130 are of interest.

4) Maraging type steels and particularly with respect to embrittlement by hydrogen.

5) Cryogenic steels for use at liquid He temperatures.

6) Extremely high strength maraging steel (400 ksi) for potential use in centrifuging machines for the concentration of uranium isotopes.

In individual discussion, Dr. T. Aoki first described his work on delayed fracture crack growth ($K_{Iscc}$) of high strength steels (4340 tempered at 250°C and 430°C and 4320 tempered at 200°C) in distilled water. Little temperature effect was noted on the value of $K_{Iscc}$, but the terminal fracture toughness parameter $K_{Id}$ calculated by measuring the crack depth at the onset of fast fracture increased rather markedly with temperature in both of the steels tempered at 250°C and 200°C. This was observed to be caused by intergranular crack branching as temperature increased. Crack growth rate was dependent on stress intensity factor for the steels tempered at 250°C and 200°C, but independent of stress intensity for the steel tempered at 430°C. An activation energy of about 9000 cal/mol was measured, in all cases, but a correction factor was applied to compensate for the effects of crack branching. Aoki also observed discontinuous crack growth. The intervals between steps were controlled by the thermally activated process with the 9000 cal/mol activation energy.

Work was also described by Aoki on the role of pitting in the stress corrosion cracking of martensitic stainless steel. A 13 percent chromium steel was studied. The corrodent was 3.5 percent NaCl saltwater and the specimens were smooth and electrochemically polarized. With anodic potential, most stress corrosion cracks initiated at corrosion pits, and the time for pitting accounted for most of the time to failure. As might be expected, the cracking process was relatively independent of applied potential.

At constant anodic potential, crack initiation time decreased with applied stress. The depth of pit at which stress corrosion cracking commenced was found to decrease with increasing stress. Furthermore there appeared to be a threshold pit depth required before cracking could be initiated.

Papers covering this work have been submitted for publication by Japan Iron & Steel Institute. The first of these will appear in June 1977.

Dr. T. Saito discussed his work on the toughness of Ni-Cr-Mo steels in the as-quenched condition (see Transactions ISIJ *16* 325 (1976)). After determining that the fracture toughness parameter $K_{Ic}$ could be obtained from the experimentally determined J integral value, Saito investigated the effects of prior austenitic grain size on fracture toughness. Fracture toughness was found to be relatively invariant with increasing grain size although tensile properties deteriorated. At very large grain size, however, fracture toughness decreased abruptly and the fracture mode changed from transgranular to intergranular. Seeking to explain the relative insensitivity of fracture toughness to austenitic grain size, Saito notes a correspondence of fracture toughness with the size of the dimples on fracture surfaces which initiate at small second phase particles. Austenitic grains larger than this interparticle distance would not be expected to have a large influence on the fracture process.

Saito is currently looking at the fracture toughness in two phase materials, in particular 4330 steel quenched from within the stable austenite + ferrite region of the equilibrium phase diagram. Some structures have been obtained which are quite tough, but the tensile properties are not spectacular. This work has been accepted for publication in Trans. ISIJ and probably will appear in March 1977.

Dr. Y. Sumitomo discussed interests in the hydrogen embrittlement of iron alloys, especially interactions of hydrogen and dislocations. He is studying an alloy of 0.001 C, 9.87 Mo, 0.003 S, balance Fe, with the idea of isolating for study the iron-molybdenum ($Fe_2Mo$) precipitation process which takes place in more complex alloys. Sumitomo applies a tensile strain, then commences electrolytic charging. Unlike the case of purer iron alloys, the introduction of hydrogen *steepens* the stress-strain curve. A change from cross slip to planar slip is observed. Sumitomo concludes that the slip processes are changed by alloying elements *which in turn change the response to hydrogen. Tests are now underway with Fe-Si and Fe-Al alloys.*

Dr. Y. Kawabe described some of his efforts to produce tough 280 kg/mm$^2$ maraging steel through control of microstructure (see JISI *62*, No. 9, 1976). The steels of interest are highly alloyed (13 Ni, 15 Co, 10 Mo, 0.1 Al, 0.2 Ti) to achieve high strength, and the precipitates are therefore difficult to dissolve. Kawabe has studied the effects of higher solution treatment temperatures (850 to 1250°C) upon the tensile properties and fracture toughness.

The fracture toughness parameter $K_{Ic}$ increases as the solution temperature increases despite grain size increases which deteriorate the tensile properties and ductility. As the fracture toughness increases, there is a shift from dimple fracture surfaces to quasicleavage fracture surfaces, the reverse of the usual relationship between fracture mode and toughness. Kawabe believes the observations reflect the dissolution of the precipitates which are regarded as more deleterious to fracture toughness than is large grain size. Large grain size, however, does deteriorate the tensile properties and ideally the precipitates would be dissolved but the grain size would remain small. Toward this goal Kawabe has been studying thermomechanical treatment and a variety of cyclic heat treatments. There has been some success but these treatments are complex and expensive and therefore the work continues.

Dr. M. Sumeta stated that he will be studying the fatigue of high strength steels in seawater in the future. He was therefore very interested in the related work underway at NRL. He intends to study steels such as HY-130, precipitation hardening steels, maraging steels, 9 Ni-4 Co steels and HY-180 type steels. The tests will be in air and seawater, and the specimens will in some cases contain sharp notches.

Dr. M. Inagaki, head of the Welding Division, is active in committee work both in Japan and internationally. He chairs the Class Structural Steel for Welding Committee of the Steel Division of the Japan Welding Engineering Society. In this capacity he represents Japan at assemblies of the International Institute of Welding. For example he presented a report on the study of cold cracking with the implant test at a meeting in Australia in August, 1976 (IIW Do. IX-970-76). Other concerns and studies of the committees are lamellar tearing and fracture in heat affected zones.

## SHIP RESEARCH INSTITUTE

Under the gentle persuasion of Professor K. Iida of the University of Tokyo, the writer visited the Ship Research Institute of the Japan Ministry of Transport. The Director General is Dr. N. Ando, and under his management are Divisions concerned with ship propulsion, dynamics, structures, welding and fabrication, engine development, marine engines, ship equipment, nuclear ships, oceanographical engineering and physical engineering. Although the Ship Research Institute was originally established in 1916, the present organization apparently took form in 1963. It was at this time that the present Ship Research Institute with the ten Research Divisions and two Branches (at Osaka and Tokai) was formed as a technical resource of the Ministry of Transportation. The Institute does research on ships in areas of concern which are indicated by the Division functions. The results of this research are published in "Report of the Ship Research Institute" and "Papers of Ship Research Institute."

In the Ship Equipment Division, under the direction of Dr. K. Ohnaga, some experiments on alternate-immersion corrosion were shown (by Dr. S. Naito). Specimens are contained in cells and subjected to fatigue in bending to maximum stress of 25 $Kg/mm^2$ while cycling between 15 and 150 cpm. The cells permit alternate filling and emptying with synthetic seawater, so that the 1/8" × 1/4" specimens are subjected to both reverse bending and alternate immersion. Temperature is controlled, and up to 12 specimens may be tested simultaneously. Specimen failure is monitored by both weight loss and fracture. At least one paper on this work is published ("Corrosion of Steel by An Alternate Immersion Method," Ship Research Institute Vol. 13 No. 2, 1976, p. 76 by K. Ohnaga, S. Naito and T. Shibata). The work is intended to apply to problems with corrosion of the ballast tanks of tankers and ore carriers. The work to date indicates rapid increases in corrosion rate with increasing water and air temperatures, but not much influence of the fatigue stress.

In the Division of Ship Structures some massive test facilities were observed. One test was underway of an entire section of a ship at 1/10 scale. This ship section test component, representative of an oil tanker, was subjected to both bending stresses and compressive stresses at the sides, as would be encountered in ocean service. Hydraulic jacks were used liberally to apply the designed multiple stresses. Massive fatigue testing machines were also seen. One Schenk Fatigue Machine of 30 ton tension or compression capacity had been modified to provide 200 tons in tension or compression.

On a more conventional scientific laboratory slant, experimental apparatus for the measurement of stored energy resulting from low-cycle fatigue was shown. A differential thermal analysis calorimeter is featured. The specimens are 3.5 mm diameter rods deformed by fatigue. No cracking is involved, hence there is no effort to measure directly fatigue-produced stored energy at crack tips.

The Ship Research Institute Welding and Fabrication Division directed by Dr. A. Kanno is concerned both with non-destructive test concepts and, again, with massive tests for fatigue resistance and brittle fracture resistance. Kanno is especially interested in radiographic techniques to detect cracks. Ultrasonic methods are also under study. The laboratory has a 300 KV Betatron for radiography of thick plate and welds (up to 50 mm). Kanno is studying the means of measuring and detecting the cross section of natural cracks by X-ray. A cylinder containing a natural crack is inserted into a close fit cylindrical hole in a thick plate. By rotating the cylinder during radiography Kanno is trying to establish the relation of defect width which appears in the radiograph, with crack morphology and orientation.

The massive equipment in the Welding and Fabrication Division features a push-pull type 3000 ton fatigue machine only 10 years old. A 15 million electron volt Betatron is available for *in-situ* radiography during these fatigue tests of massive plates and welds. There is also a tensile machine for brittle fracture tests, maximum capacity 4000 tons. This machine was installed primarily to test steels for nuclear pressure vessels.

A large test pressure vessel tank, three meters in diameter, was shown. This tank was being subjected to hydraulic pressure, and acoustic emissions from a small submerged notch were being studied. A minicomputer gives a graphical display of the location of flaws. The particular detector used is a Nortec AE Δ T Flaw Detector, NDT 256. This Richland, Washington firm is at least one example of an equipment sale to

Japan. The Ship Research Institute has under construction machines to test dynamic fracture toughness. These dynamic tensile brittle fracture machines are estimated as three years away.

The Director General of the Ship Research Institute, Dr. Ando, is Secretary to the Organizing Committee of the International Symposium on Practical Design in Ship building to be held in Tokyo 18-20 October 1977. This Symposium will celebrate the 80th anniversary of the Society of Naval Architects in Japan.

## THE RESEARCH INSTITUTE FOR IRON, STEEL AND OTHER METALS

This Institute was established in 1916 as a part of Tohoku University in Sendai, Japan. Dr. Kotaro Honda was in charge of the research work and the achievements in the development in magnetic alloy systems and in ferro-magnetic theory soon attracted national attention. This resulted in the growth of the Institute to include light metals and intermetallic and metallic compounds a few years later.

The present mission of the Institute is to conduct research on iron, steel and other metals and their alloys and in addition to perform fundamental studies of new materials with a view to advancing knowledge generally and promoting practical applications. To do this there is a staff of over 300 people including 26 professors and 27 assistant professors.

Current studies include metal physics, and materials science areas such as properties at cryogenic temperature, in very strong magnetic fields or under very high pressure. The physics of liquid metals is also under study. In the field of industrial research, studies on permanent magnetic steels, high permeability material such as Sendust, spheroidal cast iron, fine grain steel development and inclusion control are of interest.

The Institute has a number of Groups designed to meet the research requirements as listed below:

Director — Research Departments

A. Physics of Materials Group:

Theoretical Solid State Physics
Crystal Physics
Magnetism I
Magnetism II
Crystal Plasticity
Chemical Physics of Metals
Diffraction Crystallography
Metal Physics using Radioactive Beams
Low Temperature Physics
Magnetism at Low Temperatures
Physics of Electronic Compound Materials

B. Chemical Metallurgy and Metal Chemistry Group:

Surface Chemistry of Metals
Metallurgical Chemistry
Radiochemistry of Metals
State and Chemical Analysis
Crystal Chemistry

C. Physical Metallurgy Group:

Iron and Steels
Nonferrous Alloys
Physical Metallurgy of Iron and Other Metals
Physical Metallurgy of Refractory Metals and Compounds
Physical Metallurgy of Nuclear Materials
Irradiation of Materials

D. Process Metallurgy Group:

Metalworking
Melting and Casting

E. Branches for Special Research Facilities

F. Facilities:

- Specimen Preparation Lab.
- X-ray Analysis and Electron Microscopy Lab.
- Optical Microscopy Lab.
- Mechanical Testing Lab.
- Industrial Research Lab.
- Chemical Analysis Lab.
- Electronics Lab.
- Radioisotope Lab.
- Rare Earth Separation Lab.
- Ceramic Mono-Crystal Preparation Lab.
- High Magnetic Field Lab.
- High Pressure Lab.
- Mass-Separator Lab.
- Nuclear Magnetic Resonance Lab.
- Neutron Diffraction Lab.
- Far-Infrared Spectroscopy Lab.
- Terminal Station of Electronic Computer
- Gas Liquefaction Plant

On this occasion the Laboratory for Iron and Steels within the Physical Metallurgy Group was visited. This Laboratory is under the direction of Dr. T. Masumoto, son of the famous Dr. Hakaru Masumoto who was Director of the entire Institute during the years 1958-1962. The Laboratory for Iron and Steels is studying chiefly the physical metallurgy and mechanical properties of irons and steels. Studies are made on the microstructural behavior and mechanism of the ductile-brittle transitions in fracture modes under conditions of both static and dynamic stress. Also studied are creep mechanics and the deformation and fracture of cementite during the course of the working of steel. High strength materials in the form of composites and as amorphous metals or rapidly-quenched materials are a particular current interest. A further interest is in the interactions of alpha iron and austenitic iron with nitrogen within a range of high-temperature, high pressure regimes.

In preliminary discussions, Dr. Masumoto outlined the thrust of his Laboratory for Iron and Steels as this relates to other groups at the Tohoku University. There are basically three areas which complement one another nicely in understanding how materials behave mechanically and to an extent chemically. These areas are based on dimensional regimes. The atomistic approach involving lattice dislocations, point defects etc. is an aspect of structure covered by Professor Karashima and his colleagues in the Department of Metallurgy, Materials Science and Metal Processing. At the other extreme Professor Yokobori's group at the Research Institute for Strength and Fracture of Metals is oriented toward continuum mechanics and elasticity and plasticity. Masumoto's group favors the microscopic view, thus completing the line of attack from the atomistic approach (Karashima) to the macroscopic approach (Yokobori). The study of grain boundaries, precipitates, inclusions, segregations, crystal structure, etc. are thus the usual concern of Masumoto.

On the occasion of the visit Masumoto stated that his two largest research groups are concentrating in the areas of amorphous metals and in refractory alloys. Other studies, however, are going on as indicated previously. Current studies on the process and mechanism of ductile-brittle fracture in BCC ferrous alloys, for example, center on observations of substructure around propagating fatigue cracks and on the relationship of microstructure to the initiation and growth of fatigue cracks in martensitic steels. Studies of the effects of thermo-mechanical treatment on the strength and fracture of steels are related to the deformation and fracture of the cementite phase. Consideration is given to the lattice defects in the cementite, the mechanical properties of cementite and their temperature dependence, and on the fracture toughness characteristics of cementite.

Elevated temperature properties of steels are of interest with respect to transient creep and factors such as chemical composition, grain size, prestrain, texture and precipitates. A statistical study on scatter in creep property measurements is ancilliary to these studies.

In the composites area the strengthening of iron-base alloys such as Fe, Fe-Cr and Fe-Cr-Ni with dispersions of $Al_2O_3$ or $ThO_2$ is under study. Also the unidirectionally solidified Fe-$Fe_2$Ti composite is of interest.

Aside from these investigations, the metallurgy of amorphous metals or rapidly-quenched materials is an absorbing interest with Masumoto and his groups. The amorphous metals area has been a principal activity for some 7 years, according to Masumoto, and some 40 people have become involved. Already approximately 80 papers have been published and a number are in preparation.

The amorphous metal programs include almost all aspects which can be imagined. Subject areas include the atomic structure of the non-crystalline state, the physical properties of amorphous metal, the mechanical properties as related to load configuration, temperature and pressure and environment, deformation and fracture processes and the processes involved in the recrystallization of amorphous metals. Alloys of interest include iron-base alloys (Fe-C-P, Fe-C-B, etc.), nickel-base alloys (Ni-C-P, Ni-C-B, etc.) and refractory metal base alloys (Mo, W, etc.).

Masumoto reviewed some of the more interesting properties and characteristics of amorphous metals prior to reviewing some on-going projects. Amorphous metals have no dislocations so that deformation mechanisms different from those applicable to crystalline metals must be conceived. There is no strain hardening in either tension or compression and the amorphous state therefore produces an ideal elastic-plastic response to stress. There is not much ductility, but amorphous metals can be strong and tough. Surprisingly there is but a small size effect on strength (low notch sensitivity). The lack of grain boundaries eliminates such phenomena as grain-boundary sliding and pit nucleation and grain-boundary cracking in corrodents.

The amorphous structure is also conducive to high magnetic permeability, magnetostriction and electrical resistance. There is low sound velocity and low sound attenuation. The temperature coefficients of thermal expansion and elastic constants are low. There is, of course, high resistance to radiation damage.

In addition to good static strength, the fatigue strength of amorphous metals is high. There is a sharp knee in the S-N curve. Fatigue cracking involves the nucleation and growth of cracks which produce striations on the crack surfaces. The fracture surface markings are formed by alternating plane strain shear at the crack tip.

If amorphous metals are heated to the point of recrystallization, there is generally an increase in strength and hardness but a loss of ductility. Some iron-base alloys become quite brittle upon aging near the point of recrystallization without much change in hardness or strength.

The strength of amorphous metals is strongly influenced by composition, especially by the concentrations of metalloid elements (C, P, B, Si). The outer electron concentration of metals affects the bonding between atoms and in turn the hardness of amorphous alloys containing metalloids. Thus in the Fe-P-C system, the hardness decreases when the atomic number of an alloying element is larger than that of iron and increases when the atomic number is smaller (hardness decreases with increasing e/a ratio). In the iron-base alloys the metalloids harden in the order P<C<B<Si so that highest hardness is observed in the Fe-Si-B systems. For a given metalloid, hardness increases in the order Fe<Co<Ni. Thus superior hardness is seen in the systems Ni-Si-B or Co-Si-B. The recrystallization temperatures in such systems are also higher.

As for chemical properties, it is evident that the amorphous metals are subject to hydrogen embrittlement and will corrode under the proper conditions; however, some alloys display spectacular corrosion resistance. Amorphous metals based on Fe, Co and Ni which contain large amounts of metalloids are more susceptible to hydrogen embrittlement than ordinary steels. Susceptibility does not necessarily lead to stress corrosion cracking unless the alloy is poorly corrosion resistant.

Recently, Masumoto and his colleagues have shown that additions of Cr to Fe-rich amorphous alloys improves corrosion resistance greatly. In fact, Fe-P-C alloys with Cr are superior to stainless steels with respect to pitting and crevice corrosion in chloride solutions. It has been shown that the excellent corrosion resistance conferred by the Cr is not achieved unless the structure is amorphous. The superiority of the amorphous structure combined with the presence of Cr is attributed to the following:

1) The surface film which forms is protective and is mainly chromium oxyhydroxide, $CrO_x(OH)_{3-2x}nH_2O$.

2) The alloys are in fact very active chemically and form the passive film very rapidly. If the film is ruptured, recovery is fast.

3) The passive film resists corrosion because only the one phase of amorphous metal is involved and there are no crystal defects or grain boundaries to act as corrosion initiation sites.

Masumoto discussed current efforts to improve the strength and corrosion resistance of amorphous metals through compositional variations. In collaboration with M. Naka, and K. Hashimoto, for example, he has produced a paper, "Effects of Additive Metalloid Elements on Corrosion Resistance of Amorphous Iron-Chromium Alloys." The corrosion resistance increases in 0.1N $H_2SO_4$ in the order Si→B→C→P and in 3 percent NaCl in the order B→C→Si→P. An alloy based on the metalloids Si and B is attractive compared to an alloy based on P and B for corrosion resistance to saltwater and for increased strength (in iron-base alloys containing Cr). One problem is to overcome the embrittlement of these alloys which may occur on aging at sub-recrystallization temperatures. Optimum corrosion resistance requires the presence of both

P and Cr. At this time studies on why other metalloid elements are *not* effective in improving corrosion resistance is under study.

Important papers relating to this area of work are published in Corrosion Science, *16*, 935, 1976; *16*, 909, 1976, *16*, 71, 1976 and Corrosion, *32*, 146, 1976, *32*, 321, 1976.

An excellent review of the research on amorphous metals is given in Sci Rep RITU, *A-vol 25*, L32, 1975.

In related work, Dr. A. Inoue, a colleague of Masumoto is trying to produce high Cr-high C steel by rapid quenching from the melt. A eutectic alloy containing 3.6 percent C and 17 percent Cr is one composition of interest, in part because only austenite and cementite places are involved after a rapid cool. However, the rapidly-quenched alloy yields carbides and some ferrite on reheating to 400°C and the precipitation of $Cr_7C_3$ carbides occur within the cementite at 600°C (in-situ carbides).

In a rapidly-quenched alloy of iron containing 2 percent C and 30 percent Cr, ferrite is present and there is a fine carbide mix of $M_{23}C_6$ and $Cr_7C_3$.

The hope is to produce these alloys in a strong and ductile form, and some success has been achieved. For example, an Fe-16Cr-12Ni-3C alloy is ductile as quenched. Six percent elongation, a hardness of 650 VHN and a strength of 200 $kg/mm^2$ is obtained. Carbides of the $Cr_7C_3$ type which are only several thousand angstroms in diameter are dispersed in the matrix. No cementite forms. The alloy is attractive in that a high strength steel is obtained on quenching and there is no need to roll, draw or forge to obtain good properties.

There are also some efforts underway to improve the magnetic properties of certain amorphous alloys. Amorphous alloys which show zero magnetic anisotropy should be magnetically soft and have high permeability. One such alloy, $Fe_{4.7}Co_{70.3}Si_{15}B_{10}$, appears to have permeability equal to Permalloy. Practical uses of the material are being explored.

Dr. Toshio Hirai, another Masumoto associate, is working on the preparation and properties of amorphous and crystalline silicon nitride. Apparently the methods of using CVD processes have been highly developed by Hirai and he claims to be able to produce the material at near theoretical density and in thickness of 4.6 mm at a rate of 1.2 mm/Hr. There are apparently no residual stresses. A density of 3.17 (compared to a theoretical density of 3.18) is measured for the crystalline form and from 2.60 to 2.87 for the amorphous form, depending on the conditions of deposition.

According to Hirai, hot-pressed silicon nitride is less oxidation resistant at 1500°C than the highly dense silicon nitride which he deposits by CVD.

There is interest in the mixed nitrides, borides and carbides of silicon also as possible improvements in oxidation resistance and toughness compared to silicon nitride. Thus at present measurements of $K_{Ic}$ at various temperatures are being made on ceramics in the Si-N-C, Si-B-N, and Si-B-C systems. There is also an interest in the oxynitride of silicon, $Si_2O_2N_2$, which is derived from $Si_3N_4$ through oxidation. The latter compound is regarded as having attractive potential for gas turbine blades.

Hirai's group is also studying thermal conductivity by the laser thermal pulse method and studying the recrystallization of amorphous silicon nitride with a high temperature (to 2500°C) X-ray diffractometer.

These and other related subject areas under study at the Laboratory for Special High-Temperature Materials Science are described in greater detail in Journal of Materials Science, *11*, 604, 1977, *12*, 631, 1977 (letters), *12*, 1233, 1977, *12*, 1243, 1977; Journal of Crystal Growth, *36*, 157, 1976; SCI. REP. RITU, *A-Vol 26*, 1977; Journal American Ceramic Society, *59*, 324, 1976.

Two volumes on the amorphous materials studies at the Research Institute of Tohoku University are available which summarize this work very well. The reports are identified as Series A, *Volume 26*, No. 1, June 1976 and *Volume 26*, No. 4-5. March 1977.

The tour of the Research Institute for Iron, Steel and Other Metals was highlighted by a visit which Professor Masumoto arranged to the Metals Museum of the Japan Institute of Metals, which is attached to Tohoku University. The Museum was founded in 1975 for the purpose of furthering knowledge of both ferrous and nonferrous metals. The Museum regards itself as the only such metals integrated institution in the world in the sense that it encompasses all metal and alloys in the field of metallurgy.

The exhibits include:

1) Archaeological material on metals gathered throughout the world.
2) Models and technical objects from the iron and copper smelting in ancient Japan.
3) Historical literature and models which illustrate the role of metallurgy in the modernization of Japan.
4) Miniature plant models and product displays of the leading metal producers of the world.
5) Industrial art objects such as swords, ceremonial iron pots and illustrations of their production by traditional Japanese techniques.

In addition there are collections of the writings of Kotaro Honda and Kuniichi Tawara, who founded metallurgical science in Japan. A future goal is to collect as many technical objects and rare books of metallurgical significance and historical value as possible. One really interesting project is the growing collection of recorded lectures and speeches of the most famous metallurgists of the world (the writer was regretably but understandably *not* requested to record his talk). The Museum is extremely interesting, as for example, in reviewing the evolution of the manufacturing processes for producing Japanese swords. Any metallurgist visitor to Sendai should really plan to see the Museum.

In general the Research Institute for Iron, Steel and Other Metals complements the general excellence of the materials science areas at Tohoku University. The three days at Sendai were well spent, and the friendships made there are almost certain to be a future source of knowledge.

## RESEARCH INSTITUTE FOR STRENGTH AND FRACTURE OF MATERIALS

The Research Institute for Strength and Fracture of Materials was established in 1964 under the direction of Professor Tokeo Yokobori, who was host on this occasion. The orientation of this Research Institute is toward the macroscopic phenomena which influence mechanical behavior, thus complementing the atomistic approach of the Department of Materials Science and the microscopic specialization of the Research Institute for Iron, Steel and Other Metals.

The Institute is involved in a wide variety of programs in theoretical and analytical and experimental areas. A few of the theoretical studies are:

1. Non-linear interactions between the main crack and the slip band near the notch.
2. Dislocation dynamics by computer simulation.
3. Criteria for brittle fracture of notched material based on combined micro and macro fracture mechanics.
4. Mechanisms of fatigue crack propagation.
5. Interaction of fatigue and creep.
6. Cumulative damage analysis.
7. Dynamic crack propagation.
8. Finite element analysis of plastic zone sizes at crack tips.
9. Crack and slip band interactions in composites.

Some important experimental work is listed below:

1. Microscopic study of fatigue crack initiation and propagation.
2. Fractographic study of fatigue crack surfaces.
3. Microbeam X-ray studies of crack tip structural damage in fatigue.
4. Microscopic study of creep and fatigue at high temperatures.
5. Study of grain size effects on brittle fracture and fatigue.
6. Effects of temperature on fatigue crack fractographic character.
7. Delayed fracture and environmental effects.
8. Low cycle fatigue in large scale specimens.
9. Fatigue of welded structures
10. Creep of fiber reinforced composite materials.
11. Fatigue crack propagation in High Polymers.

Professor Yokobori is known throughout the world and there is no point to describing his activities extensively. He has published very widely and, for one example, has published a paper in collaboration with two ONR contractors, D.L. Davidson and J. Lankford of Southwest Research Institute (see paper on Fatigue Crack Tip Plastic Zones in Low Carbon Steel, Int. Jr. of Fracture, *12*, 579, 1976).

The Research Institute for Strength and Fracture of Materials is certainly one of the strongest such organizations in the world, in keeping with the general excellence of the materials organizations and activities associated with Tohoku University.

## DAIDO STEEL CO, Ltd.

The Research and Development Division and Control Research Laboratory of Daido Steel Co., Ltd., were visited in connection with a lecture delivered to the Japan Iron and Steel Institute and the Japan Welding Society in the Daido facilities.

The Central Research facilities include an experimental melting shop equipped with various special melting furnaces and test shops for forging, heat treatment and welding. The laboratory is equipped with mass spectrometers, thermal fatigue testers, electron microscopes and the usual mechanical test apparatus.

Among the achievements of note is the Daido-developed plasma induction melt furnace (PIF) for vacuum induction melting (VIM). For the vacuum arc remelt (VAR) and electroslag remelt (ESR) processes Daido has developed its own plasma progressive casting furnace (PPC). These processes are claimed to reduce nonmetallic inclusions, gases and other impurities even more efficiently than conventional VIM, VAR, ESR and EBR (electron beam remelt) processes.

Daido also is actively engaged in developing improved weld wire for a number of applications. For example, a wire for improved $CO_2$ ($CO_2$ - $O_2$) - arc welding has advanced automated welding. Ultra low carbon stainless electrodes have been developed for atomic and chemical equipment. At present efforts are being made to make further improvements in filler materials for joining cryogenic as well as heat and wear resistant materials.

Of course there are continuing efforts to make steel stronger and tougher. Such efforts, it was pointed out, have nearly doubled the strength of structural steel over the past 30 years.

Other special properties under investigation are machinability (inclusion control), corrosion and stress-corrosion resistance (precipitation hardening stainless steels and duplex stainless steels), high temperature properties, magnetic properties, glass sealing properties and properties of powdered metals (Daido has developed a unique metal atomization process).

The company is under the strong leadership of President Kizo Takeda. He is gradually diversifying the product line and the company is now producing industrial furnaces, environmental control systems, labor-saving devices and other items not ordinarily associated with a steel company. The claim is made that Daido Steel Company is looking forward and preparing even now for the 21st century, when it is visualized that the company name may have to be broadened to "Daido of New Materials." Whatever it may be called, one is impressed with the forward-looking attitude, and whatever the challenge ahead, one is confident that Daido will be as prepared as any.

## KOBE STEEL, LTD.

Kobe Steel, Ltd, produces not only iron and steel, but also makes or processes aluminum, magnesium, copper, tantalum, zirconium and titanium alloys. These basic metal operations are integrated with a host of enterprises which use metals, such as machinery for chemical plants and construction. The company therefore produces also castings and forgings, cutting tools, welding electrodes and a variety of equipment associated with environmental control technology and nuclear energy applications. In short, Kobe Steel is another large company which has diversified to provide a market for its own metals production and promote a keener competitive position and resiliency both at home and throughout the world.

The research activities of the company are conducted at the Central Research Laboratory in Kobe, the Structural Engineering Laboratory in Amagasaki and the Fundamental Research Laboratory in Asada. On this occasion the Central Research Laboratory was visited and the Structural Engineering Laboratory was toured briefly. Mr. K. Hosomi, Chief Researcher, was host.

The Central Research Laboratory employs about 380 people and enjoys a budget of approximately 8 million dollars. Under a director of R&D there is a general manager who controls 14 technical groups. The laboratory develops products and processes which are seen as connected to the company's future products, and to a degree the laboratory is also expected to lead the company into new market fields and into the utilization of newly developed materials. Thus, although the laboratory mission is highly conservative, there are built-in mechanisms to insure that new materials developments will be utilized. This is often a problem where materials researchers are isolated from the designers and manufacturers.

The R&D management of the Central Research Laboratory (CRL) follows the "priority principle" in which a large number of research proposals are evaluated for technical and economic merit. The laboratory often pursues a research project until production is established, so that emphasis is always on the utilization of R&D activity in profit-making enterprise. A brief description of the activities of the various research groups follows:

1) Iron making and ore treatment - improved ore treatment for producing self-fluxed pellets and sintered ore. Improved desulfurization in the blast furnace and more efficient use of fuel.

2) Steel making process research - efforts to produce low-sulfur, low-phosphorus steels utilizing LD steel making processes, the shaking ladle (DM Process) and vacuum degassing. Studies of slags and deoxidation reactions.

3) Casting research - fundamentals of solidification and minimization of segregation in continuous casting. Casting of high quality large-scale ingots.

4) Structural steel and forged product development - use of heat treatment and composition control to improve toughness and strength of hot-rolled steels, steel forgings and steel castings. Development of thick steel plates for structural use.

5) Sheet and wire product development - technology of rolling, pressing and drawing of steel sheet and wire.

6) High strength steel and high temperature steel development - fundamental studies of creep and strength - structure - composition relationships. Development of free-machining steels. Development of hydrostatic extrusion processes. Development of maraging steels and steels resistant to delayed failure. Heat resistant steels.

7) Welding research - fundamental studies on welding and weldability. Emphasis on high strength steels and weld cracking problems. Development of new high strength steels with improved weldability (e.g. low carbon normalized steel).

8) Corrosion-resistant materials - development of improved stainless steels for the chemical industry. Development of low alloy steels resistant to sulfur dew-point corrosion, atmospheric corrosion and sea water corrosion. Corrosion studies on copper and aluminum alloys and on reactive metals such as titanium, zirconium and tantalum. Developed TAICOR-S, a steel resistant to sulfur dew-point (sulfur in boiler exhaust gas) corrosion and austenitic 15Cr - 15 Ni - Si stainless steel for resistance to stress corrosion cracking. Facilities include arrangement for recirculating sea water.

9) Metal finishing - galvanizing, chromizing, electrolytic powder coating, painting. Insulation coating of magnetic steel sheets. Development of new finishing and coating techniques such as the plastic coating of cables for suspension bridges.

10) Aluminum development - studies to improve formability by control over texture. Development of precipitation hardened alloys for structural use.

11) Titanium development - development of production techniques for titanium alloy flat rolled products and castings. Application research toward use in automotive, aircraft and rocket structures. Fundamental research on plastic deformation and phase transformation. Developments include an alloy used for VTOL engine parts and automotive valves (KS130ACF) and a corrosion resistant titanum - tantalum alloy (Ti-5Ta) for use with nitric acid.

12) Reactor materials - development of nuclear fuel cladding materials, particularly zirconium alloys. Prevention of embrittlement in zirconium tubes by restricting hydride precipitation to circumferential directions.

13) Powder metallurgy - steel powder development for good compaction qualities. Development of forging processes for powder metal preforms.

14) Analysis research - analyses of trace elements and dispersed phases. Pollutant trace analyses.

In technical discussions at CRL, T. Sakai and H. Kaji first described some recent work on the nucleation and growth and coalescence of methane bubbles in low alloy steels attacked by hydrogen. This work, presented to the Spring Meeting of ISIJ, April 1977, is essentially a series of SEM observations on several alloy steels to observe directly the voids formed. The results are treated according to the model developed by Shewmon and by Raj and Ashby. It was found that bubbles nucleate heterogeneously at carbide grain boundaries. The density of bubbles is independent of temperature but dependent on heat treatment and microstructure and composition. The density of bubbles in 2¼ Cr-1Mo steel was much lower than in steels with lower concentration of Cr and Mo.

The growth rate of methane bubbles is temperature dependent as well as heat treatment and composition dependent. Bubble growth is severe at coarse grain boundaries such as seen in the HAZ of welds. Tensile stress appears to accelerate growth.

The general conclusions indicate that the Shewmon model is indeed predictive and that Raj and Ashby's equations may relate internal bubble pressure to such factors as composition and structure. The resistance of low alloy steels to hydrogen attack which is characterized by methane bubble formation is dependent on the potential internal pressure, which influences the resistance of the steel to the nucleation of bubbles.

T. Fujita and colleagues next discussed some efforts to develop steels which are resistant to stress corrosion cracking in water. Some measurements of the delayed failure properties of high strength steels are described in Proc. of Second International Conference on Fracture, Brighton, 1967. Results of notched tensile tests in water showed that delayed failure sensitivity is related primarily to strength level. Almost all the low alloy steels were insensitive to SCC to about the 110 $Kg/mm^2$ yield strength level, and sensitive at higher yield strength level. The exception was maraging steel which remained insensitive to the 140 $Kg/mm^2$ yield strength level. The time to failure was reduced with increase of temperature. The maraging steels were more sensitive with insufficient aging, despite good tensile ductility.

In later work (Hydrogen Conference, Firminy, France, 1973) the authors describe tests on TRIP steel, maraging steels and high carbon steel wire. Again, it was shown that the susceptibility to delayed failure of most steels is dependent mainly on strength, with a critical yield strength level of about 110 $Kg/mm^2$. In general an increase in toughness increases resistance to delayed failure embrittlement, but in some cases an overaged condition is better than the underaged condition even though tensile ductility is high in both cases. Additions of Ti and Al were found to be beneficial, presumably because these elements decrease embrittlement by nitrogen at 350°C (there was no mention of the possible tie of Ti to hydrogen as has been proposed in some American work). The presence of Ti, Al and N of course also restricts grain size, which was also found to be beneficial. Both TRIP steels and cold drawn high carbon steel were found to be susceptible.

All this, of course, leaves little optimism for the desired development of high strength steel bolts with 130 $Kg/mm^2$ yield strength which are also resistant to delayed failure. The current solution which Fujita and others propose involves softening of the surface layer of hardened steels, to reduce the susceptibility to hydrogen attack. The soft layer would be 0.5 to 3.0 mm thick and could be produced by induction heating or by the application of a surface overlay.

In recent work Fujita and colleagues have studied unstable fracture criteria when large plastic deformation is involved (presentation at the Waterloo Conference on Fracture, June 1977). A fracture criteria for unstable ductile failure of notched plates under uniaxial tension is described.

Y. Yamada described an interesting investigation relating the fundamentals of static strain aging of eutectoid carbon steel to a practical industrial problem. It was observed that wires of eutectoid steel drawn in summer often developed surface cracks whereas wire drawn in winter did not. The static strain aging which causes the cracking was shown to be very sensitive to temperature. Since the work of drawing is largely converted to heat, it is beneficial to keep the metal cool. Yamada and others therefore developed a means of cooling the drawing dies and wire. This permits a higher draw rate with better quality. The system for cooling the dies is described in Wire Journal, July 1976. The fundamentals of the strain aging processes which must be controlled are described in Trans. ISIJ, *16*, 417, 1976.

The company has also been active in the production of ship propellers of Mn bronze, Ni-Mn bronze, high Mn-Al bronze and stainless steels. A new stainless steel cast propeller has responded well in 25 year ship tests. The composition is: $\leq$ 0.07C, $\leq$ 1.0 Si, $\leq$ 1.0 Mn, $\leq$ 0.04 P, $\leq$ 0.04 S, $\leq$ 2.5 Cu, 4.5-6.0 Ni, 10-15 Cr, 0.10-3.0 Mo, $<$ 1.0 Nb. An alloy propeller material of this class is now being tested in the United States (Boeing Company) as a possible alternate to 17-4 PH steel. The Kobe test results are described in two unnumbered reports published in March 1976, by the Casting and Forging Division.

The Structural Engineering Laboratory, as described by the host, Dr. Yoshio Namita, is involved in the following areas:

1) Long span suspension bridges.
2) Structural analyses (buildings, bridges, ships, pressure vessels).
3) Load carrying capacity of frame structures such as bridges.
4) Concrete structures.
5) Fracture mechanics, brittle fracture and fatigue studies.
6) Lightweight metal structures.

The laboratory has produced 60-70 percent of the software for the Honshu-Shikoki bridges now under construction. Kobe is supplying cables for these bridges of 180 Kg/mm$^2$ steel.

The laboratory equipment includes a 3000 ton tensile testing machine, a 13 × 1.5 meter test bed of reinforced concrete, a 300 ton universal testing machine for full-scale tests on beams and columns, a 100 ton/60 ton servo-hydraulic fatigue testing machine, a 20 ton low cycle fatigue testing machine (also servo controlled) and a model test room.

In general, both the Central Research Laboratory and the Structural Engineering Laboratory are impressive as highly-effective problem-solving organizations. There are certainly ample scientific excellence and fine-tuned engineering ability. The only regret is that there was not an opportunity on this occasion to visit the Fundamental Research Laboratory, which must be equally excellent.

## NIPPON STEEL CORPORATION
## FUNDAMENTAL RESEARCH LABORATORIES

The Fundamental Research Laboratories of Nippon Steel Corporation is one of the three "corporate" laboratory groups which report to the President via a Research and Development Bureau. Other laboratories are in existence within the company, but these are associated with the various Works which are found throughout Japan.

The Fundamental Research Laboratories are located in Kawasaki City. The two other "corporate" research laboratories are the Products Research and Development Laboratories (also visited) in Sagamihara City and the Process Technology Research and Development Laboratories in Kitakyushu City, Fukuoka.

The Director, Dr. Shin-ichi Nagashima first described some of the history, organization and functions of the Fundamental Research Laboratories (FRL). The laboratories began as the Tokuo Research Institute of Yawata Iron and Steel Institute, Ltd. Nippon Steel, formed by merger to include Yawata Iron and Steel Co., was established in March, 1970, and in November, 1970, the present FRL was organized. There are about 270 persons employed of whom about 60 percent are professional level. Thirty-one, or about ten percent hold doctorates.

The laboratories are organized according to eight functions, as follows:

1. Fundamental Research Laboratory I — Strength and toughness.
2. Fundamental Research Laboratory II — Workability and plasticity.
3. Fundamental Research Laboratory III — Corrosion and heat resistance.
4. Fundamental Research Laboratory IV — Raw materials and iron making.
5. Fundamental Research Laboratory V — Refining and solidification.
6. Fundamental Research Laboratory VI — Coating and new materials, including composites.
7. Measurement Research Laboratory — Measurement and development of new research procedures.
8. Analysis Research Laboratory — Chemical and instrumental analysis.

With these groups the laboratory performs the more long-term, future oriented, research of the corporation. It was stressed, however, that they interpret the word "fundamental" to mean purpose-oriented, high-potential research. The similarity to the ONR mission is apparent, except that ONR has a greater variety of "purposes."

A tour of FRL, conducted by Dr. T. Murata, Senior Research Metallurgist, was necessarily short because of the time needed for discussions. A variety of automated analytical equipment developed by FRL for such elements as P, Si, Mn, N, and O was observed. Auger analyses are conducted, and a device to fracture samples within the system avoids contamination of the surfaces before analysis. Samples can also be fractured within the Auger system at elevated temperatures. This is useful in studies of hot ductility and temper embrittlement in which contaminants may segregate at elevated temperatures.

The high point of the tour, however, was the one million volt electron microscope. The microscope which of course provides good resolution is also equipped with devices to heat and/or deform specimens in gas atmospheres up to 20-50 torr. Thus the generation and movement of defects produced by these forces can be observed directly. A taped movie of some previous observations was shown. One could see the movement of dislocations as iron is deformed. As temperature increased, transformation to austenite was seen. A particle of cementite was observed to dissolve, and the carbon diffused along a dislocation. This is a spectacular movie indeed.

Two achievements of note are in the refining and metal reduction field. Very pure stainless steels and ferrochromium alloys have been made with a process called metal bearing slag refining (MSR), developed at FRL. The level of phosphorus in both ferrochromium and stainless steel can be reduced to 5 ppm by this process. The process is now in pilot plant stage.

FRL is producing amorphous metal alloys by splat cooling and is looking at the possible fields for application. The excellent corrosion resistance is considered an important attribute. Laser beams are being used as a power source for welding, and laser processing techniques to produce amorphous structures are under consideration. There were no discussions about particular welding applications of lasers.

The individual researchers at FRL are engaged in a wide variety of activities. H. Okada, Y. Hosoi and S. Abe have been studying stress corrosion cracking of austenitic stainless steels, and in particular the role of metal dissolution during SCC in chloride solution. Fractographic observations of the crack surfaces have been made. Type 304 and 310 stainless steel fractured transgranularly in boiling $MgCl_2$ (143°C). Intergranular fracture was found in type 316 stainless. Intergranular fracture was favored by increasing percentages of Mo, applied stress increases and lower test temperatures. Also, according to these authors, Fe and Ni dissolve during SCC, but Cr does not. A mechanism of cracking based on successive metal slip and metal dissolution at the fresh slip faces is proposed.

Okada and others have been active in international conferences such as the recent USA-Japan Conference on Passivity and Its Breakdown on Iron and Iron Base Alloys. Okada was co-editor with ONR contractor R. Staehle of Ohio State University of the proceedings of this conference. Among the several papers presented by FRL investigators were analytical studies of passive films by Auger analysis, studies of the transitions in fracture modes as related to the environment and composition, and studies of the cathodic reactions at fresh surfaces after mechanical rupture and the effect of phosphorus thereon. One important conclusion was that phosphorus increases the hydrogen evolution reaction at fresh surfaces of stainless steels at low pH. Chloride ions mask the effects of hydrogen, but not at high strain rates; thus, copious quantities of hydrogen may occur at crack tips. These results lend increased significance to the efforts of FRL in developing the new metal bearing slag refining process (MSR) which promises the production of stainless steel of extremely low phosphorus content.

Okada and H. Shimada have also studied the formation of rust on cold rolled sheet (Corrosion *30* No. 3, 1974). Manganese sulfide was confirmed as the source of rust initiation. In water $\alpha$ – (Mn, Fe)S dissolves most readily if the solution contains oxygen. In humid air at 60°C the rust formation process is concluded to be:

1. dissolution of some $\alpha$ – (Mn, Fe)S,
2. precipitation of fine colloidal particles of $\gamma$ – $Mn_2O_3$ ($Mn_3O_4$) around the $\alpha$ – (Mn, Fe)S particles and
3. the initiation of rust around the fine $\gamma$ – $Mn_2O_3$ ($Mn_2O_4$) particles.

Valuable summaries of the corrosion behavior of steels and weldable steels have been produced also by FRL (Nippon Steel Technical Report Overseas No. 8, May 1976).

Dr. M. Nagumo reports some interesting results on the tensile fracture processes of perforated mill steel sheet (Acta Met. *21*, 1661, Dec. 1973). Fracture did not take place by hole coalescence but rather by the initiation of a shear crack at the side of a hole. Comparison of the plastic strain energy associated with the growth of a hole with the plastic strain energy for shear cracking produced a criterion for the onset of a shear crack. This criterion proved to be applicable to predicting the effects of spherical inclusions.

Creep-rupture studies on Inconel 617 at 1000°C in helium have been studied by Y. Hosoi and S. Abe of FRL (Met Trans. vol. 6A, June 1975). Oxygen diminishes creep-rupture times by decarburizing the steel. These authors were very aware of the work of Dr. P. Shahinian of NRL, and were interested in hearing of Shahinian's latest activities.

O. Kommori and others have studied the isolation and chemical analysis of inclusions in steels. A paper was presented on this subject to the 1976 Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy, March 2, 1976 (see also JIM *12* No. 2 1971).

Another achievement at FRL is the development of a Co-free Ni-base superalloy for the HTGR by Y. Hosoi, N. Shinoda, T. Tsuchida and M. Sakakibara. The alloy is composed of 18 Cr 15 W and 0.5 Mo, with small additions of Y and Zr for improved creep strength. In helium the alloy meets the required creep rupture strength of 1 kg/mm$^2$ for $10^5$ hours at 1000°C.

N. Nagumo and T. Takahashi presented a paper on "Hydrogen Embrittlement of Some Fe-Base Amorphous Alloys" at the Second International Conference on Rapidly Quenched Metals at MIT, Boston, Nov. 17, 1975. Interesting features of the hydrogen embittlement of amorphous metals (from cathodic charging) are that the Cr in the $Fe_{70}Cr_{10}P_{13}C_7$ alloy contributes to the high corrosion resistance and minimizes hydrogen permeation. When hydrogen embrittlement is observed, it proves to be completely reversible. Finally the authors indicated that the diffusion rates of hydrogen in amorphous alloys are lower than in crystalline alloys.

M. Nagumo has prepared a paper, "Initiation of Cracks at Delayed Fracture of a High Strength Steel" for presentation at the 4th International Fracture Conference, Waterloo, Canada, June 1977. An acoustic emission technique shows incipient cracking at inclusions and grain boundaries at the roots of stressed notches. The threshold stress for cracking of stressed cathodically charged specimens is reduced by soluble nitrogen, and an interaction between soluble nitrogen and hydrogen at grain boundaries is proposed. Increasing soluble nitrogen also produces a change in fracture mode from transgranular to intergranular.

The FRL is engaged in a multitude of other research efforts, such as coating, plating and blast furnace technology, but the above descriptions hopefully indicate the flavor and thrust of FLR.

The overall impression is that this is a first-class laboratory with an eye to the future. The laboratories of Nippon Steel are certainly the equal of comparable laboratories in the world which have been observed. The scientific leaning of the laboratories coupled with the continued commercial success of the corporation suggest that perhaps science and profitability are compatible after all.

## NIPPON STEEL CORPORATION TECHNICAL PLATE RESEARCH LABORATORY

The Nippon Steel Works Laboratory at Nagoya serves the thick-plate production activities of the company. Thick plates have been in increasing demand as industrial plants and equipments have tended to become larger and subject to more severe requirements in recent years. Thermal and nuclear power plants, for example, require large boiler drums and pressure vessels and fuel oil desulfurization reactors require high temperatures and pressures.

The Nagoya Works has a capacity of seven million tons annually. Plates up to eleven inches thick weighing up to 50 metric tons can be fabricated (reportedly, only one U.S. company can produce plates this thick). Other than the problems associated with the mechanics of handling such massive plates, there are the expected problems with porosity, microcracks, purity and uniformity of composition which are common to the production of large ingots which cannot be hot worked or reduced very much.

Nippon Steel uses 15, 50 and 100 ton basic electric arc furnaces (with electromagnetic induction agitators) to produce forged slabs and a basic oxygen furnace to produce rolled slabs (the slabs in each case are subsequently rolled into plate). The basic electric furnace produces ingots which are very large and these ingots are slabbed by hot-forging with an 8000-ton forging press. This is useful in removing or healing blowholes and microcavities in the ingots through plastic deformation. The conventional electric furnace, however, requires the use of scrap, which creates some problems with purity which are avoided with the basic oxygen furnace which does not require scrap. The latter furnace is therefore attractive for smaller plates with which sufficient reduction can be obtained in the slabbing rolling mill.

All slabs are heat treated and surface conditioned prior to plate-mill rolling. Following this the plates are again heat treated prior to inspection, straightening and final mechanical properties tests. Hydrogen is always a problem with large ingots and plates, because the diffusion path to the surface is long and hairline cracks may therefore occur during cooling. Nippon Steel removes hydrogen through vacuum degassing of all melts and through dehydrogenation during heat treatment for the slabbing and plate-making processes.

A wide variety of plate steels is produced to satisfy varying service requirements. Thus a series of weldable high-strength steels (WEL-TEN class) is produced with tensile strength ranging between 60 and 100 Kg/mm$^2$. The N-Tuf steels are intended for low temperature service (-40° to -196°C). A number of low-alloy steels for medium-high and high-temperature service in high-temperature, high-pressure vessels are made. Atmospheric corrosion resistant steels of the CORR-TEN type and NAW type are also produced. The steel S-TEN is resistant to sulphuric acid. Abrasion resistant steels of the WEL-TEN and NAW class are made with increased hardness by use of lower tempering temperatures.

The research work conducted by the laboratory involves the problems of purity, segregation, porosity and structure which are inherent to thick plate manufacture. The problems of fabrication and welding relate to these problems, and are also of interest. It is desired always to maximize toughness, weldability, and fabricability and to tailor properties at minimum cost to meet specific service requirements. Some specific research areas and problems which were discussed on this visit follow:

1) Welding of high-strength (80 Kg/mm$^2$, 100 ksi) steel for pressure vessels - Pressure vessels are field welded under unfavorable environmental conditions. One hundred percent joint efficiency is required and the welding has to be done under great restraint because such heavy plate is used.

Semi-automatic and automatic welding procedures are gradually being introduced for the 80 Kg/mm$^2$ steel (WEL-TEN 80) but SMAW remains the dominant practice, especially for spherical tanks. Unfortunately SMAW welding efficiency is influenced greatly by the operator's skill. Other problems which become intensified in the welding of high-strength steel are: 1) the steel HAZ is embrittled by high temperatures and the plate cannot be readily press strengthened or formed; 2) the high strength steels are more susceptible to the harmful effects of hydrogen, and elaborate steps for preheating and post heating and a large number of passes are required; and 3) high strength steels are notch sensitive so that misfits and other sources of notch effects must be controlled.

Nippon Steel has prepared detailed manuals for the welding of high strength steels which describe the proper selection and drying of weld materials, give welding procedures and welding conditions for butt and fillet welding and specify heat input and bead length restrictions.

2) Plates for Heavy Section Nuclear Reactor Pressure Vessels - In a recent publication (Nippon Steel Technical Report Overseas No. 7, November, 1975) steelmaking procedures to minimize impurities and residual elements which cause irradiation embrittlement and the means to employ hot working and deflaking heat treatments are described. The optimum procedures are claimed to provide quality assurance and pressure vessel integrity, on the basis of COD, DT, fatigue and weldability tests. Steels of this type, low in the amounts of the harmful elements Cu and P, are currently under test at the Naval Research Laboratory (Code 6390).

A paper on the improvement of fracture toughness in reactor pressure vessel steel plates was scheduled for presentation at the Third International Conference on Pressure Vessel Technology in Tokyo, 18-22 April, 1977. The authors, H. Kunitake, H. Nakao, T. Kikutake, A. Saito, T. Isiguro and T. Takeda, report that the BOP process is effective in minimizing the concentration of harmful elements. With respect to SA 533 B steel, residual sulfur is harmful to upper shelf Charpy-V test energy. Transition temperatures are lowered by decreasing carbon levels and increasing the hardenability with manganese nickel and molybdenum additions. A small amount of chromium lowers transition temperature as does control over aluminum and nitrogen levels. Tests on a commercial scale production heat of SA 533 B steel with optimum composition bear out the experimental predictions.

3) Environmental - There are problems with stress corrosion cracking of line pipe steels and oil drill casing steels which are being studied. The problem is embrittlement or cracking by $H_2S$. Tests are being conducted in 5 percent NaCl-water at temperatures between 10°C and 80°C and with pH varied by $CH_3COOH$ additions. The level of $H_2S$ is varied by saturating the solution with various $H_2S$-$N_2$ gas mixtures.

The company has evidently been able to increase greatly the resistance to $H_2S$ by the judicious control of composition and by purposeful small additions of certain elements. These were discussed but the writer promised the details would not be disclosed.

In general the Nagoya Works Laboratory is excellent and the work there is in keeping with the high standards observed previously in the *Fundamental Research Laboratories and the Product* Research and Development Laboratories of Nippon Steel.

# NIPPON STEEL CORPORATION
# PRODUCTION RESEARCH AND DEVELOPMENT LABORATORIES

There are three central laboratories in the Nippon Steel Corporation which report directly to the President via a Research and Development Bureau. These are the Fundamental Research Laboratories, Products Research and Development Laboratories and the Process Technology Research and Development Laboratories. In addition there are research laboratories associated with each of the ten works located throughout Japan (Oita Works, Nagoya Works, Muroran Works, etc.). Reported here is a visit to the Products Research and Development Laboratories in Sagamihara City, Kanagawa Prefecture, near Tokyo.

The Products Research and Development Laboratories (PRDL) are divided into two departments, the Research Department and the Welding Research Center, both of which report to the Director, Dr. Teruo Ikeno. The Research Department is directed by Dr. Shogo Kanazawa. Five laboratories are in this department, and there are two service groups. These laboratories perform research in the areas described below:

1. Laboratory I — This laboratory is the thin steel and surface treatment facility. Major interest is in coatings of tin, zinc, chromium, etc. particularly as related to the canning industry. Substitution of an electroplated chromium coating as a substitute for tin is a current goal.
2. Laboratory II — This group does application research on thick plates and alloy steels. Studies are conducted on corrosion (wet and dry), corrosion fatigue, fracture and weldability. The group develops new alloy steels such as ferritic stainless steels. Applications in mind are plates for ship hulls, bridges and pressure vessels (both conventional and nuclear).
3. Laboratory III — This group works on forming of welded joints and rods. Finite element methods are coupled with critical experiments.
4. Laboratory IV — Application research on pipes is the major activity of this group, particularly line pipes for gas and oil and the problems which develop from low-temperature service. Nippon Steel makes some of the largest pipe in the world (48 inch) and the Oita Works produces plate 18 feet wide for forming and welding into pipe. Seamless pipe up to 16 inches in diameter is also produced and is intended for OCTG (Oil Country Tooling Goods).
5. Laboratory V — This is an analytical group. New techniques are explored for microchemical analyses and local chemical analyses, as of inclusions.

The Welding Research Center, which is only a few years old, is organized into four main research departments, as follows:

1. Welding Laboratory I — This group works to adapt existing welding equipment to special welding problems which emerge with new applications.
2. Welding Laboratory II — This group works to develop new types of welding equipment and techniques, and also develops NDT equipment (X-ray and ultrasonic). Areas of special achievement have been in automatic welding, narrow-gap electron beam welding and automatic scanning NDT (nondestructive testing) of welded joints in pipelines.
3. Welding Laboratory III — In this group the metallurgy of welding is studied. Included are studies of fluxes for submerged arc welding and the study of the fundamentals of metal-flux interactions.
4. Welding Laboratory IV — This group works with subsidiary companies to develop compatible plate-welding technique-welding material systems. It is common for the purchasers of steel to include the welding package in the deal, and Nippon Steel then assumes responsibility for the quality of subsidiary weld material producers.

The Welding Research Center also runs a Welder Training Center for companies using Nippon Steel plates and welding materials. Over 6000 engineers have graduated from the one to six month course.

Following the introduction to the organization of PRDL, a tour of the facility was arranged with N. Taniguchi, an outstanding Senior Research Engineer. The tour revealed some of the most advanced equipment in the world for welding methods and weld testing. It will suffice, hopefully, to simply indicate the types of tests and equipment which were observed, as follows:

1. In the analytical laboratory, a gas chromatographic method for measuring the hydrogen content in many specimens at the same time was shown.
2. In one laboratory, multiple cantilever beam tests for the hydrogen-charged cracking of welds were underway-Specimens are cathodically charged before test, and the specimens contain a saw-cut notch.
3. Both dead load and hydrostatic weld implant tests are conducted.
4. Patch tests for the study of the effects of high residual stresses are carried out.
5. Lamellar tearing tests and surface strain tests are going on.
6. The Tekken test of the Japanese Railroad Research Institute to measure the effects of preheat and postheat on weld cracking is used.
7. Simulations of the electric resistance welding of pipes are done to study the mechanisms of ERW and improve the toughness of the joint.
8. Both tensile and cantilever beam tests of susceptibility to cracking in hydrogen sulfide are done. The concentration of $H_2S$ in the nitrogen environment can be controlled to 10 ppm. Cantilever beam tests are being phased out in favor of the compact tension fracture mechanics specimen.
9. Compact tension fracture mechanics tests are being done to produce data for the Japan DSRV (Deep Sea Rescue Vehicle). One test is underway to see if there are differences in $K_{Iscc}$ between 1 inch and 2 inch sections of the 10 Ni-8Co type steels.
10. A very large test cell (room) with humidity controlled at any point between 20 and 95 percent and temperature between -40°C and +40°C is used for testing welding in various atmospheric conditions. For example, tropical environments can be produced.
11. Fatigue test equipment includes a 2000 ton, 6000 cpm servo type Saginamya machine used for tests on welded joints.
12. A high-speed impact machine (30 m/sec, 10 kg) is used to test vehicle safety (e.g., the sides of automobiles).
13. A high energy rate machine is used to test effects of high extrusion rates.
14. Many of the usual brittle fracture tests of welds and fusion lines in plates are conducted. The laboratory features one large machine which can apply 8000 tons static load (second largest in Japan) and 2000 ton cyclic load at 20 cpm. The massive tests are used to test steels for giant new bridges and off-shore platforms, where heavy sections are involved.
15. Lamellar tearing tests are conducted on steels up to three inches thick. Lamellar tearing is a concern in massive welded structures involving heavy sections and rigid constraints.
16. A great number of corrosion-fatigue tests of smooth specimens in synthetic seawater are conducted.
17. A massive dynamic tear test (courtesy of W.S. Pellini and E. Lange of NRL) is in operation.
18. One side, one pass submerged arc welding equipment is available. This is a notable Japanese development.
19. Narrow gap MIG welding equipment (from Battelle) is available.
20. Vertical narrow gap MIG welding equipment is in operation.
21. Simplified electroslag welding involving a fluxcoated electrode is done. The flux is on the outside of a tube, and the weld wire is inserted down the tube. Copper chills at the weld sides are used. Vertical welds 10 meters high have been made by this SES process.
22. A variety of other welding process equipment was seen, including the VASCON, OSCON and MISA processes. VASCON refers to automatic (e.g., vertical up) arc welding processes with voltage and current control. OSCON refers to automatic arc welding processes involving controlled oscillation of the welding wire. MISA refers to submerged arc welding processes using fine wire. A number of other welding processes are in use or under development. Detailed descriptions are available in Nippon Steel brochures and reports.
23. Experiments in weld overlay with stainless steel are being conducted.

The Director of the PRDL, Dr. Ikeno, next reviewed some of the history of the organization. About six years ago he visited the USA to gather background material so that he could better decide what PRDL should work on. The most impressive work in the USA according to Ikeno was being done at U.S. Steel (M. Lightner) and at NRL (E. Lange).

Upon returning to Japan, Ikeno organized his laboratory along the lines of the (former) U.S. Steel Laboratory at Monroeville. The new philosophy was that it is not enough to simply produce steel products anymore. Steel will be used in even more massive structures, at higher and lower temperatures, and in new and more corrosive environments. The steel company should therefore get involved in anticipating the requirements of the user, both present and future, so that a satisfactory product will be available when needed. It is for this reason that so many diverse facilities have been assembled at PRDL. Another feature is that all types of materials people are brought together in one laboratory, providing the multidisciplinary approach to critical problems.

Examples of the problems the laboratory gets involved in are the Alaska pipeline, the North Sea offshore structures, and the construction of tanker ships up to one million tons. The requirements of this service are fed back to the laboratory which then strives for solutions. The Alaska pipeline difficulties, for example, could be attributed to the use of untrained welders (due in part to union pressures). The problems were solved by developing an automatic girth welding system and automatic inspection-recording devices.

The girth welding procedures have been offered to the Canadian Gas Line Study Limited, presumably as an inducement to use Nippon material. Nippon Steel has apparently developed some $H_2S$ resistant steels which would be a further attraction. There was no discussion of the features of these $H_2S$ resistant steels.

Dr. Ikeno stressed that cooperative, world-wide research would be welcome, and that Nippon Steel Company would exchange information freely in such efforts. He would appreciate being contacted by any interested organizations or individuals.

From discussion of specific research activities, several areas of interest emerged, as follows:

1. Lamellar tearing — this process, referred to previously, is of concern in heavy section welded components and structures. Investigations, principally by Dr. S. Kanazawa, have been conducted on an assessment of lamellar tearing susceptibility of steel plate (IIW Doc. IX-840-73) and on lamellar tear resisting steels and how to use them (IIW Doc IX 873-74). As might be expected, lamellar tearing may be reduced by improved desulfurization and rare earth metal additions.
2. Studies of fracture initiation in normalized and cold-worked mill steels and the related effects of grain size on this process. This work is due to M. Ogasaware, M. Iino and H. Mimura (Trans JIS *11* No. 1 1970, JIS *12* No. 4 1971 JIS *13* No. 1, 1972). Transition temperatures were lowered with cold work and decreasing grain size.
3. S. Kanazawa reviewed the use of vanadium to improve properties, particularly weldability, of high strength steel at the Vanitec Meeting of 1976.
4. The development of new steels for high heat input welding was described also by S. Kanazawa (IIW IX-952-76). Welding fusion zone toughness is improved by fine tin particles.
5. S. Kanazawa and others have written on problems of stress-relief cracking in high strength steel and stainless steel. Cracking is located at the prior austenitic grain boundaries. Effects of alloying elements are given (see Trans JWS Vol. 7 No. 1 1976).
6. Several PRDL investigators, S. Kanazawa again principal author, described at the 2nd International Conference on Materials in Boston, August, 1976, the fracture safe design of welded steel structures based on large scale tests.
7. Reports by S. Kado and others, appearing in July, 1975 (IIW Doc. XIII-771, 772, 773-75) describe improvements in the fatigue strength of welds through TIG dressing and by additional weld runs with coated electrodes. The dressing appears to improve weld-toe configurations.
8. N. Taniguchi and others presented papers on "Dynamic Transition Behavior of Structural Steels" and "Modified Three Point Bend Test for Determining Brittle Fracture Properties" at the March 1977 International Conference on Fracture Mechanics and Technology in Hong Kong. The feasibility of using a sharp machined slot in the DT test instead of the Ti-electron beam crack starter is argued for steels up to strength level HT90.
9. S. Kanazawa and N. Taniguchi submitted a paper on "Effects of Crack Tip Damage on $K_{Iscc}$ with 4340 Steel" to the 3rd ICF in Munich. The conclusion is that fatigue precrack loading levels can have a significant impact on the values of $K_{Iscc}$ which are subsequently determined.

In general, the PRDL appears to be a well equipped and well staffed laboratory. The work going on is very impressive and could be a model for other steel companies in the world which may wonder at the success of Nippon Steel.

## TOMOEGUMI IRON WORKS, LTD.

Dr. Hiroshi Nakayama, Plant Manager, was my host for a visit to Tomoegumi Iron Works. Both the Oyama plant in Tochigi-ken, about 50 km from Tokyo, and the Welding Laboratory in Tokyo were visited.

The company was founded in 1917 as a fabrication shop and has grown since to serve primarily the building industry, in both design and fabrication. The company is famed for its "Diamond Truss" concept, a method for constructing curved, wide-span surfaces with trusses arranged in diamond forms. In addition to the two main lines, steel towers and Diamond Truss structures, the company builds bridges, prefabricated houses and schools and all manner of steel frame structures. The architectural section of the company is integrated with the planning, design and field construction activities, which is claimed to be unique in Japan.

With the extensive involvement of the company in fabrication it is natural that welding would be important. In this respect, the company appears to be almost exclusively employing variations of the $CO_2$ arc welding process which the company and Nakayama in particular have developed. There are both automatic and semi-automatic processes for both in-plant and on-site operations. Some of these processes for narrow-gap welds are as follows:

1. NOW-T — This is a semi-automatic process for making vertical T weld joints. It involves $CO_2$ welding with the lower part of the joint contained by a copper chill and with coated rod laid in the square butt groove.
2. NOW-H — Similar to NOW-T but the weld is horizontal T and the chill is L shaped to contain the weld metal. This is intended for on-site welding.
3. NOW-F — This is a flat semi-automatic shop welding $CO_2$ arc weld process. The weld is flat horizontal with a granular flux backing.
4. NOW-B — This is a flat automatic shop horizontal welding $CO_2$ arc weld process. A small strip is welded first to the back side to contain the filler metal. Welding is performed in one-pass, one layer in a square butt groove.
5. NOW-HB — This is an automatic on-site horizontal process with a small strip welded to the reverse side to contain weld metal.
6. NOW-TB — A semi-automatic process for T joints, similar to the NOW-T process except that a steel backing strip is used.
7. NOW-V — This is a vertical narrow gap $CO_2$ arc weld process involving arc weaving and copper chills which move with the weld. $CO_2$ gas enters through an opening in the chill.
8. NOW-VB — This is a vertical T welding process similar to the NOW—V process but with the chills located appropriately for a T-joint.

These brief descriptions are recognized to beg better illustration and further clarification and for this purpose the papers which Nakayama and his colleagues have produced are perhaps the best source. Some of the more important of these are listed as follows:

1. H. Nakayama et al., "Use of Narrow-Gap One-Side Arc Welding Process (NOW Process) to Steel Structures of Building" IIW Doc. XII-B-87-71
2. H. Nakayama et al., "A Study of Narrow-Gap One-Side Arc Welding Process for Horizontal Position Welding," IIW Doc. XII-B-105-72
3. H. Nakayama et al., "Development and Application of Narrow-Gap One-Side Arc Welding Process (NOW-Process) to Steel Structures of Building," IIW Doc. XII-B-160-74
4. H. Nakayama et al., "A Study of Narrow-Gap One-Side Arc Welding Process of T-Joints (NOW-T Process) in Steel Building," IIW Doc. XII-B-133-73
5. "Development and Application of Narrow-Gap Arc Welding Process in Japan," IIW Doc. XII-B-584-74

6. H. Nakayama et al., "Application of Narrow-Gap Automatic $CO_2$ Arc Weaving Welding Process to Heavy Steel Structures," IIW Doc. XII-B-188-75
7. H. Nakayama et al., "Application of Narrow-Gap Automatic $CO_2$ Arc Weaving Processes to Heavy Steel Structures of Building," 2nd International Symposium of the Japan Welding Society, August 1975, No. 2-2 (21). Also IIW Doc. XII-B-193-76

Nakayama's group has also been involved in studies of deformation and stress due to welding in steel buildings (IIW Doc. XV-292-70) and in studies to prevent weld cracking in high strength steel welds of building structures (IIW-Doc. IX-787-72). In the latter study a new method to prevent weld cracking was proposed involving succeeding passes within the incubation time for crack initiation without employing preheating.

At the Welding Laboratory, a recent achievement is a tandem sensor for the ultrasonic detection of defects in welds. This is claimed to be particularly effective in the NDT of narrow-gap welds. The company plans to develop the instrument for sale in the near future. Work is also under way on the development of a circular automatic $CO_2$ on-site welder. The goal is to provide automatic circular welding capability (girth welding) for underground columns of an electric power station.

At the time of the visit, Nakayama was engaged in writing a book on $CO_2$ welding and also preparing a Welding Terminology Dictionary. He was doing this in the evenings. Perhaps it is this kind of dedication that produces so many excellent industrial organizations in Japan. Tomoegumi Iron Works is one of these.

## HITACHI METALS, LTD.

Hitachi Metals Ltd separated from the large Hitachi Ltd some twenty years ago. Through the kindness of Professor T. Owadano of Kyushu Institute of Technology (KIT) a visit was arranged to both the Tobata and the Kanda Works. Dr. Ryoji Takahashi, Assistant Manager of the Castings R and D Center in Tobata was principal host.

Hitachi Metals Ltd is producing malleable iron, ductile iron and steel castings. The capacity is 7500 tons/month of malleable and ductile iron (4000 at Tobata and 3500 at Kanda) and 1600 tons/month of cast steel (1000 at Tobata and 600 at Kanda). There are 3000 tons/month of ferritic malleable cast iron, 2000 tons/month of pearlitic malleable cast iron and 2500 tons/month of ductile iron. Seventy percent of the cast steel is for the United States market, and in fact the Kanda plant was built primarily for this market. About fifty percent of the cast iron products go to the United States. There are about 1600 employees and, as was said, 1400 are "working" men and the others are in the office.

Dr. Takahashi was a student at KIT and obtained his doctorate under Owadano. Earlier he obtained his B.S. at Tokyo University. He appears to be one of the most energetic and productive men. For example, he has published over 30 papers, of which at least four are in international journals. In addition he has produced some 59 Hitachi internal publications. The total number of Hitachi research reports since World War II is nearly 300. They cover all aspects of malleable and ductile iron and cast steel production from sand treatment to shrinkage problems to high temperature resistant cast irons to improved gating and risering schemes to machining and grinding to hardening. Representative reports of Takahashi are "Improving the Melting of White Cast Iron for Malleabilizing" (HI-801), "The Influence of Nitrogen and Oxygen on the Annealing Properties of White Cast Iron" (HI-802) and "Hot Tearing of White Cast Iron" (HI-803).

Current projects of Takashi involve ductile iron, organic binders, reclamation of foundry sand and gating and casting design. For example, he is trying to develop an organic binder which will behave similar to the $CO_2$ binder; that is, contract rather than expand after the metal is poured.

The foundries of Hitachi Metals Ltd are among the most modern in the world. This is a remarkable achievement in view of the fantastic difficulties encountered immediately following World War II, when materials, fuels, sands, ferroalloys, etc. were difficult to obtain, uncertain in quality and characterized by immense lot-to-lot variations. Determined and exhausting work by men such as Takashi gradually produced a bootstrap elevation to the modern facility of today.

## FURUKAWA ALUMINUM CO., LTD.

Furukawa Aluminum Co., Ltd., is one of the leading aluminum fabricators in Japan. Products are sheet, stranded steel-core wire, castings, forgings and extrusions. The Nikko Works produces sheets and forgings at the rate of 6000 ton/month and 50 ton/month respectively. Products are foils, can sheet, painted sheets, circles, die forgings and free forgings. The company ranks third in Japan in the domestic market for sheets and extrusions.

Furukawa Aluminum Company derives from the Furukawa Electric Company, Ltd., and production began in 1920. In 1959 a cooperative agreement was made with Alcoa Aluminum Company, U.S.A. Technical exchanges are a part of this agreement. At present Furukawa Aluminum Company imports aluminum pig from Alcoa of Australia.

Developmental research activities at Nikko are conducted by 7 metallurgists, 6 chemical engineers and 2 mechanical engineers. Close cooperation with Alcoa permits the staff to focus on research which is important, complements Alcoa research, and is in keeping with Furukawa's capabilities. Five major activites are involved, as follows:

1. Packaging and forming materials—cans, kitchen utensils, fins (for heat exchangers) and foils.
2. Automotive products—body panels for automobiles, automobile wheels, plated aluminum bumpers.
3. Heat exchanger products—vacuum brazing technology and ultrasonic soldering technology.
4. Design and manufacturing of structural products—upgrading of high strength forgings, welding practice and materials, highway fencing materials toughness.
5. Others—electrolytic coloring of Al-Mg-Si alloys, chemical conversion coatings, cold working of Al-Mg-Si alloys, screw machine stock alloys.

Dr. T. Tanaka, Manager of the Technical Research Section, provided a review of the above activities with some special insight as to current emphasis. For example vacuum brazing is being developed to overcome certain hazards involved in flux brazing. Japan was the first to develop vacuum brazing on a commercial basis. Optimization of brazing alloy compositions for vacuum brazing is a current effort. Pitting corrosion and the means to protect from this by cathodic protection are also being studied. Surface finishes and the weld areas are of special interest.

Along with other aluminum fabricators in Japan, Furukawa Aluminum is trying to develop the Al-Zn-Mg alloy 7003 for structural purposes at the strength level 40 $kg/mm^2$. This alloy, which contains no copper, is also attractive for its good extrudability. Applications for rail coach rolling stock for Shinkansen bullet trains (220-260 km/hour) are seen.

The alloy 7003 is, however, subject to stress corrosion cracking, and rail applications demand a life of 30 years. Furukawa research activities are examining every way to improve SCC resistance—modification of composition, heat treatment and design factors to optimize the application of structural loads. Cantilever ASTM test methods are employed, and consideration is given to directionality.

Furukawa Aluminum produces 7075 T-73 alloys forgings for the F-86 and Phantom for the Japanese Defense Force. Greater strength and toughness are a goal of current research. The company also is involved with forgings for the marine and ship building industry. Examples are pistons, impellors and superchargers. Furukawa can hand-forge to a diameter of 1½ meters. Flanges of this diameter were made for the pipes for LNG tanks. Pistons can be forged which are 52 inches in diameter and 36 inches high. These are for installation in 300,000 ton class tankers.

With respect to welding there is need to weld plate 70-80 mm thick. Rolling stock weldments for trains are also a concern. Problems of special interest are cracking and porosity. The addition of Zr to welding electrodes has been found effective in reducing weld cracking, and the addition of B also refines the structure. Zirconium is also believed to remove hydrogen. Welding rod containing both Zr and B, developed at Furukawa Aluminum, is now commercially available.

Other current problems are the corrosion of aluminum alloy guard rail along coastal areas and the production of Al-Mg-Si alloys for use in baseball bats and in ski equipments. Furukawa hopes to eliminate the annealing operation currently practiced in the U.S.A. In summary, the laboratories at Furukawa Aluminum are trying to widen the applications of aluminum alloys by the general public as well as by defense and governmental agencies.

With respect to specific research activity, research on Al-Zn-Mg alloys commenced in 1960. Production of K-70 (Al-4.5 Zn-1.5Mg) for welded structures started in 1961. Studies of Al-Zn-Mg alloys for welding stock began in 1962, with studies on welding practice and stress corrosion cracking. In 1972 production of the alloy K 73 (Al-5.8 Zn-1.2Mg) for rolling stock, skis and motorcycle frames began. In 1974 the K74 alloy (Al-4.5 Zn-2.0Mg) was developed as a high-strength Al-Zn-Mg alloy.

Among the researchers, T. Tanaka and T. Saito have been by far the most prolific. A series of articles describe the stress corrosion cracking problems of Al-Zn-Mg alloys (see Proc. Japan Light Metals Institute: *19* No. 2, p. 55, 1969; *19* No. 8, 327, 1969; *19* No. 8, 336, 1969; *20* No. 7, 327, 1970; *22* No. 6, 403, 1972; *25* No. 6, 214, 1975). The main conclusions of these investigations are as follows:

1. Stress corrosion cracking (SCC) is worse with a narrow precipitate free zone and finer precipitates.
2. Sensitivity to SCC increases with low-temperature aging and prestraining.
3. SCC of sheared edges of welds corresponds to SCC data on plates subjected to external, not residual stresses. Residual stress cracks do not appear at the heat affected zone.
4. Step aging increases resistance to SCC at a given strength level in Al-Mg-Zn alloys.
5. Rolling reduction increases the SCC resistance of 7075-76 alloy plates. Orientation is highly significant. Grain boundaries, especially those lying perpendicular to the direction of stress, play an important roll in SCC of 7075 alloy.
6. Additions of 0.1 a/o of Cu, Cr, Ti or Zn had little effect on the SCC resistance of Al-4.5 w/o Zn, 2.9 w/o Mg alloy.

The overall impression of the Furukawa Aluminum Company at Nikko is that a great deal of important and practical development is being accomplished by an excellent but relatively small staff. The reason for this productivity is twofold:

1. There is profitable interaction with Alcoa research.
2. There is continuous interaction with production people in the plant.

# SUMITOMO LIGHT METAL INDUSTRIES, LTD. NAGOYA PLANT

Sumitomo Metal Industries dates back 300 years to when copper mining began in Japan. Copper rolling began in 1897, aluminum rolling in 1898 (the first in Japan). Sumitomo Light Metal Industries was established in 1959, when previous ties with steel companies were severed. In addition to copper and aluminum alloys, the company now produces titanium alloys in the form of tubes and plates for condensers and heat exchangers.

The Technical Research Laboratories of the company in Nagoya support the technical activities in the three light-metal alloy systems. Dr. Shino Sato, Assistant General Manager, and Y. Sugiyama, Senior Research Engineer, of the Technical Research Laboratories were hosts on this visit. As is customary in Japan, they began with a detailed account of the organization of the laboratories. There are 12 sections doing research on: 1) copper alloys, 2) aluminum alloys, 3) welding 4) corrosion, 5) surface treatment, 6) aluminum refining, 7) chemical analysis, 8) mechanical structural analysis, 9) process engineering, 10) physical metallurgy, 11) metal working, and 12) heat exchangers. There was not time to discuss in detail the activities of each group. Those which were discussed are described briefly as follows:

1) Analysis - Studies on auto-instrumentation and systems research. Development of new analytical procedures. Materials investigated are light metal alloys, organic compounds, lubricants. Environmental and pollution control requirements are of recent interest and concern.

2) Physical Metallurgy - Determination of the properties of aluminum, copper and titanium alloys, mechanisms of age hardening, fracture toughness, stress corrosion cracking. Alloy texture development and effects, alloy development and manufacturing technology.

3) Corrosion - Electrochemical effects on alloys, especially aluminum alloys. Hydrogen absorption in titanium corrosion environments, container corrosion and spoilage.

4) Aluminum alloys - The company (Dr. Igarashi) developed the alloy Extra Super Duralumin (AA 7075) before the war, which was one of the strongest alloys in the world and which proved extremely useful in Zero fighter planes. This Al-Zn-Mg-Cu alloy has now been modified to improve strength and resistance to fatigue crack growth (reduced growth rate) at low temperatures (-100°C). Other alloys developed are ZK60 and ZK61 which feature less magnesium and an addition of zirconium. These alloys display exceptional extrudability. Another alloy, GT09, is free machining and corrosion resistant and is therefore useful in precision manufacturing such as for cameras. Research in auto body sheet metal is being conducted.

5) Copper alloys - copper and copper alloy tubing for condensers and heat exchangers. Both fundamental and applied research are conducted on corrosion resistance and the design and maintenance of heat exchangers. An interesting development is the AP Bronze condenser tube which is corrosion resistant in polluted sea water.

6) Surface treatments - Sumitomo is heavily involved in this area because of the improved marketability of aluminum which is colored and weatherproof. They have developed the Sumitone process which involves anodization in a sulfonic acid bath and produces a bronze/black color with improved weathering qualities. Color is also developed in the EDECA process which features the application of color in a soluble resin by means of an electrodeposition method.

7) Welding - weldability studies of structural aluminum alloys, improvement of filler metals, inert gas arc welding, resistance and friction welding, adhesive bonding, brazing and soldering. Directed research on fluxless vacuum and inert gas brazing and ultrasonic soldering processes for aluminum heat exchangers.

Recent research has been directed at problems with condenser tubing in cooperation with some utilities in Japan. A substantial effort has also been made in the development of materials for desalinization plants. In the latter area, support has been received from the Ministry of Trade and Industry and the Ministry of Industry and Commerce. The Office of Science and Technology also sponsors work at the company.

Recent research reports (Sumitomo Light Metal Technical Reports, *17*, No. 3, No. 4, July, 1976) describe corrosion work on "Cathodic Protection and Blackening of Aluminum" and strengthening methods in "Thermomechanical Treatments of Al-Zn-Mg-Cu Base Alloys." An age-hardenable aluminum alloy which can be deep drawn (for cans, car bodies, etc.) is described as U.S. Patent 3,935,007.

Copper alloys are considered in an article on "Polarization Characteristics of Condenser Tubes by Impressed Cathodic Current." In another publication (Boshoku Gijutsu, *23*, 125-133 (1974)) Sato and Nagota wrote on "Stress Corrosion Cracking of Copper Alloys in Pure Steam and Water at High Temperatures." Alloys of Cu-Zn-Al were found to be susceptible to intergranular corrosion (in degassed steam at 150°C-300°C) with low Zn content and to exhibit poor stress-rupture strength with high Zn Content. Cupronickel alloys 90/10 and 70/30 corroded intergranularly in steam and water at 300 to 350°C, and stress-corrosion cracking was produced in autoclaves with applied tensile stresses of 10 to 20 $kg/mm^2$. Monel metal was immune. The writers concluded that the stress corrosion cracking of copper alloys in high temperature water and steam is associated with the equilibrium grain boundary segregation of active metals.

No specific research on titanium alloys was discussed, but some interesting related service experiences were described. Titanium alloys are quite immune to corrosion in seawater over a range of temperature and in more concentrated brines at temperatures below 80°C. If the brine concentration and temperature are both high, there may be problems with pitting and crevice corrosion, particularly if the solution pH is low. This can be a problem with titanium condensers. On the steam side at the air removal section the non- condensable gases $NH_3$, $0_2$ and $CO_2$ are concentrated; this is highly corrosive to copper alloy tubes, but the titanium tubes are free of corrosion. In tests in power plant condensers over the past decade, thin wall welded titanium tubes have performed extremely well with neither corrosion nor deterioration of mechanical properties. In the air removal sections of power plant condensers some problems were experienced with galvanic corrosion of the brass tube plates and hydrogen absorption of the titanium tubes. It is claimed that these troubles can be avoided by application of the proper cathodic potential (-0.45 v - 0.7v SCE). Since 1972 some 85000 welded titanium tubes have been operating in blast furnace heat exchangers with no trouble reported.

In condensers with titanium tubes attached to brass plates an increase in the velocity of the seawater coolant increases the rate of galvanic corrosion.

Some titanium tubes have absorbed hydrogen while in service. This is related to the cathodic potential. The hydriding occurs at potentials less than 0.7 (vs SCE) and hydrogen content increases with cathodic potential, as well as with time. There is apparently no problem if the potential of the titanium tube is kept more noble than -0.7V.

The fouling of titanium tubes by marine life is more severe than with copper alloy tube; however deposits are apparently easily removed.

In general the research work at Sumitomo Light Metal Industries is viewed as intensely product oriented but of high quality and of significance both to the scientific and the energy-oriented communities.

# TOYO KOGYO CO., LTD.

The research and development activity of Mazda Toyo Kogyo serves the technical needs of this large automotive firm which is located entirely in Hiroshima. According to host K. Matsui, Head of the Metal Research Laboratory, the high level management of the company is not interested in "basic" research, but perceives the need to apply technology to remain competitive through cost reduction and product innovation. Thus the five "research" laboratories within the Materials Research Division serve production activities: manufacturing, design of cars, process engineering, quality control and analytical services. In addition to the Metals Research Laboratory, there are laboratories related to Chemical Research (organic and inorganic materials), Rotary Engines (mostly materials research for these engines), Analysis and Administration. Approximately 200 people are employed by the Materials Research Division. Activity is divided 50-50 between service and research.

The Metals Research Laboratory has groups working in metal forming, casting, heat treatment, surface treatment, mechanical properties (fatigue wear, etc.), NDT, heat resistant materials, corrosion and powder metallurgy. Dr. Matsui and his colleagues described several problems which are currently active, as follows:

1) Night crying failure:

This refers to a cracking problem with high strength steel wheel bolts and propeller shaft flanges. Although these steel bolts and flanges (80-120 $kg/mm^2$) are installed and tightened without incident during car assembly, they often crack overnight, with an accompanying noise or "cry". During discussions it became clear that the problem is simply delayed hydrogen failure. Hydrogen is introduced during manufacture, probably during pickling, plating or heat treatment. Initially this appeared to cause some confusion among Mazda people in that the problem was not encountered when lower strength items were subjected to the same process, a reminder that steels become far more sensitive to hydrogen at high strength levels. Subsequently a review of a previous paper (Met Trans *3*, 1169, 1972) appeared to clarify this issue.

2) Cyclic fatigue problems:

There are apparently cyclic fatigue failures occuring with 80 to 120 $kg/mm^2$ steels which are not well understood. Again a hydrogen cause of failure was suggested, because the erratic behavior appeared in zinc-plated steel parts.

3) Corrosion problems in marine engines:

A corrosion problem exists with pans for marine engines. For economy, a cast iron pan is used, 7mm thick. The laboratory is studying the application of spray coatings of aluminum in thicknesses to 0.2 mm. to protect the cast iron pans from saltwater and salt air corrosion. Accelerated tests to date give promising results.

4) Combined corrosion/wear problems in the rotary engine:

According to Dr. Matsui and others, the problems of wear and corrosion in rotary engines are not adequately addressed in the literature. What is needed are data which directly relate the performance of the metal in engines to the lubricant, contact pressure, gaseous environment, combustion deposits and other influences. At Mazda, engine tests include determinations of weight loss, surface roughness, friction coefficient change, etc. A great deal of work over a long period has established correlations between laboratory tests and the service condition. Mazda regards this data as more useful than "basic" research data in the literature.

It is of special interest that Mazda has learned (the hard way) that the results of the engine and laboratory tests are sensitive to the skill of individual technicians. Thus the ability to correlate engine performance to laboratory tests depends on the skill, experience, intelligence, motivation, etc. of the individual making the laboratory tests and interpreting the results. One current high-priority effort at Mazda is to refine test procedures and standards to minimize this human factor.

A specific item of interest to metallurgists and technologists is that rotary engine seals are made of chilled (white) cast iron. Thus an ancient material competes successfully to this day.

Mazda was dismayed at the 1973 statement on the fuel economy of the rotary engine. Before the oil crisis the emphasis in the U.S. was on cleanliness, afterwards on fuel economy. The tests for fuel economy were conducted on a rotary engine adjusted for cleanliness; hence, the poor showing. At present, Dr. Matsui stated, an engine 40 percent improved in economy is ready. A promotion campaign is planned to overcome the previous bad (and according to Mazda undeserved) publicity and to inform the public of the excellent economy now available.

In summary, Mazda Toyo Kogyo is an excellent company which pursues materials research entirely from an applications viewpoint. A wealth of data has been accumulated which for their purposes could be more valuable than basic research studies, because they are correlated with engine performance results.

# TOYOTA CENTRAL RESEARCH AND DEVELOPMENT LABORATORIES

Toyota Central Research and Development Laboratories, Inc., was established in 1960 to provide research support for the Toyota Group companies. The current Director is Dr. Noboru Komatsu, who described the Toyota Group companies and their major interests and products as follows:

1) Toyota Tsusho Kaisha Ltd. - Exporters, importers, general merchants.

2) Toyota Automatic Loom Works, Ltd. - Spinning and weaving machinery, fork lift trucks, light trucks, automotive parts.

3) Toyota Motor Co., Ltd. - Automobiles

4) Toyota Spinning and Weaving Co., Ltd. - Cotton, woolen, synthetic yarns and fabrics.

5) Toyota Motor Sales, Inc. - Sales of automobiles and parts.

6) Toyota Machine Works, Ltd. - Grinding machines, milling machines, semiconductor strain gages, solid state devices.

7) Aichi Steel Works, Ltd. - Spring steel, bearing steel, structural steel, stainless steel, tool steel.

8) Nippon Denso Co., Ltd. - Electrical auto parts and accessories.

9) Aisin Seiki Co., Ltd. - Auto parts, drive and brake compounds, die castings.

10) Toyota Auto Body Co., Ltd. - Car and truck bodies.

The main activities of the Laboratories, many of which seem to be of interest to the Navy, are listed below:

a) Materials processing, treatment, evaluation and structural analysis
b) Applied mechanics and physics
c) Control and servo engineering
d) Combustion engines and heat transfer
e) Battery and electrochemical phenomena
f) Fatigue, fracture, wear and lubrication
g) Chemical and instrumental analysis
h) Radioisotope technique
i) Electronics and optics
j) Environmental and pollution control
k) Sensors, including semiconductor strain gages
l) Computer applications

Research programs and decisions are generated in the manner outlined in Chart 1. It is of interest that research proposals are a dual effort of administrators and research scientists and engineers. The needs for the research both inside and outside the Toyota Group are considered and there are extensive communications, contacts and surveys to assess what is new and what is ready for development within the capability of the Laboratory.

Following Dr. Komatsu's review of the managerial approach and research interests of the Toyota Laboratories, a one-hour talk on the materials research activities of ONR-NRL was given. Three selected presentations on research activities at Toyota followed, and these are described below:

1. Dispersion Strengthened Alloys for Electrode Tips (Dr. Yamada) - Dr. Sen-ichi Yamada and N. Komatsu have developed copper alloys for service, among other applications, as electrode tips for spot welding. The alloys feature the double effects of solution and dispersion hardening in internally oxidized Cu-1Al alloys with additions of Ag, Pd, As and In. The high strength is retained up to 1050°C. The basic research leading to the development has been published in a series of papers in the Japan Institute of Metals Journal, beginning in 1972. The development is now regarded as ready for commercial sales following completion of the research last year.

2. Semiconductor Strain Gages and Their Application (Dr. Igarashi) - Dr. I. Igarashi and T. Chiku describe a "Subminiature Three-Directional Accelerometer: An Application of Semi-conductor Strain

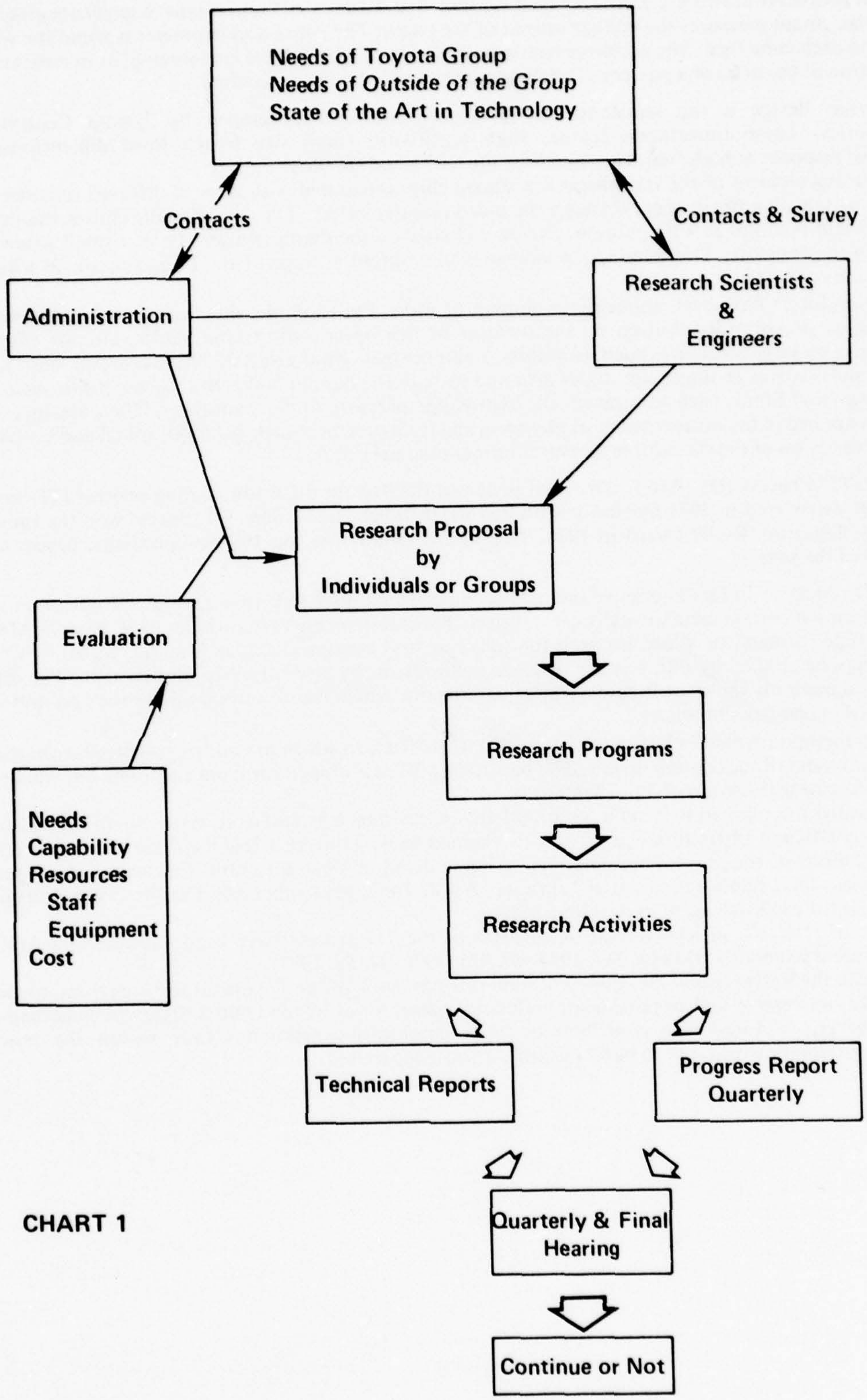
Needs of Toyota Group
Needs of Outside of the Group
State of the Art in Technology
Contacts
Contacts & Survey
Administration
Research Scientists & Engineers
Research Proposal by Individuals or Groups
Evaluation
Needs
Capability
Resources
Staff
Equipment
Cost
Research Programs
Research Activities
Technical Reports
Progress Report Quarterly
Quarterly & Final Hearing
Continue or Not

CHART 1

Gages" in Instrument Society of America Transactions, Vol. 9, No. 2, p. 119, 1970. Basically three orthogonal cantilever beams are used, to which 1.7 mm × 0.2 mm × 0.3 mm p-type Si gages are attached. A half bridge circuit measures the voltage output of the gages. The entire accelerometer is about the width of a dime on each cube face. The accelerometers are useful in human factors engineering, as in measuring the acceleration of the head of a passenger upon impact in a simulated car accident.

A similar device is the semiconductor pressure transducer developed by Toyota Central R&D Laboratories. These transducers feature high sensitivity, small size (match-head dimensions), low hysteresis, response at high frequency and long life with good stability.

The sensing element of the transducer is a silicon chip, integrated with a set of diffused resistors which perform as sensitive strain gages through the piezo-resistive effect. The center of the chip is thinner than the edges and operates as a diaphragm. Pressure change on the diaphragm produces a small strain and a change in the resistors. This produces a change in the output voltage of the bridge circuit to which the resistors are connected.

The transducers have been applied in a number of ways. For example, they have been used to measure aerodynamic pressure distribution on the surfaces of helicopter and turbine blades, aircraft wings and bodies, and on large structures such as buildings and bridges (wind effects). They have also been used to measure pulse waves at finger tip, upper arm and neck in the human body. In this case a silicone oil contained in a vinyl film is used to transmit the hydrostatic pressure to the transducer. The transducers have also been applied in the measurement of physiological fluid pressures such as blood, spinal and ventricular. Another variation of the transducer measures intracranial pressures.

3. The TD Process (Dr. Arai) - Dr. Arai reviewed the Toyota diffusion coating process (TD process) which was discovered in 1971 but has been under development since. The TD process won the Industrial Research Magazine IR-100 award in 1976. This award honors the top 100 new products, processes and materials of the year.

The TD process is in fact a series of related processes which serve to form a carbide, boride or alloy surface layer on a substrate metal, usually carbon steel. The layers formed are carbides of V, Nb, Cr, Mn, and other carbide formers, or alloys between the substrate and elements such as Mn, Al, Si, B, or Cr. The coating may be applied by dip, powder or paste methods, or by electrolysis in molten salts. The dipping method is apparently the most fully developed and the one which was discussed during the visit and which is described in company brochures.

The dip method involves a borax solvent at 800 to 1050°C, to which are added powdered carbides, ferroalloys or oxides of the coating metals. The part to be coated is dipped for from 1 to 10 hours, which gives the desired coating thickness of 5 to 15 microns.

The coatings are reputed to excel in wear and seizure resistance as well as to resist corrosion and oxidation. The coefficient of friction against steel is claimed to be 20 percent less than that of hardened steel. The applications of the process are described in some detail in Toyota Central Research & Development Laboratories, Inc., publications dated February, April, June, September and October 1976. Mitsui and Co., Ltd., is the exclusive agent in the United States.

A series of scientific articles on various aspects of the TD process have been published by Arai and others in recent issues of JJIM (*39*, 247, 1975, *40*, 925, 1976, *41*, 68, 1977).

In general, the Research and Development Laboratories, Inc., of the Toyota Group are typical of similar wide-awake, aggressive and opportunistic industrial laboratories in the United States. It is perhaps too easy, however, to forget the contributions such laboratories make not only within the practical engineering-military world, but to basic scientific knowledge as well.

## TOSHIBA TOKYO SHIBAURA ELECTRIC CO. LTD. RESEARCH AND DEVELOPMENT CENTER, METALS AND CERAMICS LABORATORY

The Toshiba Research and Development Center in Kawasaki was organized into its present form in 1961. There are approximately 1680 employees at present (double the number in 1961) of whom about 800 are professional level, and 100 hold doctorates. The center is composed of ten specialized laboratories. The laboratory visited was the Metals and Ceramics Laboratory, which is grouped into (1) electric and magnetic materials, (2) structural materials and (3) ceramics and glasses. Other laboratories are concerned with chemicals, electron devices, integrated circuits, electronics equipment, information systems, consumer products (appliances, radio), nuclear and electrical engineering, mechanical engineering and microwave electronics.

The Metals and Ceramics Laboratory, under the direction of Dr. Y. Yoshida, is divided into six sections. The Electric and Magnetic Materials group is concerned with magnetic, superconducting and electric materials. The Structural Materials Group is concerned with corrosion resistant metallic materials, high temperature metallic materials, fiber reinforced composite materials, powder metallurgy and nuclear reactor materials. Stress corrosion cracking is a serious concern of this group at present. The Metal Processing and Evaluation Group evaluates materials and their processing and control. The Special Ceramics Group looks at ceramics for high-temperature applications and as ionic conductors. The Glass Group studies glass fibers for optical and electronic communication as well as glass manufacturing processes. Finally, the Electronics Ceramics Group studies ferrites, piezo-electric materials, nonlinear resistors, surface wave materials and the processing and manufacturing of these materials.

The visit began with a historical overview of the organization by Dr. S. Chiba, substituting for Dr. Y. Yoshida who was in the United States at the time of this visit. A brief movie was shown which indicated activities of the organization in the area of water purification (by ozone), ultrasonic diagnostics, ion implantation, light emitting diodes, silicon solar cells and in the development of the so-called "silentalloy." The latter is an iron-base alloy with unusually large damping capacity and is useful where noise and vibration must be suppressed.

Individual discussions followed a presentation on NRL-ONR interests. Mr. M. Hishada discussed some of his work on stress corrosion cracking of stainless steels. He is studying the corrosion of type 304 stainless at constant strain rate ($8.3 \times 10^{-7}$ to $10^{-5}$) in high temperature water (209°C). According to Hishada, an accelerating environment such as boiling magnesium chloride is not predictive in the case of high temperature water and therefore the autoclave tests are necessary. The results indicate that stress corrosion cracking takes place only when two conditions are satisfied: the water must contain dissolved oxygen and the steel must be sensitized. Either condition alone does not produce cracking.

Hishada has recently spent a year in the United States studying with ONR contractor R. Staehle at Ohio State University. Three papers by Hishada (with H. Nakada) have been submitted to NACE entitled, "Constant Strain Rate Testing of Type 304 Stainless Steel in High Temperature Water," "An Investigation of the Chloride Effect on Stress Corrosion Cracking in Constant Strain Testing of Type 304 Stainless Steel in High Temperature Water," and "Critical Cooling Rate of 18Cr-8Ni Stainless Steel for Sensitization and Subsequent Intergranular Stress Corrosion Cracking in High Temperature Water."

Mr. I. Watanabe described current work on the carbide reactions in heat-resistant steels. He hopes to relate microstructural observations to predictions of life and residual life of materials in high-temperature service. Specifically, he is trying to estimate (1) the effects of carbide spacing and size on creep rates and (2) the effects of solid solution strengthening of the matrix, as this is influenced by the effects of alloying elements in the matrix on carbide solubility. The prevention of stress corrosion cracking through studying the means to impede depletion of chromium in the grain boundary region is also under study.

Watanabe studies in situ each carbide particle with respect to composition and local chemistry, using X-ray analytical procedures. Carbide morphology is studied by extraction replica techniques. Watanabe was cautioned that his goals are difficult to achieve. Predictions of long-term performance on the basis of structural features have been less than totally successful.

Mr. A. Tsuge next described some of the company's activities in nitrogen ceramics. The major achievement claimed is a high-strength $Si_3N_4$ material with a $Y_2O_3$ additive to promote sintering. A flexural strength of 120 ksi at 1400°C is claimed. The material can also be water quenched from 1000°C without damage. According to Tsuge, the addition of rare-earth elements such as yttria and alumina to silicon nitride (followed by sintering) is the secret. The rare earth additives increase the high temperature strength of the ceramic material by combining with $Si_3N_4$ to form $Si_3N_4.Y_2O_3$, which is very resistant to heat. The grain boundary phase in the improved materials is crystalline, in contrast to the glassy phases which form with MgO additives. The $Y_2O_3$ additive also produces a change in fracture mode from intergranular (with MgO) to transgranular at elevated temperatures. The new ceramic is expected to have wide application in gas turbine blades and vanes, heat exchangers for high temperature gas reactors, seals in rotary engines, gas bearings and in crucibles for molten metals. Background material for this development is published in J. American Ceramic Society *58* No. 7-8, 323, 1975; J. American Ceramic Society *57* No. 6, 1974; Toshiba Review No. 92, July 1974.

The visit concluded with a visit to the Toshiba Science Institute. This is essentially an elaborate exhibit intended to give the viewer a preview of the electronic world of the future (TV telephones, trains without wheels, etc.). Toshiba seems to be aggressive, alert, working hard, and generally in tune with the latest in technology which applies to its interests.

## TOSHIBA TOKYO SHIBAURA ELECTRIC CO. LTD.
## HEAVY APPARATUS ENGINEERING LABORATORY

Under the guidance of M. Arii, Manager of the Plant and Equipment Engineering Department, Atomic Power Division, a visit was made to the Metals Engineering Group of the Heavy Apparatus Engineering Laboratory of Toshiba. Arii was formerly head of the Heavy Apparatus Engineering Laboratory.

The visit began with a tour of the laboratory, located at Tsurumi, Yokohama. The laboratory is composed of several groups. One group studies the techniques for electrical insulation. A second group is involved with metallurgical engineering. Studies of interest involve SEM studies of fatigue striations, acoustic emission, zone refining equipment and TIG welding developed for ultra-high precision parts. A third group is concerned with wastewater treatment engineering. A fourth group is concerned with atomic power equipment engineering. Examples are: mock-up of fuel handling device for fast breeder reactor, electromagnetic pumps for liquid sodium, bellows type vacuum vessels for experimental nuclear fusion devices and mock-up of plasma experimental devices. Another group studies electrical machinery engineering. Featured are an anechoic room, hydraulic vibration machines for earthquake strength tests and large thrust bearing testing equipment. A hydraulic machinery engineering group features a high-head test stand for pump-turbines, a data processor for model tests of water turbines and a 5-axis numerical controlled machine to machine turbine blades of precise configuration.

On the tour an assortment of enormous, impressive equipments were observed, as follows:

1. A steam turbine generator coil winding shop. Generators (steam turbine) to 1000 million watts were seen in production.
2. Direct current motors for shipment overseas, mostly to steel companies were seen in production. These range in size from 700 to 7300 KW. They were destined for such diverse places as Crete, Venezuela and Cleveland, Ohio.
3. A welding shop was seen which produces welded components for water turbines. Stock up to 6 inches thick was being welded from 80 $kg/mm^2$ steel by electroslag welding.
4. Truly giant water-turbine machinery for hydroelectric power facilities was being fabricated. The water turbines were fabricated of 13 percent chromium stainless steel.
5. Most welding is $CO_2$ arc welding, but special problems involve MIG, TIG and electroslag welding. A 31 MeV Betatron is used to test welds.

A study of stress corrosion cracking susceptibility of 304, 316, 316C and 347 stainless steels was described. Test selections are 4 inch diameter, 8 mm thickness pipes containing three-welded joints. Loads are either tensile, up to 75 ton, or 4-point bending. The pipes contain water at 75 $kg/cm^2$ pressure and 290°C temperature. Cyclic loads are used, at a rate of zero to maximum once or twice a day.

Acoustic emission studies are being conducted on large pipe sections which contain a machined notch. The notch, 0.3mm thick, 16mm deep and 19mm wide, simulates service conditions for a feed water nozzle of the BW reactor. Fatigue loads are related to notch extension. The particular test piece observed had endured 100,000 cycles at a rate of 6 or 7 cpm. The acoustic emission detector is a Dunegan Model 1032, obtained from the USA.

A biaxial stress test apparatus and specimen was seen. The specimen is cruciform and costs $3000. A saw cut notch is placed at various orientations within the specimen center. A creep gage is inserted in the notch. The idea is to determine whether the $K_{Ic}$, slip or, J-integral criteria for fracture apply to biaxial fracture.

Studies of creep-fatigue interaction are underway, with the goal of supplying essential data for the FBR at 650°C.

Dr. Arii serves with Dr. Iida of Tokyo University in setting up an International Symposium in Tokyo on 25-27 September 1978 on Criteria for Service Fracture of Welds and Welded Structures. This meeting, sponsored by the Japan Welding Society and the Japan Academy of Sciences, will feature welding, metallurgy, identification of defects and in-service inspection.

Individual discussions were arranged on the subjects of stress corrosion cracking of stainless steel, fracture mechanics and the application of high strength steel (HT 80) to the casings of hydraulic pumps. The substance of these discussions follows:

1. Stress corrosion of stainless steel—Toshiba is interested in short term countermeasures to improve welding procedures but is also interested in long term countermeasures for problems which may develop in BWR plants. They are therefore studying corrosion cracking in constant strain rate tests and constant load tests and are involved in the pipe tests described previously.

Some principal achievements have been quantitative chemical characterization of sensitization, and the use of flowing water in the pipe during welding (after the first pass) to produce compressive residual weld stresses at the weld inside the pipe (a short term countermeasure proposed by IHI).

Another achievement has been the development of weld cladding prior to butt welding of pipe. The process permits the retention of sufficient delta ferrite to impede stress corrosion cracking and the heat affected zones can be solution treated.

2. Fracture mechanics—This work originated from tests on turbine generator rotor forgings. These were spin burst, deep notch tests and $K_{Ic}$ tests. Acoustic emission monitoring suggested that crack growth was not always related to the direction of maximum stress. Tests were therefore conducted under conditions of biaxial stress, as described earlier. The results indicate that indeed both the values of $K_I$ and $K_{II}$ must be evaluated to get the true fracture resistance, because the flaw growth direction is not always perpendicular to the direction of maximum stress.

3. Heavy thickness high strength steel for pump casings—The primary interest here is for nuclear pumps. The discussions were on the resistance of high strength steels to crack propagation in gaseous hydrogen as well as to other sources of embrittlement.

The substance of the interest of the Heavy Apparatus Laboratory is contained in several publications which have appeared in recent years. Plane strain initiation of brittle fracture in rotor forgings is discussed in Mechanical Behavior of Materials, Proc. of the 1971 International Conference on Mechanical Behavior of Materials, Vol. V, 1972, p. 407. A correlation of fracture toughness by the spin burst and deep notch test is described in Theoretical and Applied Mechanics, *21*, University of Tokyo Press 1973. The fatigue strength of HT 80 spiral castings for hydraulic pump-turbines is given in IIW Doc. XIII-728-74. Slow crack growth and acoustic emission characteristics in the COD test are described in Engineering Fracture Mechanics, 7, 551 (1975).

The Heavy Apparatus Engineering Laboratory is obviously current and keenly aware of practical problems and the shortcomings of current laboratory predictive capabilities with respect to crack growth, fatigue and fracture.

## HITACHI, LTD.

The Hitachi Research Laboratory in Hitachi is one of six large research laboratories of the company, all of which report directly to the President and Board of Directors. The Hitachi Research Laboratory (HRL) became an independent laboratory in 1939 and in 1962 the present main building was constructed on the Mikanohara Plateau, a beautiful site which overlooks the Pacific Ocean to the East and mountains to the West.

Dr. Toshio Doi, Deputy General Manager, first outlined the organization of HRL and described briefly also the other five major laboratories. The other five laboratories are:

1. Central Research Laboratory (Tokyo)
2. Mechanical Engineering Research Laboratory (between Hitachi and Toyko)
3. Atomic Energy Research Laboratory (Kawasaki)
4. Production Engineering Research Laboratory (Yokohama) and
5. Systems Development Laboratory.

The total number of people working in the six laboratories is about 4000. The Hitachi Research Laboratory employs 1600.

The research fields covered at HRL include energy, information processing and control, industrial machinery and transportation, and environmental control. Materials research is related mostly to heavy electrical machinery. A close relationship with the company manufacturing works is maintained to assure feedback and prompt application of research results. In fact, HRL maintains branch laboratories at eight of the various works to assure close liaison. The various Works sponsor 75 percent of the research; the remaining 25 percent is sponsored by the corporate head office. Hitachi spends 200 million dollars a year on research and development, with about 30 million of this going to HRL.

Brief introductions to the Fifth Department and the Third Department were given by S. Kirihara, and S. Kusumoto, respectively Senior Researcher in the Fifth Department and Manager, Third Department. These Departments are the two which were visited, although there are approximately 11 Departments at HRL covering materials aspects in the electrical, mechanical, materials, nuclear and environmental areas.

The Fifth Department is active in a number of areas concerned with metallurgy and welding, as follows:

1. Corrosion resistant materials—problems of stress corrosion cracking in stainless and other steels for steam and water turbines and nuclear power plants.
2. Heat treatment of structural materials—heat treatment for structural improvements as well as surface treatments and coatings.
3. Function materials—these are electrically conducting, superconducting and contact materials.
4. Welding
5. Physical metallurgy—ultrahigh strength maraging steels.
6. Weldability—the weldability of alloys as contrasted to welding techniques.
7. Forging and casting—applications for water and steam turbines, large and heavy forgings and castings.

Several achievements were cited for the Fifth Department. First a multifilament $Nb_3Sn$ superconducting material has been developed. The diameter is 0.74 mm and consists of seven strands, each with 331 fine ($\approx 8\mu m$) niobium filaments, embedded in a copper and bronze mixed matrix. Each niobium filament has an $Nb_3Sn$ filament of about $1\mu m$ thickness at the surface developed by the selective diffusion method. Good features claimed are:

1. instrinsic stabilization
2. bendability and
3. low electric resistance at low but not superconducting temperatures from the mixed copper-bronze matrix.

A second accomplishment is the development of 300 kg/mm² maraging steel. There was no specific discussion of this, but several papers were given relating to strengthening by control of

1. solution treatment (JIM *62* No. 8, 59, 1976).
2. grain size (JIM *62* No. 2, 56, 1976), and
3. cold working and aging (JIM *62* No. 9, 101, 1976).

The third achievement cited was the high abrasion-resistant A1-Si alloy. This alloy combines the strength of duralumin with greater abrasion resistance. The alloy is formable, weldable (TIG and MIG), machinable and resistant to SCC in solutions containing chloride ions. No reference works were obtained, but Hitachi has produced brochures.

The fourth achievement is the extension and application of fracture mechanics to production machinery. A series of papers by S. Kusumoto and others develop critical analysis and evaluations of the stress intensity factor, including the development of the three-dimensional stress intensity factor by the finite element method (see JPHN *13* No. 6 1975; Proc. 1974 Symposium on Mechanical Behavior of Materials, Kyoto; Proc. JSME-ASME applied Mechanics Western Conference, March 1975, Honolulu).

The fifth accomplishment cited is the development of various welding techniques and their applications. These are deep-penetration electron beam welds, electroslag welds and the soldering of microelectronic components. A series of papers dealing with electron beam welds appear in JIM *42*, 32, 1974; JIM *44*, 33, 1975; Proc. Second International Symposium, JWS, Osaka, 1975. The latter reference also includes papers on problems and improvements in large heat input electroslag welds.

The main subjects of interest to the third department, as outlined by Mr. S. Kusumoto fall into three areas. Area one is strength of materials, vibration and noise. Area two is rolling mill control and area three is robots for welding and painting.

Area one includes the structural integrity of nuclear power plants. This involves a three-way thrust at:

1. non-linear stress analysis and fracture mechanics,
2. X-ray stress analysis and fractography, and
3. the creep fatigue, stress corrosion cracking and delayed hydrogen cracking of structures.

Structural reliability of rotating machinery involves similar concerns, but with greater emphasis on vibration problems and less on environmental effects. The structures of interest are pipes, pressure vessels, runners and castings for water turbines, coils, tanks and cases for transformers, elevator and home appliance structures.

A number of papers were discussed which document the work being done. Brittle fracture characteristics of weld joints in 60 kg/mm² and 80 kg/mm² steel are described in one series of articles by S. Sasaki and coauthors (see JWS *45*, 56, 1976; JWS *44*, 54, 1975; JWS *44*, 47, 1975; JWS *44*, 22, 1975). The same group has published on the effects of prestrain on the fracture toughness of S35C steel, a steel used for mill roll working table rollers (JIM *62*, 93, 1976).

A whole series of papers has been written on welding cracking problems: "Effects of Weld Heat Impact on Weld Cracking and Restraint Stress" (IIW Doc IX-957-76), "Effects of Restraint Stress on Delayed Cracks in Welds of 80 kg/mm² High-Strength Large Gauge Plate Steel" (IIW Doc IX-735-71), "Effects of Restraint Stress and Intensity of Restraint on Delayed Cracks in the Welds of 80 kg/mm² High Strength Thick Plate Steel" (IIW Doc IX 784-72), "Effects of Restraint Intensity on Delayed Cracks in the Welds of High-Strength Steel" (IIW Doc IX 346-73), "Determination of Preheating Temperature for Crack Prevention for High Strength Steel Weld" (IIW Doc IX 875-74), and "Studies of Delayed Crack in Welds of High-Strength Steels—Correlation for Method of Various Weld Cracking" (IIW Doc IX 956-76).

An equally impressive series of papers has been written by H. Ouchida, Chief Engineer, HRL, with several coauthors on the subject of fatigue in pressure vessel materials with cracks and without cracks and in the welded zones. Without attempting to list all these papers, the interested reader is referred to Bulletin JSME 18 No. 119, May 1975; JWS *17*, 1975; JSME *18* No. 125, Nov. 1975; JSME, *17* No. 103 Jan. 1974.

In the nuclear field Kutsumoto and others have presented papers on internal pressure fatigue rupture of the fast reactor fuel cladding (Type 304) and on the effects of hydrogen content temperature and crack configuration on fatigue crack propagation and unstable fracture in Zr-2.5Nb pressure tubes. Both papers were presented at the 2nd International Conference on Structural Mechanics in Reactor Technology, Berlin, 1973.

Y. Nakagawa and T. Tamamura studied the effect of steel hardenability on the residual stresses developed during heat treatment and reported a significant effect (Proc. 1973 Symposium on Mechanical Behavior of Materials, 1973, Society of Material Science, Japan).

In connection with residual stress determinations, discussion with M. Nagao on a white X-ray system for measuring residual stresses was interesting. Claims for the system are generous. These are for the non-scanning white radiation machine as follows:

1. Short time exposures of 3-4 minutes are sufficient. Inaccessible surfaces such as at the roots of gears can be reached.
2. All varieties of metals can be measured.
3. High temperatures (to 500°C) are permitted.
4. X-ray fractography can be performed. A high intensity beam can be generated which penetrates to the depths of the plastic zones. It is therefore possible to study the history of a fatigue crack, looking at the fracture surfaces.

For example the number of cycles can be determined.

This development has been described in several papers, along with several special applications. This development may be important so a few of the key papers are listed, as follows:

1. N. Nagao and V. Weiss (Syracuse University), "X-ray Diffraction Study of Low Cycle Fatigue Damage in Plain Carbon Steel," ASME paper No. 76-WA-Mat-10.
2. H. Ohuchida, A. Nishioka and M. Nagao, "X-ray Detection of Fatigue in Corrosive Environment," Thirteenth Japan Congress on Materials Research-Metallic Materials.
3. H. Ohuchida, T. Iwasaki and M. Nagao, "Size Effect on Fatigue of Annealed Carbon Steel (X-ray Investigation on the Detection of Fatigue Damage in Machine Parts)," Proc. 14th Japan Congress on Materials Research, Kyoto, 1 1971.
4. M. Ogasawara, M. Adachi, M. Nagao and Voker Weiss (Syracuse University), "Crack Initiation at Notches in Low Cycle Fatigue," Proc. 1973 Symposium on Mechanical Behavior of Materials, Japan, 1974.
5. H. Ohuchida, A. Nishioka and M. Nagao, "Size Effect on Fatigue Strength of Machined Carbon Steel (X-ray Detection of Fatigue Damage in Machine Parts)," Bull. JSME *16* No. 94 Apr. 1973.
6. M. Nagao, S. Kusumoto and Y. Ito, "Non-destructive Sub-surface Distribution Measurement of Physical Quantities—an Application of Poly-chromatic X-ray Technique," Society of Materials Science *26* No. 280, 18, January 1977.
7. A detailed description of the polychromatic X-ray stress analysis system is presented in the Proc. 25th Sagamore Materials Conference, 1976, U.S.A.

The tour of the HRL revealed the usual equipment which has become familiar in tours of a series of steel companies, ship building companies and electrical companies. The concerns are with welding, fracture (especially in large sections), corrosion, corrosion fatigue cracking and fatigue cracking. Taking the tour in order, the following were seen:

Corrosion tests for the BWR plant. Five loops are available. One loop tests SCC under various conditions of flow (0-3-1/min), temperature (to 300°C) and percentage of oxygen in the water (0-36 ppm). Another loop tests for general corrosion. Other loops introduce variables such as temperature, pH, the proportions of oxidizing and reducing species, and differential pressure. One system tests for general corrosion in high temperature water and the effects of electrochemical potential on this high temperature corrosion.

The usual 1000 ton machine for study of low-cycle fatigue was seen. Tests are being run at 1/3 scale, 3-5 cpm, up to 20 kg/mm². The current tests are for water turbine components. A 2800 ton test rig is used to study delayed fracture in welds, lamellar tearing, hot cracking and stress-relief cracking. The same rig tests for defect influences and fracture toughness in brittle fracture. A rigid restraint weld cracking tester measures the stresses developed in welds; the capacity is 400 tons.

The high temperature laboratory has over 140 creep testing machines. Under test are superalloys and other high-temperature alloys. One machine has a capacity of 50 tons at a temperature of 1380°C. This machine is engaged in tests of Cr-Mo-V steels and stainless steels. Creep-crack growth type tests with fracture mechanics type specimens are underway. Low-cycle high temperature tests are also going on. The interaction of static and dynamic fatigue is a subject of current study. The available equipment can provide a variety of fatigue-creep load configurations. Tests can also be conducted in liquid metals.

Stress-corrosion tests of 4 inch diameter welded pipe were described. These tests are almost identical to tests going on (and described previously) at Toshiba Electric Company. Basically the tubes contain water at 290°C and 70-75 kg/cm² pressure. Welds of the pipes are introduced. The pipes are tested in tension and in 4 point bending, and in fatigue. The material is 304 stainless steel.

The general impression is that HTL is a truly first-class laboratory. Only a fraction of the activity could be flavored in a one-day visit, but enough could be seen to confirm the excellence of the organization. Fortunately, there are obvious interactions with the USA underway, notably with Syracuse University. The interaction of Hitachi with the Office of Naval Research is certainly worthy of increased emphasis.

## HITACHI ZOSEN
## (Hitachi Shipbuilding and Engineering Co., Ltd.)

Hitachi Zosen (Hitachi Shipbuilding and Engineering Company, Ltd.) has grown since being founded in 1891, into another giant Japanese company. employing upward of 25,000 people. The main products are 1) ships (passenger, cargo, ore, oil, LPG, naval craft, hydrofoil boats), 2) ship repair and remodeling, 3) ocean development equipment (oil drilling equipment, pipe laying barges, etc.), 4) marine engines (diesel, steam turbines, boilers, etc.), 5) machinery (steel rolling mills, cranes, hydraulic presses, etc.), 6) steel structures (bridges, stacks, penstocks, towers, etc.), 7) environmental equipment (incinerators, anti-air pollution equipment, etc.) and 8) castings and forgings.

The Technical Research Institute of Hitachi Zosen was established in 1949 and is the "corporate" research laboratory. The mission is to improve conventional technology and product quality as well as to develop new technology and new products. As outlined by Dr. Eng. Shojiro Okada, Director of the Technical Research Institute, 50 percent of the effort is problem solving, 25 percent is seeking technical alternatives, 20 percent is finding new markets using present techniques and 5 percent is seeking new markets through new technology.

There are about 280 people at the Technical Research Institute of whom about half are professional technical level. The budget runs at about 7 million dollars per year which is distributed among several research departments. The No. 1 Department, headed by Dr. Eng. Seizou Watanabe was the only department visited because this department conducts most of the materials work. However, the Sakai Department studies yard applications of welding techniques. The No. 1 Department studies welding, coating and painting, properties of industrial materials, materials tests and process metallurgy.

The visit began with a presentation on the activities of ONR and NRL in the materials area. This was followed with a Hitachi Zosen movie and discussion on the welding and testing of pressure vessels. The movie illustrated, through unnotched and notched fatigue tests on a 30 ton welded pressure vessel, that the new Hitachi Zosen electro-slag welding process (HINES welding method) produces better welds of thick plate than shielded arc welding. Since HINES is an automatic process the speed is also much greater. The development came about following difficulties in welding 80 $Kg/mm^2$ high tensile steel. The high heat input required causes upper bainite to form and this becomes brittle on slow cooling. Therefore manual welding was formerly required to provide faster cooling rates. The HINES welding method quenches the welded part by forced cooling immediately after electroslag welding, and follows with an immediate temper.

The next discussions were on some interesting alloy development work which has produced a series of so-called HZ alloys. A brief description of these follows:

1) CE-1 - a cavitation and erosion resistant alloy of copper, aluminum and berylium (Cu-8Al-1 Be nominal composition). The alloy may be further hardened to give very good wear resistance. The major application is high speed marine propellors where the cavitation problem is severe. In this respect the HZ-CE alloy is far sûperior to Mn-bronze and Ni-Al-bronze, according to Hitachi Zosen test data. The alloy is apparently commercially available and has previously been tested by the U.S. Navy (NAPL by D. Kallas).

The improved cavitation resistance is attributed to the development of a very fine beta phase and an alpha phase which is strengthened by the presence of berylium. The beta phase contains some K phase.

2) CE-3 - this is a filler material for inert gas welding (TIG, MIG) of the CE-1 material. Weldability is good, cavitation-erosion resistance is outstanding and the mechanical properties are good. Corrosion resistance in a number of media including saltwater is excellent. Overlay of parts produces outstanding wear resistance. For example, overlay on a nickel-aluminum bronze propellor for a small hydrofoil boat resulted in spectacular improvement in cavitation resistance as measured by weight loss and by visual inspection.

3) HZ-CM - a copper base alloy used for molds in the continuous casting process for steel. This alloy contains nickel and silicon. The alloy is strong at high temperature and is a good heat conductor.

4) HZ-CL - a nickel base alloy (Ni, 15-30 Mo, 1-5 W, 1-4 Cu, <5 Fe, <2 Cr, <2 Co, 0.5 Ti) with very high corrosion resistance to HCL, $H_2SO_4$, NaOH, $H_3PO_4$, HF and organic acids. In addition the alloy is forgeable, weldable and castable and can be drawn. The alloy is similar to Hastelloy but the weld HAZ zones are precipitate free and hence more corrosion resistant.

The HZ-CL alloy is also useful as a submerged arc weld wire for 9 percent nickel steels. The alloy Ni, 15-30 Mo, 1-5 W, 1-4 Cu has been licensed for manufacture by Nippon Steel as a weld wire for submerged arc welding of pressure vessels, LNG tanks, etc. A cooperative agreement is also being arranged with Chicago Bridge and Iron Co.

5) HZ-SO - a lead base alloy resistant to $H_2SO_4$. The addition of a small amount of Te or Se, is the means of conferring resistance greater than that of pure lead.

6) HZ-PO - an alloy resistant to phosphoric acid and generally useful in chemical plants where wet process mechanical action is involved. The alloy is composed of Fe, 38-40 Ni, 20-23 Cr, 7.5-8.5 Mo.

7) HZ-80C - a low alloy steel used in casting K and Leg bracing for off-shore and undersea structures of 80 $Kg/mm^2$ steel (welds at regions of high constraint are thereby avoided). The composition of the alloy is patented. As quenched and tempered, the steel is resistant to stress corrosion cracking. At the present time research is underway to develop a similar steel at the 100 and 130 $Kg/mm^2$ strength level.

The company is very active in studies of NDE techniques, with emphasis on acoustic and ultrasonic monitoring of large pressure vessels. A multi-probe tandem technique involving many transducers has been developed for the ultrasonic inspection of very thick steel plates. A prototype has been made but there is not commercial availability.

Much of the technical progress cited is described in company brochures, but there are also published works in the literature and in company technical journals. The low-temperature fatigue behavior of weld joints of 9 percent nickel steel is described, for example, in IIW DOC. XIII-649-72. A study of fatigue crack growth in 9 percent nickel steel plate appears in Engineering Fracture Mechanics, *7*, 481, 1975. A strain energy release rate relationship to the increase in area of a surface crack subject to fatigue was established.

A series of reports have been issued on the subject of pressure vessels and piping. See Hitachi Zosen Technical Reports HTZR-PVP-1 through HTZR-PVP-7. These reports deal with design, fatigue tests, fabrication, quality assurance, etc. One paper (HTZR-PVP-4) discusses the means of preventing hydrogen-induced cracking of weldments, in terms of the preheat and postheat conditions required before cooling the weld metal to 100°C.

Several recent papers in the Hitachi Zosen Technical Reviews are in the materials area. One article is on the adaptability of calorized steels to hydrogen sulfide at high temperatures (*37*, No. 1, 8, 1976). At 600°C the coatings are resistant to corrosion in $H_2S$ but are very brittle and thermal shock resistance is poor. Coated welded joints are not corrosion resistant.

In a latter issue (*37*, No. 4, 1, 1976) the question of wear and seizing of flake graphite cast iron (as cylinder liners, piston rings, etc.) is addressed. A harder matrix improves seizing resistance. Vanadium additions also improve seizing resistance while copper and chromium improve wear resistance but deteriorate seizure qualities. Another paper (*37*, No. 4, 10, 1976) discusses the effects of carbide precipitation on the creep of 18-8 stainless steel at 700°C. The effects of the precipitation are greatest between stress levels where creep is controlled by stress and lower stress levels where creep is controlled by metallic diffusion.

In the same issue (*37*, No. 4, 33, 1976) an automatic vertical TIG welding method for 9 percent nickel steel spherical tanks is described. The alloy HZ-CL wire is used. Good welds are apparently achieved with savings of from 50 to 70 percent in weld time and weld cost compared to manual welding.

In summary, the Technical Research Institute of Hitachi Zosen appears to be one more highly efficient and practical-minded Japanese corporate laboratory. As one visits a succession of such activities, the feeling grows that they make a significant contribution to the health and growth of the parent industry as well as to all Japan.

## ISHIKAWAJIMA-HARIMA HEAVY INDUSTRIES CO., LTD.

The Ishikawajima-Harima Heavy Industries Co. Research Institute is composed of the Research Institute in Tokyo and the Welding Research Institute in Yokohama. On this occasion only the Tokyo Institute was visited, but a delegation from the Welding Research Institute was present for the discussions.

The IHI Company is so large and so diverse that a description of its activities in any detail is impossible in this brief account. IHI supplies a range of products to industries on land, sea and in the air. On the land, machinery and entire plants for such basic industries as steel, electric power, chemicals, material handling and construction are supplied. For the water, ships of every type are built including the world's largest tankers. The company also builds jet aircraft engines. In percentage of sales, land machinery plants provide 56 percent, ships 38 percent and jet engines 6 percent. Products and services are exported to 80 countries around the world. For example IHI has constructed three blast furnances (capacity 2.4 million tons annually) in Ipatinga, Brazil.

The Research Institute serves these extensive business activities with a variety of basic and applied research efforts. The work is carried out in a number of departments. These were described by Dr. T. Maeda, Associate Director of the Institute, as follows:

1) Fundamental Technology Department - physics of solids; non-destructive testing; chemical processes; catalysts and catalytic reactions; applied microbiology.

2) Structures and Strength Department - structural analyses; structural vibration; anti-fatigue design; earthquake-proof design; fracture mechanics; structures; cryogenic materials.

3) Machinery Department - machine elements (bearings, seals, gears); friction and wear; plastic working of metals; forming of plastics; vibration.

4) Fluid and Heat Department - fluid dynamics; compressors; turbines; rocket engines; diesel engines; heat transfer and heat exchangers.

5) Turbomachinery Department - centrifugal compressors; fans; blowers; superchargers; freezers and air conditioners; radial turbines; gas turbines; steam turbines; helium turbines; organic compound gas turbines.

6) Metallurgy Department - science of metallic materials; advanced casting; heat treatment; strength; toughness; fatigue (cryogenic through refractory temperatures); marine service materials; metallurgical refining processes.

7) Chemistry Department - analytical instruments; oils and fuels; lubricants; paints; corrosion; organic materials.

8) Measurement Science Group - measurement and statistical evaluation of forces; stress analysis; photoelastic studies; vibration analysis.

9) Nuclear Power Technology Department - components for nuclear reactor systems (especially liquid Na-cooled fast breeder reactor and high temperature gas cooled reactor); He technology; Na technology; materials for nuclear power components.

10) Ship Performance Department - ship resistance; ship propulsion; manueverability; seakeeping; hull vibration; propellor cavitation; hydrographical/hydraulic studies (marine structures, dams, water gates, buoys, etc.).

11) Ship Propulsion Department - ship model experiments (resistance, self-propulsion and propellor open water tests, wake and wave analysis); ship models and propellor models; prediction of propulsive performance.

12) Ship Strength Department - hull structural analysis; hull vibration analysis; design optimization; hull reliability; wave load.

13) Chemical Equipment Department - pilot plant studies of chemical industry processes; desulfurization and denitrogenation of exhaust gases; desalinization of seawater; waste utilization.

The Welding Research Institute, described by Mr. H. Okabayashi, Manager, performs welding information service and studies welded structures, welding mechanics, welding design, welding metallurgy and welding technology (common materials and special alloys). Other activities are the development of high-speed welding, automatic welding and testing and inspection of welds.

The specific groups contacted on this visit were the Structure and Strength Department and the Metallurgy Department of the Research Institute, as well as the delegation from the Welding Research Institute. Informal contact was also made with persons from other Departments who attended the lecture on ONR activities which was given in the afternoon.

Dr. M. Fukagawa discussed work on grain boundary embrittlement due to precipitation of AlN in high strength (80 $Kg/mm^2$) steels. Fukagawa and his colleagues conclude that once AlN or niobium carbonitride precipitates in the austenitic range steels became embrittled, and it is almost impossible to recover their ductility by subsequent heat treatment. Therefore production of AlN or Nb-bearing steels should utilize procedures designed to impede the undesired precipitation while cooling through the austenitic region (see Trans Iron and Steel Institute of Japan Suppl. Trans. vol. 11 1971).

One of the very active younger members of the Research Institute, Nobu Iino, described some work on fatigue and fracture. One paper suggests that the concept of COD (crack opening displacement) is a quantitative criterion for the onset of brittle fracture in large steel structures (IIW Doc X-628-71). Iino and others presented a paper at the recent International Conference on Fracture Mechanics and Technology in Hong Kong, March 1977, entitled "A Generalized Strip Yield Model Applied to Fracture Initiation Studies." The effects of plastic constraint and multi-axiality of stress state in relation to the COD concept and fracture initiation were considered. A strip yield model, proposed originally by B.A. Billy, was modified to encompass the multi-axial state of stress and combined mode loading (cracks at an angle to the direction of stress were treated).

Along similar lines, Iino has discussed fatigue crack growth in a structural member subjected to combined tensile and bending stress (Int. Jr. of Fracture *11* p. 685, 1975). The results showed that the mean stress has effects on the fatigue crack growth rate and growth. The growth rate can be expressed as,

$$\frac{da}{dN} = (K_{max})^m (\Delta K)^n$$

The results were applied to implications of combined bending and tensile stresses on the leak before fail concept.

A paper entitled "Effect of Angular Distortion on Fatigue Strength of Transverse Butt Welds in High Strength Steels" was prepared by Iino, in collaboration with well-known Professor K. Iida of University of Tokyo, for presentation at Commission XIII of IIW in Copenhagen, 1977. The advantages to fatigue life of overstressing angularly distorted butt welds was discussed. Another paper by Iino, intended also for the 1977 Copenhagen Conference is entitled "Fracture Toughness Testing Using Precompression Induced Crack." A precompressed machined notch was found to give about the same fracture toughness value as a fatigue crack. The procedure is first to apply a compressive bending load, then a tensile load in bending at liquid nitrogen temperature (-196°C). The tension cycle initiates a sharp precrack.

Mr. H. Okabayashi of the Welding Institute discussed research activities in which he and his colleagues have been involved. One concern has been stress relief cracking in heat affected zones, especially of low alloy steels (IIW Doc IIX-X-531-69 and Trans. Japan Welding Soc. Vol. 1, No. 2, 1970). The cracking problem is related to fine intergranular precipitates which lead to stress concentration at three-grain junctions. The effects of pre- and post-heating on weld cracking has also been studied (Trans Japan Welding Society Vol. 5, No. 2, 1974).

The effects of hydrogen and carbon on fracture toughness of low alloy steels has also been considered by Okabayashi and others. Noting first that linear elastic fracture mechanics may be applied to hydrogen-induced cracking evaluations, an expression is developed which relates fracture toughness to temperature: $G_{Ic} = G_0 \exp T/T_0$, where $G_{Ic}$ is the fracture toughness and $G_0$ and $T_0$ are material constants. $G_0$ is affected by the carbon content, but not structure. $T_0$ depends on the structure, such as grain size.

An interesting experiment was described. A fracture toughness test shows reduced toughness if the hydrogen charged specimen is pre-loaded first at room temperature before fracturing at -196°C. This supports the concept that hydrogen diffuses to regions of stress concentration, causing the reduced fracture toughness. This work was followed up with further studies of delayed fracture of steels at room and low temperature. Activation energies were obtained to account for incubation times at various temperatures for HT-80 steel.

The work on delayed failure may be seen in IIW Doc. No. IX-796-72; Proc. of Conference on Mechanical Behavior, Kyoto, published in 1973; Engineering Fracture Mechanics, vol. 7, p. 541, 1975.

The mechanisms of heat affected zone cracking under weld overlay cladding were discussed in Trans ASME Vol. 98, p. 348, 1976. The causes of this cracking and suggestions for prevention are presented.

A tour of the Research Institute revealed much activity with respect to problems of corrosion and SCC of the BWR reactor (IHI is cooperating with Hitachi and Toshiba and General Electric Company). There are for example test loops with control over pH, dissolved oxygen, temperature, pressure and electrical conductivity. Flow rates to 60 liter per hour, maximum pressure to 100 $Kg/cm^2$ and maximum temperature to 400° are important features. There are also tests of pipe (4 inch diameter) of 308 ULC steel in mock up of reactor conditions. The steel is very low in carbon concentration

There are of course numerous creep and creep rupture tests also under way. Some of these tests apply to the high temperature gas-cooled reactor. The effects of impurities such as hydrocarbons, hydrogen and oxygen on the high-temperature properties of Inconel 617 are under study, for example. The findings have been that at the temperatures of 800-1000°C, which are of interest, the superalloy is decarburized. The investigators are now studying the possibility for preventing this by adding methane to the helium.

Studies were also observed on the effects of environment on creep and fatigue, with the variable of temperature and hold-time of interest.

The usual massive machines for tests of fatigue and brittle fracture of ship and massive land structures were also seen. It was pointed out that Japan with its involvement in massive ships and structures favors these massive tests as being perhaps more predictive, but that the trend in the United States is to "go small." Of course, small tests are much to be preferred if they do predict service performance, so perhaps a measure of confidence in technical capabilities as well as a taste for gambling is involved.

A system for nitriding with ionized nitrogen was observed. This has been a development of IHI which is now available commercially.

A computer-controlled electron probe microanalyzer was also seen (JEOL JXA-50A) which can analyze for carbon.

In summary, there is no question that IHI is highly advanced in the heavy industry area. The Research Institute and the Welding Research Institute both seem to be contributing to this strong position.

## KAWASAKI HEAVY INDUSTRIES, LTD.

Kawasaki Heavy Industries is one of Japan's largest companies with over 33,000 employees. There is a large array of products including ships, rolling stock, aircraft, machinery, industrial plants, steel structures and motorcycles. Kawasaki Steel Corporation is the world's seventh largest steel manufacturer. The operations of the company are world-wide and truly international in scope, with a host of licensees and licensors.

At the Kawasaki head office in Kobe both a Technology Division and a Development Division have been established to promote research and development of new technology and products. Reporting to the President through these divisions is a Technical Institute located for the most part in Akashi City, Hyogo Prefecture. The Technical Institute is the heart of company research activity and it is favored with the most advanced equipment and well-trained researchers. The organization thus establishes a centralized control of technical information which serves all the operating and business divisions including eighteen "Works" throughout Japan. The research and development efforts cover such basic studies as strength, materials, welding, pollution control, utilization of resources, automation, cost reduction and labor utilization as well as such large-scale projects as ocean development and atomic energy as a power source.

The organization of the Technical Institute was reviewed by host Dr. K. Terai although only the Welding Research Laboratory at Kobe and the Kawasaki Works at Harima were visited on-site. A brief description of the more materials-related groups (laboratories) within the Technical Institute follows:

1) Fluid Dynamics Research Laboratory - hydrodynamics of ships, ship propellors, ocean structures, wave motion etc. Also similar studies on turbomachinery such as steam turbines, gas turbines, blowers, compressors, etc. Wind-tunnel studies at both subsonic and supersonic speeds.

2) Strength Research Laboratory - A stress analysis section studies stresses in ships, prime movers, industrial machinery etc. Fatigue data are obtained to show effects of fabrication, surface hardening, welding, size, press fitting, corrosion, and temperature.

3) Materials Research Laboratory - fundamental studies relating metal properties and structure to processes such as heat treating, casting and forging. Ion nitriding is of current interest.

4) Physical and Chemical Research Laboratory - applied chemistry and applied physics. Studies of pollution, $NO_x$ removal, non-polluting combustion systems for heavy oil, insulating materials for LNG tanks, coating systems, solar collecting systems, physical properties of composite materials.

5) Welding Research Laboratory - development of EB welding processes. Development of practical means to weld spherical LNG carrier tanks, boilers, pressure vessels, offshore structures, nuclear vessels. Evaluations of weldability of materials, welding mechanics, metallurgical mechanics, fracture mechanics testing and analyses of large welded structures.

6) Gifu Laboratory - research and development on aircraft products of the Aircraft Manufacturing Division in the Gifu Works. Studies of aerodynamics and noise. Design factors for wings, high lifting devices, fuselages. Applications of technology to advanced aircraft. Structural analyses for wing-body applications.

The visit to the Harima Works was for the purpose of observing the welding and general construction of the large spherical LNG tanks which are made of aluminum. The operating temperature is -162°C so that a material inherently resistant to low-temperature embrittlement is required. Alternate materials are the nickel steels, but Kawasaki has opted for aluminum and appears to have mastered the technology to the extent that several orders for large LNG carriers have been received. The economic slowdown slowed the rate of production but a nice technical lead is enjoyed.

The tanks are made of 5083 aluminum alloy with 207 mm maximum thickness. The weld process is MIG involving a large current of 800-1000 amperes. The construction involves a subassembly, main assembly and a final assembly. Current production is one tank a month. The tanks are quite enormous (capacity 37 100 $m^3$). Finished tanks are lifted from the quay by an enormous floating crane for installation in the ship.

All welds of the aluminum LNG tanks are inspected by radiography and dye penetrant. Also all horizontal welds are inspected ultrasonically. Thirty percent of the vertical welds are inspected by ultrasonic techniques.

Following the visit to the Harima Works, a movie showing the extensive activities of the company was enjoyed at the Welding Research Laboratory in Kobe. Dr. Terai then summarized some of the current activities of the Welding laboratory. These activities currently emphasize electron beam welding; prevention of distortion in steel, aluminum and stainless steel caused by welding; and the technology of submarines and submersible vessels as related to fabrication and welding. Recent, current or planned research projects are on EBW; diffusion bonding; one-side automatic welding; large current MIG welding; underwater welding; welding of high strength steels; welding of steels for low temperature service; welding of steels for high temperature service (stainless steel, Inconel, etc.); welding of heavy section aluminum alloys; welding of titanium alloys; cold cracking as monitored by RRC, TRC and Implant tests; problems of hot cracking as monitored by the RRC and TRC tests); problems of weld stress and strains; prevention of weld deformation or distortion in rolling stock and ships; weld brittle fracture, fatigue and corrosion resistance; computerization of weld techniques; welding of special structures such as submarines and LPG, LEG and LNG tanks.

Dr. Terai who manages the Welding Research Laboratory is most enthusiastic about the potential of EBW. Some of the attractive characteristics he summarized are listed below:

1) EBW welds produce less than one tenth the distortion of arc welding
2) Dissimiliar metals can be welded (arc welding is restricted to steel)
3) EBW requires low heat input
4) EBW produces less contamination
5) EBW welds are completed in one pass

The current emphasis is on applying EBW to large structures. This can be done by providing either a very large vacuum chamber or by providing a mobile localized vacuum chamber. These developments would be useful for boiler construction and are in part supported by the Ministry of Trade and Industry. Some of the results are described in *Iron Age*, March 24, 1975. One pass aluminum welds up to 360 mm thick have been made.

At the present time Terai and his group are trying to apply EBW to submarines, in particular to the welding of steels up to the HY 110 and HY 130 class (NS46, NS63, NS80 and NS90) in pressure hulls. At present HY130 (NS90) steel is limited to TIG welding, and as strength is increased from the HY 90 to the HY 110 (NS80) class, arc welding is no longer satisfactory. Japan has compromised on the HY 110 steel (NS80) for its DSRV but future vehicles may require the HY 130 type steel. Terai would explore the distortion, NDT and computer simulation of weld parameters as well as brittleness problems. There exists a closed committee between the Japan Defense Agency, Nippon Steel and Kawasaki Heavy Industries, and Terai would like to increase cooperative research efforts with the United States, notably with Professor Masubuchi's group at MIT.

The development of EBW could eventually be useful in welding thick section high-strength steel. A 1.6 MV EBW machine for use in air has been assembled at Kawasaki. Attempts are being made to weld steel 50 mm thick. The power required and the massive equipment needed are of course serious drawbacks.

Dr. S. Matsui described some research on the prevention of distortion on welded thin plate for rolling stock and ships plate. Present practice is to straighten with the judicious application of a torch, an expensive and skilled operation. The Welding Research Laboratory has determined that applications of heat and tension *before* welding can effectively eliminate the undesirable distortion. Thus plates are stretched while heated at 100°C.

It is of interest that submarines in Japan are to be made of NS80 (HY 110). Kawasaki Heavy Industries and Mitsubishi Heavy Industries are the only firms with the required capability to produce submarines.

A volume of "Welding Progress in Japan 1974" has appeared, following an earlier volume in 1972. Apparently this second volume is also published by the Sanpo Inc., 10-17, 1-chome, Hamamatsu-cho, Minato-ku, Tokyo (107), Japan. Dr. Terai is author or co-author of every paper except one (by Professor I. Masumoto of Nagoya University) so that a marvelous review of welding in Japan and at KHI in particular, is available. As expected, the issue deals heavily with EBW. No mention is made of laser welding.

In summary, Kawasaki Heavy Industries is an international corporation with a strong research activity. This is seen particularly in its leadership in welding. By following the work of this organization and by interaction and exchanges of information with its technical people, much can be learned.

## KOMATSU, LTD.

While speaking with Professor I. Masumoto of Nagoya University on 1 March, the writer had the good fortune to be introduced to Mr. Yukio Mori, Manager of Welding of the First Research Laboratory of the Production Engineering Research Laboratory of Komatsu, Ltd. Komatsu, Ltd. manufactures a variety of construction and earth-moving equipment. An invitation from Mr. Mori to visit was readily accepted.

At the Production Engineering Research Laboratory (PERL) discussions were held with Mr. Mori and with Mr. Masao Kikuchi, the Manager of the First Division of PERL. By training, Mr. Mori is a welding engineer while Mr. Kikuchi is a metallurgist and foundry engineer. A metallurgist, Mr. Taguchi, is General Manager of PERL.

Approximately 80 men are employed by PERL, which was established in 1975. One division is concerned with management methods, one with mechanical, assembly and inspection methods and the last (First Division) with research foundry, welding and heat treatment.

The weld shop is developing electron beam welding, friction welding, automatically controlled welding, and arc welding. The NDE and inspection of welds are also of interest.

In the casting area there is an effort to develop boron steel castings. Such castings, after water quenching, are claimed to have high shock resistance.

There are also efforts to develop steel castings usable in the as-cast condition. The yield strength is raised by additions of vanadium and the levels of carbon and manganese are changed.

In the case of aluminum alloys there are efforts to develop pressure-cast, heavy-section, hydraulic pump gear cases of aluminum. The pressure casting is a means to increase the strength.

The visit concluded with a tour of the manufacturing facilities. It was interesting to see the applications of welding and to observe the massive earth-moving equipment being assembled. The building of these massive machines, some of which operate under water and are controlled remotely, involves almost every metallurgical specialty in the fabrication, welding, casting, forging, heat treating and machining areas.

**MITSUBISHI HEAVY INDUSTRIES, LTD.**
**SHIPYARD AND ENGINE WORKS - KOBE**

A visit to the Kobe Shipyard and Engine Works of Mitsubishi Heavy Industries was arranged during a visit to the Takasago Technical Institute of the same company. The Kobe Shipyard and Engine Works is active in shipbuilding, ship repair, diesel engines, steel structures, boilers, nuclear power plants, environmental and sanitation equipment and materials handling equipment. A few highlights of these activities follow:

1) Ship Division - This division is very modern with respect to layout and control. An electro-print marking system has been developed at MHI which, from drawings, programs automatically the marking of ship plate for cutting. There are also numerical control drafting machines and cutting machines. This division also boasts remote control bending machines for steel plate, various types of automatic welding equipment and the largest ship repair facilities in Japan. This division builds mostly commercial ships, but also makes small submarines and other submersibles primarily for the Japanese Defense Agency. The ship repair work includes major conversions and alterations, enlargements and general modernization.

2) Machinery Division - This is an extremely well-equipped and large activity. Current emphasis is on machinery for nuclear power plants and boilers. Pressure vessels are constructed from thick steel plates (up to 400 mm thick) which are bent and welded to form.

3) Nuclear energy - Through technical agreements with the USA (Westinghouse) the company is manufacturing PWR type nuclear power plants, including the reactor vessels, steam generators, pressurizers, pressure vessels and related machinery.

4) Prime movers - The company manufactures a variety of boilers including high-temperature, high-pressure, large-capacity boilers for utility companies. MHI built the 3180 ton/hr (evaporating capacity) super-critical-pressure boiler for Tokyo Electric Power Company's 1000 MW plant. This is the largest boiler in Japan.

5) Diesel engines - Kobe Works manufactures many diesel engines, ranging in size from 175 HP to 36000 HP. The capacity is up to 48000 HP, 12-cylinder marine diesel engines.

6) Environmental equipment - The company manufactures a variety of plants to purify water and air, precipitate or otherwise remove particulates or undesired liquids and gases, and treat wastes. Japan is extremely concerned about the threats of pollution which the heavy industrialization has brought.

7) Rocketing and oceanography - The company interfaces with research in these areas by manufacturing test facilities and equipment. For example the company builds rocket launch facilities and wind tunnels. They also make high pressure facilities and equipment for ocean and waste water distribution studies.

8) Materials handling - This includes equipment for stacking crates, boxes, pallets, etc. automatically and under computer control.

9) Steel structures - The company makes and builds towers, frames, bridges, pipelines, penstocks and gas storage towers. The engineering for all of these including the construction of complete plants is also provided.

10) Undersea habitat - There is a tremendous interest in Japan in the development of the means for exploiting ocean resources. Under sponsorship of the Science and Technology Agency, MHI has built an undersea "habitat" for use by Japanese aquanauts. The chamber has been operated successfully at depths to 100 meters.

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AN OVERVIEW OF MATERIALS SCIENCE AND ENGINEERING IN JAPAN.(U)
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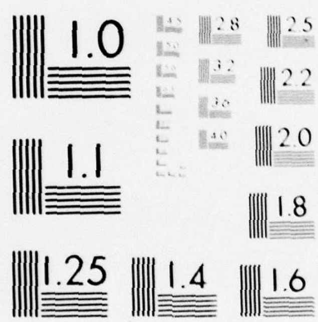


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## MITSUBISHI HEAVY INDUSTRIES TAKASAGO TECHNICAL INSTITUTE

Mitsubishi Heavy Industries is so large and so diverse that it is difficult to give even a superficial review of its activities. There are plants at Nagasaki, Kobe, Yokohama, Hiroshima, Takasago, Sagamihara, Nagoya, Mihara, Kyoto, Akaski, to name the major areas. Technical Institutes are operated at Nagasaki, Hiroshima and Takasago. All of these institutes were visited, with the visit to the Takasago Institute reported here.

The Technical Institutes of course support and strengthen the technical interests of the company. The main products are as follows:

1) Shipbuilding and steel structures - ship building and repairs, steel bridges, towers and offshore structures including ocean exploitation equipment.
2) Power systems - boilers, steam and gas turbines, diesel engines, water turbines, nuclear power plants, pumps, marine machinery.
3) Machinery - chemical plants, railroad stock, automatic material handling equipment, new transportation systems, textile and paper machinery, cast and forged products, steel making machinery, cement making machinery, construction machinery.
4) Aircraft - aircraft, aircraft engines, space systems equipment, missiles
5) Refrigeration and air-conditioning machinery
6) Precision machinery - machine tools, transmission equipment, hydraulic equipment, industrial robots.
7) Agricultural machinery and special vehicles.

The Takasago Technical Institute (TTI) was formally established in Takasago in the early 1970's although various elements of the organization had previously been active in research for many years. For example, research groups were active at the Kobe shipyard prior to and particularly during World War II. The Tokai Laboratory in Ibaragi Prefecture was added to the Takasago Institute in 1972 for studies connected with atomic power problems such as radiation embrittlement and fuel enrichment.

At the present time, according to the Manager of the Materials Research Laboratory of TTI, Dr. H. Suskida, there are about 450 people employed at TTI, which incidentally is also the technical headquarters of the company (the company head office is in Tokyo). The technical activities at Takasago are about 50 percent devoted to nuclear power interests (fast breeder reactor technology, turbines, etc.), 30 percent to prime mover equipment (gas, steam and water turbines) and 20 percent to "fundamental" research (welding, chemistry, etc.).

A tour of the institute included the structures laboratory, anechoic laboratory, materials laboratory, metallurgical laboratory, chemical laboratory, combustion laboratory and welding laboratory. The structures laboratory features an interesting two-way earthquake simulator to evaluate resistance of nuclear components and structures to earthquake damage. This is of obvious importance, particularly in Japan. Similarly there is much activity in NDE techniques for flaw detection and monitoring in nuclear vessels, boilers, etc. Methods used are ultrasonic, electric resistance, eddy current, magnetic and acoustic emission. For example eddy current methods are used on steam boiler tubes and ultrasonic methods for nuclear pressure vessels.

Other test equipments in the structures laboratory are horizontal and vertical test beds and tests of deep diving vehicles involving pressures to 1200 $Kg/cm^2$. There is also an assortment of fatigue, tensile and brittle fracture test machines and equipment to test thermal fatigue. A 1000 ton MTS machine tests WOL specimens in fatigue at 500 tons and 1.5 Hz, with a 150 mm stroke and an approximate 3000 mm span. Specimens weighing up to 600 Kg and 240 mm thick can be tested. A dynamic tear test machine modeled after the machines of Pellini and Lange at NRL is also operating.

The anechoic laboratory is used to test silencers for gas turbine engines. Five-sided test chambers are an interesting feature.

The materials laboratory performs tests for creep up to 1200°C. Tests of tubes at temperatures to 800°C and under internal pressures up to 2000 Kg/cm are also conducted. Boiler tube steel such as AISI Type 321 is tested also in high temperature steam. Heat-check and thermal fatigue tests of cobalt-base superalloys are underway. The materials laboratory is equipped fully for SEM and TEM examination and electron probe analyses. There is also a high-power 50 KW X-ray diffraction unit (Rigaku). A microfocus X-ray unit for residual stress measurement is also available (also Rigaku).

The chemistry laboratory is involved in stress corrosion tests in recirculating sea water. This is one other advantage of the Takasago location.

The combustion laboratory studies the design of gas turbine combustion engines with the goal of improving fuel efficiency and performance. Full scale tests can be conducted in a high temperature corrosion chamber with combustion inlet temperatures up to 1000°C. Thus, for example, the performance of such alloys as 25-20 stainless, AISI 310 and Hastelloy X in engines burning ash-bearing heavy fuel can be determined.

The welding laboratory conducts tests on new welding techniques and on the welding of new materials and alloys. The results are applied throughout the company as in nuclear power plants (overlay welding, seal welding, automatic pipe welding), chemical plants (site welding of pressure vessels or towers), ship building (automatic welding in all positions, high-speed gas cutting), cryogenic plants (automatic welding of aluminum alloys, membrane welding), etc. Current studies are on optimum preheat for welding of pressure vessels, plasma cutting and welding, stellite alloy overlay, automatic TIG welding of LNG containers and TIG welding of heat exchanger tubes. One especially interesting development of the welding laboratory is weld-forming techniques using the electroslag remelt process. By these processes, for example, a pipe elbow of 18-8 stainless steel with 2-inch thick walls can be made. Thus the usual casting or forging processes may be replaced entirely by a weld deposition and forming process.

A 1973 company brochure describes some of the advanced welding methods which the company uses in shipbuilding. In June 1974 a paper entitled "Characteristics of the Narrow Gap TIG-Arc Welded Joint of 10 Ni-8 Co Steel for the Pressure Hull of Deep Submersibles" was issued by the Takasago (Kobe) Institute. The authors were M. Satoh, N. Sakamoto, H. Morihana and T. Satoh. It was claimed that a high quality welded joint can be obtained with a large capacity TIG-Arc welding apparatus designed for field welding of pressure hulls of deep submersibles. The characteristics of 10 Ni-8Co steel welded joints are also described, including stress corrosion cracking data on fracture mechanics type specimens. A subsequent paper published in 1976-7 entitled "Study on Welding Process for Pressure-resistant Hulls of Deep-sea Submersible Research Vessels" expands further on the use of the narrow gap TIG welding process for 10 Ni-8Co steel 100 mm thick pressure hulls. A turning process is described to permit equator welding in the flat position. Stress corrosion data show a $K_{Iscc}$ value of the weld joint at 450 Kg/mm 3/2 compared to the base-plate toughness of 650 Kg/mm 3/2. This paper is in Japanese and appears in Vol. 13 No. 4 of the *MHI* technical reports.

In discussions, Y. Harada and others discussed U-Bend SCC tests of 18-8 stainless steel in water at 250°C. The chloride ion and oxygen ion concentrations were varied. The results show that chloride ion concentration as high as 500 ppm does not cause SCC if the oxygen ion concentration is less than 5 ppm. A chloride ion concentration of only 50 ppm can be tolerated if the oxygen ion concentration is increased to about 50 ppm. These synergistic effects are important in MHI diagnostic studies of cracking in boiling water (BWR) and pressurized water (PWR) reactors.

In summary, the activities of Mitsubishi Heavy Industries are extensive and technologically intensive. The Takasago Research Institute is well equipped and active in supporting these world-wide interests.

## MITSUBISHI HEAVY INDUSTRIES - HIROSHIMA TECHNICAL INSTITUTE

The Hiroshima Technical Institute is one of three such research institutes of Mitsubishi Heavy Industries; the others are located at Takasago and at Nagasaki. Since the general organizational and managerial features of the company have been described previously in the report of the visit to the Takasago Technical Institute, the technical activities and discussions at Hiroshima Technical Institute will be described without further introduction.

Dr. Y. Nishio, Assistant Chief Research Engineer and principal host, arranged a tour of the Hiroshima Works as the first activity on this visit. The advanced engineering and competence in the construction of massive structures such as ships and giant off-shore platforms are the predominant recollection.

In discussions, Dr. D. Yamasaki, Manager of the Material Research Laboratory at the Institute, described some work on the resistance of coilayer vessels to hydrogen attack. The coilayer design is effective in containing hydrogen at high temperatures and pressures. An inner layer (surface contacting the hydrogen) of stainless steel is backed by a tightly wound coil of carbon steel. Steels such as 2Cr, 0.5 Mo and 1.25 Cr, 0.5 Mo may be used as intermediate layers. Vent or "weep" holes are drilled through the carbon steel layers. A gradient in hydrogen concentration exists between the inner and outer surfaces, and the alloy steels are so located as to match the regions higher in hydrogen concentration, in accordance with the tolerance for hydrogen indicated by the temperature versus hydrogen-pressure Nelson diagrams. The vent holes release hydrogen following diffusion into the carbon steel coil. The interspaces between layers allow hydrogen to escape and recombine to molecular form without damage to the steel structure.

The welded joints of the coilayer construction proved to be a problem, with some abnormal cracks occuring during service at 500°C with pressure over 2000 psi. Intergranular cracks were seen in HAZ zones, contrary to Nelson diagram predictions. A series of experiments with 0.5 Mo and 2.25 Cr, 1 Mo steels proved that post-weld heat treatment was required for freedom from the cracking and for validity of the Nelson diagrams. The post-weld treatments were 650 for 4 hours for 0.5 Mo steel and 690°C for 2 hours for the 2.25, 1 Mo steel. A report in English has been issued on this work by Mitsubishi Heavy Industries dated June, 1976, authored by D. Yamasaki, T. Shinkawa, H. Makimoto and T. Oe. Dr. Nishio, with Y. Yoshida and Y. Miura has performed some related work on the problem of diffusible hydrogen and weld cracking in thick weldments. Diffusible hydrogen, according to Nishio, remains in a thick weldment for over sixty days. The hydrogen content is not uniform. Maximum value of the hydrogen content occurs under the surface.

The cracking incubation period on the weld surface (first crack appearance) is as long as four days. The increased cracking in thick weldments is primarily caused by the increased hydrogen introduced from multiple passes. Immediate post heating at 300°C for 30 minutes reduces the hydrogen sufficiently to avoid cracking, and this treatment is an adequate substitute for the common intermediate annealing at 600°C during the welding of thick-wall vessels.

Dr. R. Ebara and others of the Strength Research Laboratory of the Hiroshima Technical Institute have been very active in studies of environment on fatigue strength. One study, presented at the International Conference on Mechanical Properties of Materials, Boston, 1976, deals with effects of air on fatigue crack growth in titanium alloy Ti-6Al-4V. All regions of the crack growth curve (in fracture mechanics type specimens) showed faster crack growth in air than in vacuum, and a marked decrease in the threshold level as well.

It is of interest that the striation spacing was found to correspond to the macroscopic $\Delta a/\Delta n$ value only at intermediate $\Delta K$ levels. At low crack growth rates the spacing is larger than the macroscopic growth rate. Thus the stress intensity-structure-environment-crack growth rate relationships are complex and not thoroughly understood, but this also gives hope for improved properties when a better understanding is reached. This work is being pursued cooperatively with investigators in the United States at the University of Connecticut (A.J. McEvily, J. Groeger), with acknowledgment of U.S. Air Force Office of Scientific Research support.

Dr. Ebara and others have also been studying the corrosion fatigue behavior of quenched and tempered 13 Cr stainless steel in saline solution and steam. Rotating beam tests showed a fatigue strength related to the NaCl concentration. Steam deteriorates fatigue life at stress levels above the threshold but the effect decreases as the threshold is approached and is zero at the threshold. Except in air, corrosion pits and subcracks were observed. Corrosion pits were often located at fracture initiation sites. At high stress and low fatigue life, striations were seen; at low stress and longer fatigue life, intergranular crack growth was predominant. This work was presented at the ASTM Symposium on Corrosion Fatigue, November 1976, Denver, Colorado, and was revised in February 1977 for possible publication by ASTM. Other work now underway involves 500 to 1000 hour tests to determine $K_{Iscc}$ values of 18 Ni-300, 350 and 400 maraging steels. These studies are being conducted in cooperation with the Japanese government, and the results are not generally available.

Dr. Nishio described some work on the development of underwater welding systems. This work is intended to meet a need for in-situ underwater welding of large offshore structures. An automatic welding system has been engineered which involves an underwater camera which monitors the weld torch position and weld bead appearance. The MIG welding process is used with a 100 mm diameter torch. The gas flow under pressure is stabilized by use of annular water jets, so that a stable gas zone is formed beneath the torch. Steels of strength up to 50 $Kg/mm^2$ can be welded in this way. A cracking problem develops with higher strength steels. A descriptive paper appears in IIW DOC XII-B-213-77. The work is known in the USA and the system will be used by NOAA at St. Croix in the Virgin Islands. Cooperative experiments with the Coast Guard and U.S. Navy are also underway. Professor Masubuchi of MIT is a consultant.

Dr. Ebara has studied also fatigue processes in metal matrix composites and is coauthor with A.J. McEvily of the University of Connecticut and K.M. Prewo of United Aircraft Research Laboratories of a paper delivered to the Third International Conference on Strength of Metals and Alloys in London, 1973. The paper involves torsional fatigue tests of aluminum strengthened with boron fiber and aluminum strengthened in-situ by $Al_3Ni$. The differences between fiber-matrix interfacial strengths, fiber diameter and continuity and matrix structure between the two systems were explored with a view toward identifying relationships to fatigue crack initiation and growth, cyclic hardening or softening and the shape of hysteresis loops.

The results show that in the Al-$Al_3$ Ni system there is an initial softening followed by hardening, and this was attributed to the initial and subsequent distribution of dislocations. On cooling from high temperatures dislocations are trapped near the fibers and few are available for plastic deformation of the matrix. There is also a dislocation bias which leads to an SD effect. The initial easy flow (softening) is seen as resulting from the development of mobile dislocations within the matrix, and the eventual hardening as the interaction of these dislocations. The aluminum-boron system shows no SD effect. It is suggested that matrix-fiber breakdown may occur during cooling because of differential strains. Unusual hysteresis loops at high strains were attributed to elastic fiber buckling during compression and plastic deformation of the matrix.

The fatigue process of Al-$Al_3$ Ni in torsion is similar to pure metals, but the life is longer because the fibers retard crack growth. In the aluminum-boron system crack initiation is fiber controlled. This work was also supported by AFOSR. It is of interest that Dr. Prewo is a current ONR contractor in the field of composite materials. Thus, there are precedents for cooperative work between Japanese and American investigators under U.S. government support.

For the future, the Hiroshima Technical Institute investigators wish to pursue further environmental fatigue testing. Specifically, the effects on the fatigue of such steels as 13 Cr and 4340 of varying R value and various concentrations of $CO_2$, $SO_2$ and $H_2S$ in moist air and steam is of interest. These results are important for geothermal equipments such as compressors. There is also interest in the behavior of structural steels in cracked gases in the oil industry. The effects of gas composition on fatigue are not now well enough known, and corrosion fatigue is known to be usually more severe than static tests would suggest.

In general, the Hiroshima Technical Institute appears to conform with the high standards of the other MHI laboratories and other excellent industrial laboratories in Japan. The goals of this laboratory are very practical, but there is no hesitation to apply science at the highest level, and they have the technical people to do it. The number of joint projects and publications with outstanding American metallurgical investigators attests to the scientific excellence.

## MITSUBISHI HEAVY INDUSTRIES - NAGASAKI TECHNICAL INSTITUTE

Among the three technical institutes of Mitsubishi Heavy Industries (Kobe, Takasago and Nagasaki), the Nagasaki Technical Institute (NTI) was the last to be visited. This laboratory adjoins the Nagasaki Shipyard and Engine Works of Mitsubishi Heavy Industries and functions to serve this "Works" in applying and advancing technology, although NTI reports directly to the Technical Headquarters of the company in Takasago. Nagasaki Shipyard and Engine Works is engaged primarily in shipbuilding and such related areas as steam turbines, boilers, diesel engines, propellers, hydraulic machinery, ship repair, steering gear, and blowers. The ships constructed are as large as one million DWT in cargo size (1 DWT is 2200 lb). The marine diesel engines are as large as 36,000 bhp, the marine turbine engines as large as 45,000 bhp. Land boilers producing 600,000 KW and steam turbines for thermal electric power plants with output to 350,000 KW are also produced.

The Nagasaki Technical Institute employs about 600 people of whom about 250 are college graduates, according to vice manager Dr. E. Ueda who reviewed the organization. Some twenty research laboratories within NTI report to the general manager. The general areas of study are hull design and form; hull strength; propellers; hull vibration; marine and industrial materials handling and pollution control equipment; boiler heat transfer and combustion; water treatment and chemical cleaning of boiler waters; plant automation; steam turbine performance; internal combustion engines; development of diesel engines; turbochargers, strength and materials; tribology; chemistry and corrosion; stack gas pollution control; and aerodynamic stability of structures such as bridges. On this occasion the Materials Research Laboratory, Strength Research Laboratory, Sea Keeping Research Laboratory, Ship Strength Research Laboratory, Welding Research Laboratory, Coating and Sea-Water Laboratory and the Tribology Laboratory were visited and there was also a tour of the dockyard activities.

The Materials Research Laboratory, managed by Dr. T. Daikoku performs research on materials which affect the performance, reliability and cost of structures and machines produced by MHI, particularly at Nagasaki. Such activities have been pursued for over seventy years, although various reorganizations have of course taken place.

In the discussions, eight main activities were covered, as follows:

1) High strength materials for turbines.

One material developed is a new material for turbine blading with strength of 90-110 Kg/mm$^2$ and also with high damping capacity. The new blading material is a 12Cr-5Ni-3Co-3Mo maraging steel, and is referred to as "NMB-1", for "Mitsubishi Nagasaki Blading". Further background and details are given in MHI Tech Rev, Sept., 1970.

Titanium alloys are also being developed for blading materials for large steam turbines. Titanium alloys are strong and have low density, which is desirable, but these alloys are generally poor in damping capacity. A current effort therefore is to develop titanium alloys which combine high damping capacity with good strength. No further details were released on this subject.

Another study aims at developing large single casing turbines, in particular large turbine rotors with good resistance to creep-rupture and a low temperature impact transition temperature, FATT (fracture appearance transition temperature). An alloy designated HL-12, a 12 percent Cr-Mo-Co steel, has been developed with 80-83 Kg/mm$^2$ yield strength and FATT of near zero °C. The properties can be obtained in a rotor with diameter as large as 2000 mm. The alloy also has good high temperature strength.

2) Heat resistant material for boilers.

At present 2.25 Cr-1Mo steel is used for superheater tubing and reheater tubing for temperatures up to 585°C (1085°F) and 18 Cr- 8Ni austensitic stainless steels are used for higher temperatures. The NTI materials laboratory would like to develop an inexpensive grade of materials for use at intermediate temperatures. The efforts have begun with attempts to improve the existing 9Cr-1Mo steel T-9 for this service. A new steel designated HCM9M (low C-9Cr-2Mo) has been developed which is characterized by improved weldability and higher elevated temperature strength compared to 9Cr-1Mo steel. The claim is made that the allowable stresses in the new steel are 140 to 160 percent greater than could be allowable in the original 9Cr-1Mo steel. This development has attracted attention in the U.S.A., and the Detroit Edison

Company, for example, is currently conducting tests on the material. Also, Argonne National Laboratory is studying the material for potential use as heat exchanger tubing in the FBR (as of the date of this visit to NTI). A paper on this subject by T. Yukitoshi, K. Nishida, T. Oda and T. Daikoku appears in Trans ASME and Journal of Pressure Vessel Technology, Paper No. 75-WA/PVP-2.

3) High hardness reduction gear materials.

To reduce weight and size there is a need to use harder materials for the gears in reduction trains for marine turbines. At NTI, a higher hardness gear alloy designated, P-4 has been developed for pinion gears and an alloy designated P-5 has been developed for wheel gears. The P-4 gear is over 400 BHN and the P-5 gear is 300-330 BHN. The P-5 alloy, basically 3 Ni-1Cr-0.3Mo.-1Al-V, is given a three step quench, temper and draw heat treatment to develop the desired hardness. The alloy P-4 is a precipitation hardened alloy. The alloy P-5 is stated to have good weldability despite the high hardness. The ability of this alloy to retain high hardness after the required tempering (for toughness) is attributed to the alloying elements. Tests have shown that the surface durability of the new alloys is 130 percent better than the usual alloys. Background and development are described in MHI Tech. Rev. 7, No. 6, 1970.

4) Casting techniques

The laboratory has succeeded in developing continuous casting techniques for copper alloy and cast iron pipes that permit wall thickness as thin as 5 mm in a 150 mm diameter pipe. Work is also being conducted in molding processes to minimize pollution and energy consumption. Developments have been an improved vacuum sealed molding process and a fast-hardening molding process.

5) Marine propeller materials

Mitsubishi has been in the propeller business for many decades, and developed propeller alloys of high-strength brass and Ni-Al bronze which are still in use. In recent years the stainless steel propeller alloy MCF has been developed. This alloy is composed of 18Cr-6Ni-1Mo-1Co and less than 0.03 C. The stainless propeller alloys are stated to permit a lighter propeller design with greater efficiency. The new MCF alloy also has better tensile strength and fatigue strength than the copper alloys. Corrosion fatigue tests in seawater, using the cantilever type Wohler test at N = 10 cycles and 360 rpm, indicated that MCF stainless specimens cut from an actual 400,000 ton tanker propeller had a threshold of 27 Kg/mm as contrasted to a value of 13 Kg/mm for Ni-Al bronze specimens cut from a similar propeller. No report of this work has yet been prepared.

6) Sintered material and ceramics

The research to produce new heat-resistant material has led to dispersion strengthened powder metallurgy alloys. A 13 Cr steel strengthened by $Al_2O_3$ particles shows mechanical and creep rupture strength equal to 18Cr-8Ni austensitic steels. Research is being conducted also on ceramic materials for high temperature use such as in gas turbines and in insulation of metallic engine parts. A multilayer ceramic coating, for example, has been developed which contributes to the development of an adiabatic engine. The multilayers are made of ZrO and NiAl, with the ZrO /NiAl ratio increasing from the metal surface to the outer surface. This permits a gradual accommodation to different thermal expansion coefficients.

7) High damping alloys

To reduce noise and vibration, new high damping capacity alloys are desired. One alloy class developed is in the Mn-Cu-Ti system. The titanium prevents the decrease in damping capacity with time which occurs with these alloys which contain 40 to 90 percent manganese. The background on this study may be reviewed in MHI Tech Rev, *11*, No. 6, 1974.

High damping capacity cast irons are also under development. The best are gray irons with 4.2 percent carbon equivalent and 0.3 percent zirconium.

8) Corrosion and stress corrosion cracking (SCC)

These researches have concentrated on stress corrosion cracking of stainless steels and high nickel alloys using electrochemical techniques. The results have become so developed that the electrochemical tests are now used to control quality of 18Cr-8Ni stainless steel boiler tubing in the Nagasaki shipyard. The approach is to obtain a polarization curve of current versus potential. Sensitized tubes do not show the region of passivity which non-sensitive tubes display.

The Strength Research Laboratory is conducting theoretical and experimental investigations on strength using photoelastic and computer modeling techniques. Materials properties are related to fatigue, thermal fatigue, creep and brittle fracture.

The Ship Strength Research Laboratory is developing new types of ships and is attempting to improve structural integrity. A water impact generating tower, 100 ton corrosion fatigue and 250 ton fatigue machines, and a 1000 ton brittle fracture test machine are featured test equipment. The fatigue machines are programable with respect to wave form, and random noise may be generated.

The Welding Research Laboratory concentrates on the development of new automatic welding methods and in the application of these new methods to improve the economics and feasibility of welds in structures and ships of ever increasing size. Some of the achievements and techniques developed are as follows:

1) One side vertical CO MIG welding in the inclined position.
2) Automatic one-side vertical CO MIG welding (tilted opposite way to 1), above).
3) Multiple wire-tandem welding (MIG & MIG & SAW [last]).
4) Computer controlled welding of T pipe joints (CO MIG).
5) Friction welding

There is no electron beam (EB) welding at NTI as yet. It was stated that there is interest in laser welding, but no equipment has been assembled.

The Coating and Seawater Laboratory is studying corrosion fatigue by alternate bend tests in seawater. Basic chemical research is also done on ships and prime movers, combustion and combustion equipment. The work is considered a serious influence on the success of the company, because the constantly increasing heat flux, temperature and pressure of boilers aggravates material deposition and wall corrosion. Other work applies to the design of equipment for the gasification of oil fuel and in the control of the formation of NOx in the flame during combustion.

The Tribology Research Laboratory studies friction, wear and lubrication problems. Research is conducted on sterntube bearings and reduction gears for large ships and on bearings, pistons and exhaust valves of diesel engines. The gear tests may run as long as three months, followed by detailed microscopic and chemical analyses of the tooth surfaces. During the tests, temperature is measured with thermocouples embedded 0.5 mm below the tooth surface. The tests observed were massive and applicable to company products. These experiments are extremely valuable. Although they are costly, they provide a rare link between 1) theory and laboratory data and 2) the service condition.

The Nagasaki Technical Institute is well equipped and staffed by very competent engineers and scientists who work hard to serve the interests of the Nagasaki Shipyard and Engine Works as well as MHI in general. With the two other technical institutes at Hiroshima and Takasago, MHI appears to be very strong in modern technology and in a position to initiate and exploit new technical opportunities.

## NIPPON KAIJI KYOKAI

A visit to Nippon Kaiji Kyokai head office in Akasaka had been scheduled previously, and at the instigation of Dr. K. Iida of the University of Tokyo a visit was also arranged to the Research Institute located at Mitaka, immediately adjacent to the Ship Research Institute of the Ministry of Transportation. Nippon Kaiji Kyokai is an international classification society which promotes safety at sea. The Society is a member of the International Association of Classification Societies (IACS) consisting of nine major classification societies. Experienced surveyors of the Society survey ships with a view to certification for construction and safety. The results of such inspections are published annually in the Register of Ships. The highest class of certification is designated NS* and is recognized by both London Underwriters and the American Marine Insurance Clearing House. The Society serves essentially the same function as the American Bureau of Shipping. In 1975, 3729 ships aggregating 50 million tons gross representing 40 nationalities were classed by the Society.

The Society maintains the Research Institute to help ensure that its technical rules and requirements are rational and up-to-date. The results and focus of the Research Institute are always related to the behavior of Nippon Kaiji classified ships in service, which range all the way up to 500,000 ton tankers.

The Nippon K. K. Research Institute is organized into three sections: ship hull, machinery and material research. There is also a modest computer research section attached. Current materials activities focus on 9 percent nickel steels, maraging steels and aluminum alloys and their behavior in air and in saltwater. There is no activity at present with respect to precipitation hardened or other high-strength steels. Fatigue and crack propagation by fatigue in hostile environments is the chief concern. Massive carriers for LNG, ore, oil and lumber are the related interests.

One interesting paper was described which will be published eventually by the Japan Society of Mechanical Engineering. This paper entitled "A Study on Fatigue Crack Growth from Surface Flaw" by J. Arai, Y. Ino and H. Iwaki was an outgrowth of research on alloys for use in LNG carriers (9 Ni steel and Al alloy). Liquid nitrogen was used to control test temperatures, and it was noticed that specimens behaved differently depending on whether residual nitrogen was or was not present during the test. This triggered an investigation, with the following results:

Crack growth rate in Al-Mg alloy A 5083-0 is lower in nitrogen than in air. A decrease in temperature to -162°C also decreases growth rate. The environmental effect of nitrogen is, however, the greater. Additionally, the different environments produce a different shape of crack front. The surface crack fronts are semi-elliptical in nitrogen gas and semi-circular in air.

The observations are explained by asserting that reversed (cross) slip is easier in nitrogen than in air. The different crack front shapes are explained on the basis of easier crack closure in nitrogen than in air. Air impedes the closure of cracks by cross slip (reversed slip) because of the impurities formed on slipped surfaces.

A tour of the Research Institute showed further advanced, large-scale, testing machinery. A large fatigue machine involved a servo pulse of $10^{-4}$ sec and a capacity of 400 cps. Diagramed loading is possible. Data from on-board records of fatigue loading can be programmed into the machine to duplicate the load spectrum of service conditions on test specimens. A hybrid analog and digital computer is available for analysis of the dynamics of vibration and impact.

A number of large rotating-type fatigue machines were shown. Some of these involve bending and torsional fatigue and fretting as designed to duplicate crankshaft service. A large 300 ton low-cycle fatigue test machine was also observed. Fatigue and crack propagation tests are made on very large specimens — up to 700 × 30 mm. Cryogenic control is through use of liquid nitrogen which is used liberally. The cost of liquid nitrogen alone runs to 10 million yen per year (30-40 K).

The general impression of the Ship Research Institute and of Nippon Kaiji Kyokai Research Institute is that first class, practical research on the behavior of ships with respect to design and materials is going on. There does not appear to be any significant interest in the metallurgical structure of base plate or welds. The behavior of the designs assuming a material continuum is the central interest.

## NIPPON KAIJI KYOKAI HEAD OFFICE

Following a visit to the Nippon Kaiji Kyokai Research Institute, this one to the Headquarters Office was perhaps redundant. Nevertheless, interesting discussions were held with several people. Dr. Y. Akita, Vice President of Nippon K. K. described some current activities. He is the Chairman of the International Symposium on Practical Design in Shipbuilding to be held in Tokyo 18-20 October 1977, and he is very busy arranging the details of this meeting.

The only directly technical contribution of the day involved a demonstration (by Dr. Shin-Ichi Kaku, Head of Planning Division) of an extremely compact ultrasonic NDT test device. This was developed under sponsorship of Nippon K. K. by Tokyo Keiki, a company in Tokyo. The compact device weighs perhaps one-half pound and is readily carried by inspectors to the most difficult areas for ship and piping inspection. The device checks for cracks and poor penetration in welds, to a depth of two inches.

## NIPPON KOKAN KABUSHIKI KAISHA

Nippon Kokan K. K. is one of the giant steel making, and shipbuilding companies in Japan. The company is also deeply engaged in heavy industry construction and engineering, plus a few peripheral activities such as fertilizer manufacture. Dr. Kazuo Horikawa was the principal host for my visit to the Technical Research Center in Kawasaki, and discussions were held with approximately ten other technical persons as well.

The meeting began with private discussions with Dr. Horikawa, Technical Counselor to Nippon Kokan K. K. He related his experiences during World War II as a Japanese Naval Officer engaged in industrial pursuits, notably the development of improved armor plate for ships. He stated that he was invited to work with the U.S. Navy after the war, presumably because of his accomplishments for the Japanese Navy, but he declined in fear of entering the "enemy" country at that time.

Following these preliminary amenities, the writer presented a summary of the ONR-NRL research organization and activities before a group of technical specialists. There were many questions, and particular interest was shown in the operation of the contract research programs. They found the concepts of brutal competition, Navy purposes and the lofty pursuits of academic basic researchers difficult to reconcile. This is perhaps not too startling since some people in the United States are equally baffled.

Dr. Horikawa reviewed briefly the activities and organization of Nippon Kokan K. K. Historically, the company was established to make steel pipe, but thereafter expanded into steel making and heavy industrial functions. Today the iron and steel making is the largest percent of sales (75-80 percent) followed by ship building and heavy industry (each about 10 percent of sales). Approximately 20 million tons of steel are produced annually at the Fukuyama Steel Works and about 6 million tons at the Keihin Works. The company also manufactures ferroalloys (ferrochrome at Toyama and ferromanganese at Niigata). Ship building is located in three plants with capability of up to 500,000 ton ships at Tsu, 160,000 ton ships at Tsurmi and 27,000 ton ships at Shimizu. Heavy industry activities are also concentrated at Shimizu.

The Kehin Steel Works, built over 60 years ago, is now burdened with obsolescence and pollution problems. Nippon Kokan K. K. is solving this by constructing an entirely modern steel works at Ogishima, an artificial island created in Tokyo Bay by hauling sand from Chiba, approximately 40 kilometers away. Connection to the mainland is by bridge and tunnel. When the new facilities are completely operational, the outdated facilities are scheduled to be dismantled. There will be some consolidation of facilities for pipe mills and part of the area will be sold for the development of the Yokohama-Kawasaki area.

The company claims special strength because of its integrated steel making, ship building and heavy industry interests. Special achievements are the computerization of manufacturing controls, the development of the first UOE 56 inch O.D. pipe mill, the first 100 inch O.D. spiral weld pipe (1975), and the development of continuous casting of slabs, blooms and billets directly from basic oxygen furnaces. All of the research in the company is conducted at the Technical Research Center. The work undertaken may be basic, but is intended to relate to the three Steel Making, Shipbuilding and Heavy Industry Divisions. The activities are organized into six research departments plus four attached research organizations in the Tsurumi, Keihin, Fukuyama and Tsu areas and range from coal research to steel processing, steel properties, coatings and corrosion, welding and ship structures. Product research related to steel, welding and surface treatment has led to the development of high strength steels for ships, construction, tubes and sheets for deep drawing. There is pride in large scale tests of welded members up to 220 mm in thickness at temperatures between -70°C and near absolute zero. The results are applied to welding techniques for liquified gas storage vessels for cryogenic service. Developments of continuous heat treating and coating processes have been pursued. As a leading pipe manufacturer, NKK is studying plasma welding, LNG tank piping and the means of welding complex piping systems.

The Technical Research Center is equipped with a wind tunnel to study the effects of wind pressure on long-span bridges and other exposed steel structures. Wind velocity of 0.3 to 50 m/sec can be generated across a 15 m test area. There is also a large circulating water test tank for analysis of the resistance to waves, currents and pressure in a fatigue-producing motion sequence. Endurance tests on large hull segments are made.

Presentations were made by several members of the Technical Research Center. First Mr. I. Matsushima described the work of the Corrosion Laboratory. Matsushima is a general corrosion expert and has published widely. He spent two years in the 1960's at MIT where he published papers with H.H. Uhlig. Their work was on hydrogen cracking and stress corrosion cracking of stainless and precipitation hardening steels. At NKK he has been concerned with a number of problems. For example, he has written (Nippon Kokan Technical Report-Overseas, Dec. 1974) on the improvement in resistance to polythionic acid of stainless steel type 321 by increasing the ratio of Ti to C and by annealing at 1000 to 1500° C. This corrosion problem was encountered in the petroleum industry. He has also published on the subject of weathering steels, with emphasis on the structural and environmental factors which control the protective nature of the rust film which forms in such alloys (see Corrosion Science, *11* 129 (1971) and Boshoku Gijutsu, *23* 177 (1974)). More current interests are on the cathodic protection of coated pipeline (presented at Corrosion 73, NACE) and the corrosion of metals in sulfurous exhaust gases from sintering plants (presented at Corrosion 75, NACE, in Toronto, Canada). Of perhaps greater interest to the Navy, he has studied the corrosion behavior of metals in geothermal steam power plants (Trans ISIJ, *16* 689 (1976)). It was reported that resistance to corrosion and erosion is improved in hot water and steam well conditions with increasing percentages of chromium, and little corrosion occurs with chromium above 13 percent. Weathering and low-alloy steels, which enhance corrosion resistance in the atmosphere, are not effective in this type of service.

Dr. Masanori Kawahara of the Engineering Laboratory described some of his work in fatigue. The facilities for fatigue studies at the Technical Center are excellent from the standpoint of large component testing. Almost every imaginable type of test is done, from tests of pipe K-joints in a submersible drilling rig, to wave-effect tests of critical ship load-bearing structures. Kawahara has published, for example, on the fatigue strength of a particular ship structures design (Nippon Kokan Technical Report-Overseas, Dec. 1975). He is also scientifically inclined and has written on the retardation of fatigue crack growth in a HT80 steel from overload in the fatigue cycle (Engineering Fracture Mechanics, *8* 507 (1976)). Very recently he has written on growth of fatigue cracks from a surface flaw. He shows that flaw growth from a surface flaw produces a different shape crack front, depending on whether the specimen is strictly tensile or involves a bending moment. This differs from the ASME code which assumes that both crack fronts grow identically. According to Kawahara, it is for this reason that quite often plots of $da/dN$ versus $\Delta K$ produce scatter if different specimens are used. Kawahara has developed expressions which he claims overcome the difficulty, and says that he can determine relationships between a (crack depth), b (crack width) and $da/dN$ in specimens subjected to combined tensile and bending loads. These results, which may be very important to an understanding of fatigue crack growth, may be applicable in part to studies of crack growth from stress-corrosion. Kawahara (with M. Kurihara) is presenting this work before the 4th International Fracture Conference, Waterloo Canada, 1977.

Mr. N. Seki and Mr. Oichi next described some problems and concerns with stress corrosion cracking and hydrogen embrittlement. The company has several interests here. Nitrite stress corrosion cracking is a concern in the fertilizer trade. Steels of 40-60 kg/mm$^2$ tensile strength are involved. Cracking from $H_2S$, stress corrosion, and blistering internally from hydrogen are of concern to linepipe steels of 50-80 and 40-60 kg/mm$^2$ respectively. City gas tanks of steel 50-80 kg/mm$^2$ tensile strength are subject to $CO$-$CO_2$ mixtures, and stress corrosion may be a problem. Finally the area of sea water and pure water stress corrosion cracking is of interest with steels of tensile strength 110-140 kg/mm$^2$.

Although papers on the stress corrosion cracking of high strength steel in $CO$-$CO_2$ gas (Nippon Kokan Technical Report Overseas, Dec. 1974) and on the stress corrosion cracking of pipeline steel (Proc. 5th Int. Cong. on Metallic Corrosion, 493, NACE) were distributed, all discussion was avoided because of the sensitive nature of the subject matter. A manuscript on the stress corrosion cracking of high strength steel bolts by M. Tanimura and N. Seki was discussed quite freely, however. In essence, they have studied the effects of notch morphology on the value of $K_{Iscc}$. Various combinations of V-notch and slot plus a fatigue crack (to give a constant crack depth) were studied. The V-notches and slots serve to open up the crack toward the specimen surface. The findings were that crack growth rate above $K_{Iscc}$ may be influenced, but that the value of $K_{Iscc}$ is fairly constant.

Not very much was heard about welding but the Manager of the Welding Laboratory, Dr. J. Tanaka did relate some implant test results generally. The implant test is a notch test designed to determine the strength of the heat affected zone of welds. It is a measure of the cold cracking susceptibility. Under stress and with time a threshold stress for cracking is determined which increases with temperature. The threshold stress may also increase with time, which probably reflects the egress of hydrogen. There was no opportunity to tour the facilities during the busy day. The overall impression is that this is a first-class technical group which is alert to the needs of the company and well aware of what is going on world-wide in related areas.

As a final comment, NKK notes that it enjoys a very low absenteeism rate (less than one percent) and relates this to the assurance by the company of job security, good pay and opportunities for advancement. Does the high degree of paternalism weaken the employees resolve to work hard? On the contrary, says NKK, it heightens the resolve to do the best possible job. Comparing this situation with that in the United States, it is obvious that the big difference is job security. Perhaps in Japan the worker identifies with the company whereas in the United States loyalty is less often given and received; the individual career is of first consideration. Of course, "high pay" and "opportunities for advancement" are subject to interpretation, and certainly, from outward appearance at least, the United States worker is better off materially. Still, the industrial success of the Japanese system gives pause.

## SUMITOMO METAL INDUSTRIES, LTD.
## AMAGASAKI

Research divisions were established by Sumitomo Metal Industries as early as 1935 at Osaka Steel Works and the Steel Tube Works. Somewhat later, research divisions were established at the Wakayama and Kokura Steel Works. These were incorporated into the Central Research Laboratories in 1959 and the consolidation of the laboratories at Amagasaki took place the following year. In 1974 the Hasaki Research Center near the Kashima Steel works opened.

The Amagasaki Central Research Laboratories perform work relevant to the company activities, develop new products and processes, and generally promote the use of steel products through technical advances. The Hasaki Research Center is dedicated to steel construction and pipelines, with the capability of full-scale tests.

At the Amagasaki Laboratories the research work is divided into three main areas which cover iron and steel processing, product research and fundamental research. The product research area includes the Mechanical Metallurgy, Applied Mechanics, Chemical Metallurgy, and Welding Sections. Discussions on specific research were held primarily with people in the Mechanical, Metallurgy, and Welding Sections although some other activities in the materials area were discussed generally. A brief account of some general areas of research follows:

1) Research on the most efficient use of resources and energy. Sintering of ore, use of non-coking coal in the blast furnace, studies of coal-slag-coke reactions in the blast furnace.

2) Research on steelmaking processes. Techniques of desulphurization, dephosphorization, deoxidation, etc., solidification and continuous casting.

3) Research in computer control, automatic inspection and quality control devices.

4) Press formability of steel sheets.

5) High temperature tube and pipe materials for boilers, chemical industry plants and nuclear power plants. Tensile creep and creep by internal pressure tests.

6) Research on heat resistant alloys for the high-temperature gas-cooled reactor (HTR). Studies of creep, fatigue and corrosion in helium test loop facility.

7) Stress corrosion cracking tests of materials for the light water reactor (LWR) in a circulating autoclave system with water at 300°C, 87 atmospheres. Variables which may be controlled are dissolved oxygen, pH, and concentrations of specific anions and cations. Maximum flow rate is 5ℓ/min. Specimens are subjected to tension.

8) Research on weldability, strength and toughness of high strength steels for ships, bridges, penstocks, line pipe etc. Studies of microstructure and microalloying.

9) Welding research with "Gleeble" machine which programs heating, cooling, tension, compression, fatigue and research dilatometric data.

10) Non-vacuum electron beam welding process. Development for welding of pipes, plates and large scale steel structures.

11) Large scale closed-loop servo-controlled fatigue tests of welded steel plates, bars, gears, frames etc. Fatigue crack propagation at high and low temperatures and fracture mechanics analyses.

12) Delayed fracture studies of high-strength bolts. Large diameter weather resistant bolts with resistance to delayed fracture are claimed to have been developed.

13) For pollution control, research on the desulphurization and denitrification (removal of SOx and NOx) of stack gases from sintering plants.

14) Fundamental research on hydrogen embrittlement and stress-corrosion mechanisms in steel, stainless steel and titanium alloys. Instrumentation includes the IMMA, EPMA, SEM, GC-MS and DTA.

In the Mechanical Metallurgy Section Dr. Hiroo Ohtani described work on bainite in low-carbon, low-alloy steels. Three types of bainite are identified according to the morphology of cementite precipitation. Bainite type 1 is formed at 500°C and is carbide free. Bainite type 2, formed at intermediate temperatures, is mainly ferrite laths separated by cementite layers. Bainite type 3 is formed at temperatures near $M_s$ and is characterized by dispersions of cementite in a ferrite lath structure. All these bainite types exhibit the same ferrite habit plane, <111> {110}.

Best combinations of strength and toughness are always found in mixed martensite-bainite structures in low-carbon, low-alloy steels. The toughness of the bainite, however, increases with lower transformation temperature, which reduces the thickness of the ferrite laths, and the bainite type 3 formed near the $M_s$ temperature is tougher than martensite tempered to the same strength level. The duplex martensite plus bainite structure can be further toughened by tempering at 650°C.

The mechanism of toughening of the duplex structure is related to the initial separation of the austenite grains into several parts by the formation of bainite type 3. The "unit crack path" is thus reduced, and toughness is inversely related to this unit length, according to Ohtani and his colleagues. These investigators also show that the transition temperature from ductile to brittle fracture is lowered as unit crack path for cleavage decreases. The concept of unit crack path has been extended to the initiation and propagation of small cleavage areas on {100} planes of ferrite-pearlite and martensite structures in low carbon steels. Thus the overall picture is of a discontinuous cracking process with the toughness related to the population of discontinuities. For greater detail on this work see *Trans Iron and Steel Institute of Japan 11*, 250, 1971; *12*, 118, 1972; *12*, 146, 1972; *12*, 45, 1972. Also, see *Iron and Steel*, 647, December, 1972, and *Metal Science*, *8*, 357, 1974.

Dr. Minoru Fukuda next described some work to improve steel toughness by microalloying and controlled rolling. This is designed to increase toughness by control over grain size and precipitation hardening. The brittle to ductile transition temperature is also lowered which is of immediate concern for large diameter line pipes.

The "secret" to grain refinement is to provide a large number of ferrite nucleation sites by deforming the austenite below 800°C. Normally the ferrite nucleates at austenite grain boundaries, and this limits the amount of ferrite grain refinement to some fraction of the recrystallized austenite grain size. However, if the austenite is worked at temperatures below 800°C, where recrystallization does not occur, the ferrite may nucleate on deformation bands in the austenite. This produces grain refinement such that ASTM size 10 to 12 may be achieved.

The strengthening effects of V and Nb are complex and vary with the rolling temperature and plate thickness. Precipitation hardening by V raises the transition temperature unless the rolling is finished at 700°C (low temperature). There appears to be no penalty from V or Nb additives with respect to transition temperature if the finishing temperature is low (700°C). For additional information see The Sumitomo Search, No. 9, 8, 1973 and No. 14, 17, 1975.

Another problem with line pipe mentioned by Dr. Fukuda is that of propagation by shear fracture. This must be combated by increasing the fracture tear toughness, which can be done by controlled rolling, decreasing the concentrations of carbon and sulfur and by control over the shape of sulfides. Line pipe must be capable of arresting cracks whereas the welds must only resist crack initiation.

Other work in the Mechanical Metallurgy Section, undertaken to improve production of heavy thick steel plate of 80 Kg/mm² strength with optimum toughness and weldability, was described by S. Watanabe. Adequate hardenability is promoted by boron additions, but the amount of boron required relates to the levels of nitrogen, oxygen and aluminum. Therefore studies on the morphology of boron compounds in steel and their formation and behavior during rolling, heat treating, etc., have been of interest (See Sumitomo Search, No. 15, 27, May 1976 and *Trans. ISIJ 15* 637, 1975).

Watanabe and Kunitake have also been studying the formation of austenite between $Ac_1$ and $Ac_3$ from the lath ferrites such as low-carbon martensite or bainites. Such transformations give rise to the acicular austenites which are understood for Fe-Ni alloys but not for low-carbon steels.

It has been found that austenite formed from low-carbon steel martensite or bainite laths has the same crystallographic orientation as the laths, the Kurdjomov-Sach relationship. When cementite is involved, the austenite has the same relation to the ferrite and the Pitsch orientation relationship to the cementite. The acicular austenites therefore all have an identical orientation relationship to the lath structure. Upon heating above $Ac_3$, coarse austenite forms. This austenite consists of several divided regions which correspond to regions of recovered ferrite. These regions are of possible importance in the development of unit cleavage path after subsequent heat treatment and test. Thus these experiments bear on considerations of fracture toughness. Papers on this work appear in *Trans. ISIJ, 16*, 28, 1976, and in *Proc. First JIM International Symposium* on "New Aspects of Martensitic Transformation", Kobe, 1976.

In the Welding Section Dr. Yoshinori Ito and others described work relative to problems with line pipe welding and with welding thick plate. As always, problems with cracking and fracture toughness are the major concern. The heat affected zones are particularly sensitive. It has been found that managing the levels of alloying elements together with proper rolling and heat treatment procedures can be effective. The silicon level in 60 Kg/mm² plate should, for example, be under 0.1 percent, and the ratio of nitrogen to boron should be between 0.25 and 0.5. Representative papers on this work are in Sumitomo Search, No. 6, Nov., 1971; IIW, Doc. IX-576-68; DOC IX-738-71; DOC IX-831-73.

More recently this work has focused on the problem of cracking in the through-thickness direction of thick welded plates. This lamellar tearing is serious in large structures with severe constraints.

The first accomplishment has been the development of steel plates with greater resistance to lamellar tearing. These plates, now available under the trade name SUMI-Z, feature specifications on chemical composition, inclusions and diffusible hydrogen. In addition to control over the ordinary elements (C, Cr, Mo, Si, V, Mn, etc.) it has been found that calcium additions are effective in changing inclusions to a more spherical form. This is called the SCAT (Sumitomo Calcium Treatment) process.

The critical problem with the weld metal is the diffusible hydrogen. Through-thickness cracking is minimized if diffusible hydrogen is very low. Extra low hydrogen electrodes have been developed for thick-plate welding. This work may be reviewed in greater detail in Proc. of the Rome Conference on "Welding of HSLA Structural Steels," Nov., 1976; The Sumitomo Search, No. 13, 8, May, 1975; IIW IX 969-76 and JIW, *46*, 62, 1977.

Another development in the Welding Section has been the use of cellulose coated electrodes for girth welds of line pipe. During welding the cellulose burns and the gas produced keeps oxygen and nitrogen out. The arc is also improved for deeper penetration.

In summary, the research at Sumitomo Metal Industries' Central Research Laboratories is first class, mission-oriented, and offers an excellent example of how scientific research can foster economically desirable ends.

## APPENDIX
## (GENERAL ABSTRACT OF PRESENTATIONS MADE IN JAPAN)

### SOME CURRENT MATERIALS PROBLEMS IN NAVAL RESEARCH

Above all other things the Office of Naval Research of the United States is engaged in the advancement of science and engineering technology. The basis for this was expressed long ago, in 1885, by the then Secretary of the Navy William C. Whitney, who said, "It is of little service to a nation to have any Navy at all unless it is a fair expression of the highest scientific resources of its day."

With this philosophy in mind, it is easy to understand the interests of ONR in basic science and in interacting with the academic community at home and abroad. A wide variety of subject areas are of interest to ONR - from mathematics to biology and psychology, but here only activities in materials science and engineering are discussed.

With respect to materials science and engineering, it is obvious that improved materials performance may lead to improved commercial and Naval capabilities on, under and over the seas. Desired goals are greater maneuverability, speed, range and deep diving capability, coupled with improved economy and efficiency. Improved communications are also desirable.

To achieve these goals materials and components must be made stronger, lighter and cheaper while retaining or improving at the same time the essential characteristics of good weldability and fabricability; resistance to corrosion, stress corrosion, corrosion-fatigue and fatigue; resistance to low and high temperature embrittlement; good high temperature fatigue strength, creep resistance and oxidation and corrosion resistance. Other specialized characteristics such as improved resistance to wear, erosion and irradiation or improved magnetic permeability and larger magnetostriction are often also needed.

In short, there is a spectrum of materials goals and problems of interest to ONR. Therefore research programs are supported in several materials areas. The research is performed either directly, at the U.S. Naval Research Laboratory in Washington, or indirectly through contracts with universities, companies and nonprofit research centers. We will first describe briefly the organization and some current projects underway at the U.S. Naval Research Laboratory, and then describe some types of projects being conducted under contract to ONR.

The U.S. Naval Research Laboratory has four major divisions engaged in materials work under the direction of the Associate Director of Research for Materials (Dr. Al Schindler). These divisions are 1) Engineering Materials Division, 2) Materials Science Division, 3) Chemistry Division, and 4) Radiation Division. We will discuss activities in each of these divisions, with particular emphasis on examples of work in the Engineering Materials Division, which is involved with problems of greatest interest to materials engineers.

Discussions of the projects under contract to ONR will fall into three categories: 1) metal alloys, 2) corrosion and 3) ceramics. The metal alloys projects are divided into several classes: a) high strength-high toughness alloys, b) light weight structural materials, c) fabrication, d) magnetostrictive alloys, e) composite materials, and f) amorphous metals. The corrosion projects are divided into a) stress-corrosion cracking, b) corrosion fatigue, c) hydrogen embrittlement and d) design data. Discussions in the ceramics area will reflect interests in applications for gas-turbine engines.

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