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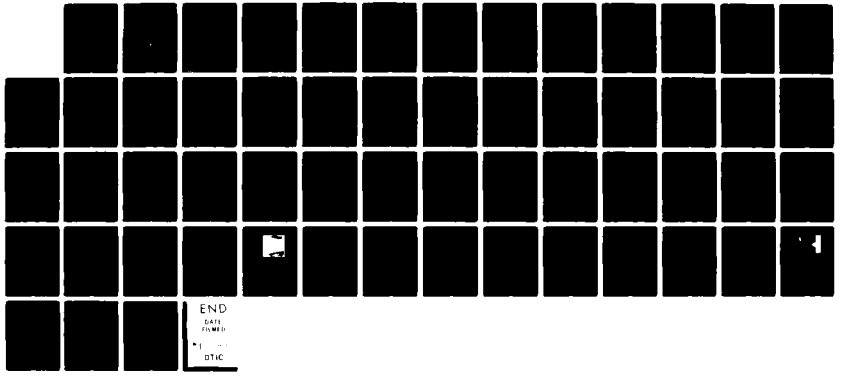

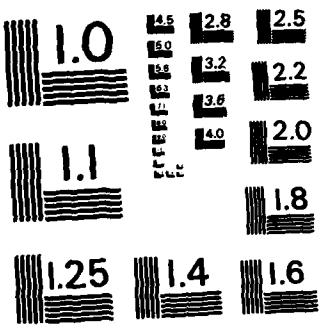

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European Scientific Notes (ESN) is a monthly publication with brief articles on recent developments in European scientific research. The publication is not intended to be part of the scientific literature. The value of the ESN articles to Americans is to call attention to current developments in European science and technology and to the institutions and people responsible for these efforts. ESN authors are primarily ONRL staff members. Occasionally articles are prepared by or in cooperation with staff members of the USAF European Office of

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EUROPEAN SCIENTIFIC NOTES
OFFICE OF NAVAL RESEARCH
LONDON

Edited by Ronald W. Armstrong
Larry E. Shaffer

Vol 37, No. 8 31 August 1983

BEHAVIORAL SCIENCES

Intensive studies in Britain have questioned the maxim that small businesses are the key to industrial growth and job development.

CHEMISTRY

The 23rd meeting of the UK High Polymer Research Group centered on the synthesis and properties of thin polymers and on the devices that can be made from them. Applications include thermography, electro-optical displays, electric tranducers, and sounders in telephones.

COMPUTER SCIENCES

ASEA has taken maximum advantage of the use of microprocessors in the control system for robots. A new control system uses a "joystick" in combination with a self-instructing, interactive dialogue. The system combines the advantages of function-oriented and typewriter keyboards.

The Software Systems Research Center at Linkoping Institute of Technology, Sweden, is developing a broad competence in various aspects of computer software, including applications, programming environments, and artificial intelligence. The goal is to carry out research relevant to industry and society.

ELECTRONICS

About 90 people gathered in Maidenhead, Berkshire (UK), to hear first reports of record-setting semiconductor performance. Emphasis was on two-dimensional electron gas devices; the French, in particular, had much to contribute.

Investigators at Louis Pasteur Univ. have shown that spectroscopic ellipsometry and Raman spectroscopy can be used as complementary tools to assess ion implant profiles, damage, and electrical activation. Electron spin resonance techniques can be used to assess radiation damage.

ENVIRONMENTAL SCIENCES

The conference addressed the impact of large-scale coastal engineering works on marine and estuarine ecosystems.

MATERIAL SCIENCES

This is the fifth in a series of articles reporting research on fiber composite materials in the UK. This month, research at the Univ. of Nottingham and Fulmer Research Laboratories is featured.

Bioceramics, silicon nitride materials, strength and testing methods, phase equilibria, sintering, and optical, electrical, and electrochemical ceramics were the main topics in a European-based meeting. The conference also included reports by representatives from the Shanghai Institute of Ceramics.

PHYSICS

Research and development programs at the Atomic Energy Research Establishment (AERE) are guided by the needs of the nuclear industry. This article provides basic information about the interaction of low energy neutrons with matter, describes neutron sources available at AERE and elsewhere for material physics, and presents some highlights of condensed matter studies at AERE.

SPACE SCIENCE

The European community is actively pursuing low gravity research in space. Initial work emphasizes materials, fluids, and the life sciences.

STATISTICS

Papers presented at a recent conference suggest a trend toward use of computer implemented optimization methods in the design of sampling plans.

NEWS & NOTES

Miniworkshops, fire-resistant fabrics, by V.T. Stannett; regression software, by D.R. Barr; ductile fracture, by R.W. Armstrong; Queen's Honours, by M.N. Yoder; computer year in France, by L.E. Shaffer; sand probe, by R. Dolan.

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BEHAVIORAL SCIENCES

SMALL FIRMS: GROWTH AND JOBS?

In the developed democracies, great emphasis is now being placed on the small enterprise as a source of new job opportunities. In both the US and the UK, there are extensive loan and grant programs to new firms. Britain offers substantial cash prizes (up to £100,000) to leading new enterprises that convert some scientific or technological finding into a stable business. A few highly successful firms are mentioned frequently; sometimes, it appears, a business started by two men in a garage can grow into a major enterprise. Such successful entrepreneurs often become media heroes, and their stories of "how they did it" are repeated over and over. In a recent British election, it was widely noted that if each small business hired just one new worker, the unemployment problem would be solved. Such observations are politically engaging because hiring just one more person often sounds quite local and manageable, and the structural vulnerability of a large economy is occluded.

Academic studies may favor the small-enterprise message, too. A famous Massachusetts Institute of Technology study by David Birch, first reported in 1979 but cited many times since, observed that two-thirds of the increase in US employment from 1969 to 1976 was in firms employing fewer than 20 workers. A recent series of British studies affords a careful evaluation of the belief that small business is a force in job development and economic growth. While one can always argue that conditions across countries are different, certainly some of the same industrial patterns (recession, high unemployment, high interest rates, decline of heavy industry, growth in services) can be seen in all the Western democracies. Intensive study of small business in Britain may therefore be instructive for other countries.

David Storey (Centre for Urban and Regional Development Studies, Newcastle Univ., Newcastle upon Tyne, England NE1 7RU) has been reviewing job losses and gains in northern England from 1965 through 1978. His work has been sponsored by many agencies, such as the European Economic Community (EEC), the UK Manpower Services Commission, and various UK county councils. The results introduce some major reservations about the effectiveness of the small firm as an important creator of jobs, or as a major factor in regional and national economies. Storey's survey probably is important to many Western economists because it covers hundreds of businesses over a time long enough to include boom and recession, and because it gives some solid data-based estimates of small-firm economic impact.

Some findings from the Cleveland, Durham, Tyne, and Wear areas of England are typical. New manufacturing businesses created about 1,000 new jobs annually over the 14 years from 1965 through 1978, but over 10,000 jobs were lost in the area due to manufacturing closures, and this loss total excluded vanished jobs in the declining steel industry. Also, the garage-to-major-enterprise transition is extremely rare. More than 30% of new manufacturing enterprises went out of business within 4 years, and less than 1% of the new manufacturing firms grew to 100 employees within 10 years. The firms surviving to the sixth year had a median payroll of only about 10 workers.

For the Cleveland area in the industrial North, nearly a quarter of new businesses were started by unemployed workers, and over three-quarters of the output (products and services) were delivered to customers in the immediate area. Thus, the new small businesses usually had to rely on local markets. Storey also observed that for small, locally based service firms, the conditions of textbook-perfect competition obtain, leading to nearly as many failures as start-ups (from 1980 to 1982, only 10% of new British firms were manufacturing firms [Lloyd and Dicken, 1982]). A new firm that manufactures something generally depends on subcontract orders from large businesses nearby (Storey, 1982). A recent Nottingham study confirmed these findings; nearly half of the new enterprises in that area were started after the owner had been released from another job or had been threatened with unemployment. A new firm, then, often is formed because of the need for security in employment, a need that can be satisfied with a small operation employing only a few people. The security motivation is rather different from that of the more ambitious entrepreneur who seeks success and monetary rewards, and who sets no limits to growth. Security needs also may stimulate employees to work long hours for relatively little pay. Another factor that often operates during a recession is the availability of bargain low-wage labor, machinery, and equipment as many plants close. Such cheap machinery and labor may help new businesses to start, but it may hinder established firms who pay regular wages and must amortize higher capital

costs. The result may be that a new business start does not reduce the number of unemployed in a given area (Atkin, Brinks, and Vale, 1983).

Such findings certainly do not support the idea that small firms are the key to industrial growth or to massive job development. Small businesses cannot replace the jobs lost in smokestack industries such as steel, heavy machinery, or shipbuilding. Encouraging and assisting new small businesses in depressed areas may be an especially high-risk investment, as there is often no way for the new firm to escape its dependence on local conditions and local markets. Storey's research is continuing. For example, he is pursuing the development of indicators that can predict whether a new enterprise will be a "winner" or a "loser." Actually, it is already clear that demographic considerations are bound to be predictive in the aggregate, with more winners in southeast and southwest England than in the northern industrial regions.

A different approach to research on small businesses was taken by Richard Scase and Robert Goffee at Kent Univ. (Canterbury, England CT2 7NZ). They looked at employment relations and at growth propensities in 100 small businesses. Just as the common wisdom holds that small business is a key to new jobs, there is also a prevailing belief that human relations are better in the small enterprise, where the owners and managers can know all employees personally, and where there is often no labor union. It turned out that many employees do indeed appreciate the "high trust" concept of work in a small-business environment. The manager trusts the worker to deliver a "fair day's work," and the worker trusts the manager to leave him alone to "get on with the job," to design and schedule the work, and perhaps to improve the work situation. The arrangement often gives the staff people a sense of discretion and autonomy at work, and it also enables the owner-manager to concentrate on marketing, finance, and other activities.

A rather surprising observation in the Kent study was that an owner-employer's attitude about employee relations was by far the best predictor of a company's attempt to grow. Apparently, many owners are afraid that growth will cause the loss of their personal control over the enterprise. Also, though many owner-managers have a high opinion of themselves as businessmen, they are not so sure of their skills in organizing and supervising the work of others. So they may choose *not* to expand, even when markets, availability of financing, and technical prospects seem quite positive. Some entrepreneurs thought that if their enterprise expanded, they would have to give up their "productive" or output-related work and instead would have to spend all their time in administration and staff meetings. Some believed, too, that growth would bring new administrative requirements, which would increase overhead in the business, and thus make it less "lean and mean." It appears, then, that supervisory style preferences and administrative self-confidence are major factors in small business growth.

What about the rather few companies that do expand and that do change from a personal entrepreneurial style to a different management setup? Scase and Goffee found that two alternatives covered a large fraction of the successful expansion cases. One was a Drucker-type scheme of management, wherein a few senior executives just below the owner-manager level are engaged in setting and meeting sales and production objectives; each executive answers directly to the main entrepreneur. Another option was to spin off small "operating" units or companies. Each of these could be a separate financial or corporate unit, but the owner would maintain real control throughout. In either model, to accomplish the switch from a smaller integral company to one of the two options might require financial and legal sophistication, which the typical small businessman would not possess (Scase and Goffee, 1982).

Scase and Goffee noted a strong "self-selection" process in their set of 100 small industrial units. Often there is little room for continual conflict between employees and owners; those who disagree with company objectives and methods have only one option, to leave. Those who remain are just those who do share goals and values, and thus the "happy family" atmosphere is largely a self-selection phenomenon.

The data from the Kent survey point up several problems that are mystifying, to say the least. A large fraction of managers value the personal-relations features of their businesses so highly that they actually resist expansion rather than face the prospect of a big firm's management problems. But they expressed no desire to take management courses, hire management consultants, and take other steps to improve personnel management. Why this resistance to management problems and variables? Most management tasks are not nearly so taxing, in a strictly intellectual sense, as some of the technical problems

that any significant business has to face. There are perhaps two major reasons for avoiding big-industry personnel management. First, in a large organization, disgruntled employees do not leave the system; they stay within it and try to change it to their own benefit. Second, instead of an emphasis on trust and shared values between staff and management, the industrial relations system may seem to accentuate value differences between groups of people. Large industries may appear not to honor excessively the contributions of management, and in various ways may discourage personal control of the enterprise by one or a few individuals. Managers, it seems, do not want to face this challenge to their autonomy every day. Another small surprise, which several British investigators noticed but which was emphasized by Storey, involved government assistance programs. People who start small businesses may be quite willing to accept government loans and grants, but they are generally wary of government and would usually prefer to be left alone. Small businesses do not systematically explore the small loan programs and send applications to several government agencies. Apparently, the entrepreneur thinks that government acts too slowly, and believes that the civil servants who run advice centers or approve loans are not to be trusted because they have never operated a business.

The legendary upas tree was believed to have the power to choke off other plant growth within a radius of 15 miles of its shade. Something similar seems to happen with heavy industrial complexes, which kill nearby enterprises. New businesses do not often sprout up near giant steel mills, for instance; the singular nature of the mill product, the enormous capital investments, and the highly organized but semiskilled nature of the human work required seem to prevent new spin-off enterprises in the area. The large plant does not seem to develop its employees in the kinds of problem-solving skills and flexible thinking that new enterprises demand. A large industrial complex may narrow the spectrum of occupation within a region, and it seems that innovation and enterprise flourish best in an area with a highly variable work pattern. Education and opportunity for management experiences also may be essential features that favor new ventures, and again the large plant seems to squeeze them out (Lloyd and Dicken, 1982).

There are interesting parallels between the successful Cuban entrepreneurs in Miami, FL, and the Asian immigrants in the West Midlands of England. In the Midlands 20 years ago, there was no substantial clothing industry owned and operated by Asians; now the area industry turnover is the equivalent of about $250 billion a year, and it is dominated by Indians and Pakistanis. In retrospect, the positive mechanisms seem clear enough. Some years of working at relatively high wage rates in the heavy engineering industries, along with Asian habits of saving, provided sufficient capital for a small operator to get started. Cheap premises became available as local shops and factories closed. There was ample cheap labor among the Asian women and ready local markets to which a small operator could quickly respond. All this was done almost entirely without government assistance, though probably at great cost to the Asian women doing the semiskilled hand work. It seems unlikely that the remarkable growth of the industry within the last two decades will continue in the same way. Now that the industry turnover is so large and individual units have attained significant resources, there probably will be more standardization and amalgamation among small operators, and financial arrangements will more closely resemble those seen in other businesses (Ward, 1983). In Miami, one now finds "Cuban banks," trust companies, real estate trusts, and corporate conglomerates; there is every reason to expect similar trends in the West Midlands textile scene.

"Labor hoarding" occurs when the output of a business falls but the employer does not make similar reductions in staffing. During the 1980 recession, industrial output in Britain fell sharply, by about 16%; but employment fell only 9%. A team at Warwick Univ. (Coventry, England CV4 7AL) has been investigating the causes of labor hoarding. Their conclusion is that two factors are primarily responsible: technical inflexibility and plant closure policy. In some industries, a certain number of people must be on hand simply to operate the plant, and such employees cannot be laid off as output decreases. If a firm anticipates only moderate fluctuations in demand and sets up a technology that is rather inflexible but is believed to be capable of long-term profitability, then the firm has few options. In fact, if large downswings in demand occur, closing the plant may be the best choice. Ordinary industrial statistics do not yield much information about the effectiveness and long-term impact of labor hoarding in various production sectors; for example,

if labor hoarding results in permanent loss of industrial capacity, then increase in demand may not affect the level of unemployment, as the demand is satisfied by imports (Deaton, Turk, and Bowers, 1982). Nobody knows how much labor hoarding occurs in new, small enterprises and in the high technology industries.

From a methodological standpoint, the British research on small business development shows that present interviewing and statistical techniques are quite adequate to explain some complex questions about small enterprises, new jobs, growth, and productivity. However, one cannot simply sort through official statistical reports and extract the desired information. Sharply focused special studies are required; a strength of the work briefly reviewed here is that each research team looked at the new enterprise situation from a slightly different viewpoint. While studies like these may not easily solve the problems they explore, they can certainly indicate the limits of proposed solutions and political-based litanies.

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Scase, R., and Goffee, R., *The Real World Of The Small Business Owner* (London: Croom Helm, 1982).

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N.A. Bond, Jr.

CHEMISTRY

HIGH POLYMERS AS THIN FILMS

The 23rd meeting of the UK High Polymer Research Group dealt with polymers as thin films. One of the principal objectives of the group's meetings is to make polymer scientists aware of contemporary trends and developments in a specific subject.

The conference was held from 25 through 29 April at Moretonhampstead, Devonshire. Prof. J.C, Bevington (Univ. of Lancaster) was chairman, and Prof. A. Ledwith (Univ. of Liverpool) organized the program. This year the program centered on the synthesis and properties of thin polymer films and on the devices that can be made from them. There were 100 delegates, including 13 from the US, two from Canada and nine from Western Europe. Fifteen lectures were presented, seven from the US and eight from the UK. The unusually high proportion of contributions from the US was ascribed to the predominance of American developments in this particular field. All the lecturers and participants attended by invitation of the organizing committee; no proceedings will be published.

The general introduction by Ledwith distinguished two main themes: (1) the development of polymers with special electronic and optical properties for use in microelectronic and even molecular electronic devices, and (2) the fabrication of polymeric molecular, monolayer, and multilayer membranes with functional properties resembling those of biological materials.

Dr. J.M. Feast (Univ. of Durham, UK) discussed "New Methods for the Synthesis of the Polyacetylenes." One method involved a metathetical ring opening technique via a soluble intermediate polymer. *ESN* 37-5:167-168 (1983) describes one specific example. Feast presented four additional examples; the general scheme may be represented as shown in Figure 1.

The initial soluble polymer, B, was formed by opening the cyclobutene ring using a metathesis catalyst prepared from tetramethyl tin and tungsten hexachloride. Finally, the polyacetylene and expelled compound, C, were formed by heating. The temperature range needed for the various compounds and the expelled aromatic compound are shown in Table 1.

Thin coherent films of polyacetylene were produced in this way. The films have a chemical structure similar to that of the conventional polyacetylenes and can be doped to similar levels of conductivity. The films are catalyst-free and are processible. Details of the synthesis are to be published in *Polymer*.

The synthesis of two other classes of conjugated polymers was also discussed. One involved the Diels-Alder addition of dichlorvinylene carbonate to

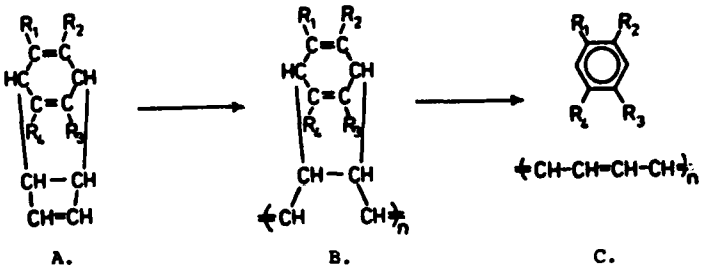
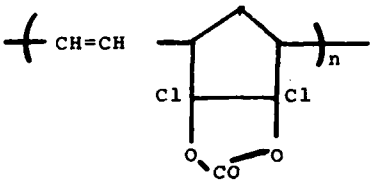
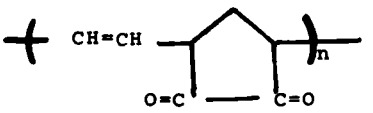


Figure 1. Metathetical ring opening technique.

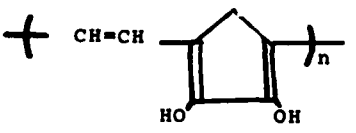
cyclopentadiene followed by the polymerizations of the adduct to:



This is a soluble polymer and can be cast into clear films. On heating the polymer changes to:

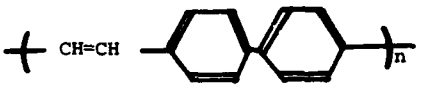


which subsequently can be enolized to the black and shiny conjugated polymer



The electrical properties have not yet been investigated in any detail.

The poly (arylene vinylene)s are a second class of potentially interesting polymers. These can be prepared, for example, by the condensation polymerization of 4,4' dibenzoylbiphenyl to the soluble polymer:



Some details of the work have recently been published (Feast and Millchamp, 1983).

Prof. G.W. Gray (Univ. of Hull) reviewed the synthesis and properties of liquid crystals, mainly nonpolymeric. Thin films of nematic and smectic crystals about 5 mm thick could be prepared on glass plates aligned parallel or perpendicular to the substrate; by ordering, these lead to light extinction. Polymeric forms with optically active molecules could also be used in thermography, including thermal mapping. Certain side chain polymers also are of interest for electro-optical displays. The polysiloxanes are useful backbone polymers. No new information was presented, and the background has been described in some detail by Gray (1979).

Dr. P. Pantelis (British Telecom Research Laboratories, Ipswich) presented a paper on the properties and applications of piezoelectric polymers. The basic principles and crystal forms of polyvinylidene fluoride, the most effective piezoelectric polymer, were briefly reviewed, including the poling and aligning mechanisms and techniques. The material is usually available as films prepared by blowing or flat-die extrusion. The films are then poled at an elevated temperature by application

Table 1
Temperature Ranges

$R_3 = R_4 = H$ in each case except 4, below

1. $R_1 = R_2 = -CF_3$	50-120°C	o-ditrifluoromethyl benzene*
2. $R_1 = R_2 = -COOCH_3$	50-120°C	dimethyl phthalate
3. $R_1 = R_2 = H$	20-50°C	benzene
4. $R_1 = R_2 =$	100-150°C	naphthalene
5. $R_1 = R_2 = R_3 = R_4 =$	175-200°C	anthracene

*See also *ESN* 37-5:167-8 (1983).

of an electric field or by a corona discharge at room temperature. Stretching changes the crystal phase to the planar zigzag conformation (Form 1 or β); poling lines up the dipole in the field direction, leading to the actual piezoelectric properties. Although other explanations have been proposed, the molecular dipole orientation appears to be generally accepted. Both uniaxial and biaxial films were said to be useful. The films are metallized on one side with aluminum or nickel before poling, and the finished film is metallized on both sides. Isothermal aging of the films at 67°C caused an initial small drop in piezoelectric activity, which then appeared to be stable for more than 1.5 years.

Applications in telecommunications include electroacoustic transducers in microphone receivers and sounders in telephones (Cleaver and Pantelis, 1982). British Telecom has developed techniques for the continuous production of poled piezoelectric small bore tubing (Pantelis, 1983). Poling was achieved with a corona discharge applied outside with a grounding wire inside the tubing. Wall thicknesses of >100 microns have been achieved. The pyroelectric response of the tubing has been used for measuring absorption losses in single-mode optical fibers (Kashyap and Pantelis, 1982). Since polyvinylidene fluoride has an acoustic impedance quite close to that of water, underwater transducers for sonar applications should be a possible application (see Bloomfield et al., 1978, *for example*). Considerable ingenuity is clearly needed to exploit these possibilities.

Dr. J. Brettle (Plessey Research Center, Towcester) reviewed the use of photochromic films for optical data recording. The films provide rather slow but inexpensive reversible processes with potentially large storage capacities. The materials are colorless in their quiescent state but change to a deep color with light; the change in refractive indices on exposure can also be exploited. Cheap solid-state lasers can be used. Plessey has developed a number of useful photochromic materials that can be dispersed in polymeric matrices either by mixing in the melt, by the use of solvents, or by polymerizing *in situ*. See *ESN* 37-2:63-66 (1983) for a general discussion of the efforts of Plessey research in semiconductors, electro-optics, and new types of electronic devices.

Dr. R. Kellner (Crossfields Electronics Co., London) reviewed the laser gravure printing process. Gravure printing surfaces were generated by the ablation of polymers using a high-powered, carbon dioxide infrared laser. Kellner often used epoxies and novolac resins, sometimes filled with carbon black. The technique also can produce photogravure cylinders.

Prof. N.B. Graham (Univ. of Strathclyde) reviewed his work on the use of polymeric thin films for the microencapsulation of solids. The films are used primarily for the controlled release of drugs and similar applications (see also *ESN* 37-6:202-5 [1983]). One of the

drugs, for example, is β-estradiol, used as a promoter for menstruation. Crystals of the drugs have been successfully coated down to less than 1-μm diameter. Langmuir-Blodgett (LB) films were used to give information about the number of layers of the polymer coating needed for adequate coherence. It was found that the prior absorption of monolayers of surfactants acted as a template for the subsequent formation of the polymeric coating. The coatings were deposited by precipitation or interfacial polymerization. Details of the actual methods were not disclosed because patents have not yet been granted.

Dr. D.H. Roberts (Director of Research, General Electric Co., Hirst Research Center, Wembley) described some of his experiences over 25 years in molecular electronics. (The work of the Hirst Research Center was reported in *ESN* 37-7:257-60 [1983]). Molecular electronics was the term coined in the late 1950s to describe what have become known as SICs (silicon integrated circuits). Roberts stressed that research in new areas must take into account silicon work, including current developments. For example, studies of the electronic and optical properties of polymeric materials should be considered.

Finally, Prof. G. Roberts (Univ. of Durham) reviewed the formation and applications of LB monolayers and multilayers. He described the sophisticated systems required to deposit high quality films of suitable materials, such as anthracene, phthalocyanine, and diacetylene polymers. He described applications involving the deposition of LB films on various semiconductors, with special reference to field effect transistors, electroluminescent displays, and solar cells. (See *ESN* 36-12: 332-334, 340 [1982] for further details.)

The following is a list of the US contributions. Dr. R.H. Baughman (Allied Chemical Co., Morristown, NJ) gave an opening review lecture on "The Synthesis and Applications of Conducting Polymers." Dr. G.B. Street (IBM, San Jose, CA) discussed "Conducting Polymers Derived From Heterocyclics"; Dr. E.C. Chandross (Bell Telephone Laboratories, Murray Hill, NJ), "New Developments in Polymers for Optical Lithography"; Dr. J.M. Pearson (Eastman Kodak Co., Rochester, NY) "Optical Recording in Polymeric Media"; Dr. D.J. Williams (Xerox Corp., Webster, NY), "The Preparation and Characterization of Polymeric Materials with Large Non-linear Responses"; and Dr. A.D. Ketley (W.R. Grace Co., Columbia, MD) "Dielectric Barrier Coatings for Printed Circuits." Finally, Prof. J.B. Lando (Case Western Reserve Univ., Cleveland, OH) reviewed "Some Possible Device Applications of Polymerized Monolayers and Multilayers."

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V.T. Stannett

COMPUTER SCIENCES

ROBOTICS AT ASEA

One of the recent important developments in robotics at ASEA (Vasteras, Sweden) is a new generation of robot controllers that place greater emphasis on man-machine communication.

The ASEA Group is made up of ASEA AB, the parent company, and 170 subsidiaries in 37 countries with about 56,000 employees; 36,000 of these are in Sweden. With the backing of the parent company, the Industrial Robot Division has become the leading robot manufacturer in Europe. New production units were recently started in the US and Spain. ASEA has also started a long-term program in Japan. Robot centers were inaugurated in Tokyo and Kobe; manufacturing will begin in 1983. Robot assembly will also start in France.

The real breakthrough in the robotics field was the introduction of microprocessors to control the systems. With microprocessors, an advanced and powerful control system for a multi-axis mechanical unit can be built without prohibitively high manufacturing costs. In real time, microprocessors can

convert operator commands or stored instructions to a flow of data that control and execute the desired function by the robot.

A sequence of two kinds of instructions must be defined. Position and input-output instructions define the movements and other functions of the robot. All operation commands are entered through some form of man-machine interface.

A robot is generally programmed and used through a programming unit connected to the robot or its control system. The unit is usually a function-oriented keyboard or a typewriter keyboard. A function-oriented keyboard has one panel with fixed keys for different, predetermined functions and one panel with digit keys. The function keys are pressed in a sequence corresponding to that in which the robot should execute various instructions. The digit keys allow one to add further details. Advantages of the method include the close connection between key and function and the possibility of building small portable units, which the operator can hold while programming the robot. However, as the number of required functions grows, so does the need for more keys.

The typewriter keyboard usually has a visual display unit combined with a smaller hand-held unit for controlling the robot. Commands and instructions are written letter by letter on the keyboard. Although the method allows a large number of functions and instructions, the operator must have a good knowledge of the programming language used. It is also a time-consuming system.

ASEA's new robot control unit combines several of the advantages of the above two systems. It has a "joystick" and a self-instructing, interactive dialogue. The joystick is used for manually running the robot, and the interactive dialogue is for programming and for communication between the operator and the robot system.

The programming unit is a panel with keys, a display, and a control unit. The control unit includes a joystick that has three degrees of freedom and that can be signaled between control of robot arm and robot wrist. The control unit also has an enable function and an emergency stop. The alphanumeric display has 2×40 characters of the fluorescent type.

Positioning the robot gripper involves controlling the arm in five or six degrees of freedom. To control the movements of the gripper, rather than each robot axis, one needs to control the position and orientation of the gripper in a straight-line or cylindrical coordinate system.

A common method is to use two push buttons per axis for lateral movement and a separate knob for speed control. By operating a joystick, however, one can determine directly a movement's direction and speed to give a more natural and surer positioning of the robot and to shorten programming time.

Several tests at ASEA showed the following:

1. A joystick is quicker than other methods. A 25% reduction in positioning time was measured on the average.
2. Learning was faster on the joystick.
3. Operators with a lot of experience liked push buttons best. However, measurements showed that the same operators positioned the robot more quickly with a joystick.

The joystick has three degrees of freedom; therefore, the position can be controlled in the x, y, and z axis or in the r, z, and θ axes. The joystick also can be run in hand-oriented coordinates. In this mode, there is a straight-line movement in the wrist or gripper, or a movement at right angles to it.

The Z movement (up and down) is brought about by turning the knob of the joystick. To alter the orientation of the wrist with its position unchanged, the joystick function can be switched over to the wrist with a selector switch. The three degrees of freedom of the joystick then allow the gripper to be rotated around one of its three axes.

All movements of the robot apply to the Tool Center Point (TCP). This means that a determined point on the gripper has been defined by the operator as the working point and that all movements are actually calculated in the microprocessor for this point. When we say the position of the robot is changed, we refer to the TCP. When the orientation of the gripper is changed, the position of the TCP remains unchanged and the gripper rotates around the TCP.

By using an alphanumeric display and five function keys, an interactive dialogue between the operator and the robot system can be carried out. The five control buttons are used for programming position (POS), programming other instructions (INSTR), editing (EDIT), manual operations (MAN), and automatic running (AUTO). Pressing one of the function keys causes the system to define the permissible subfunctions by displaying a new text above the

function keys. The operator thus sees which functions are permitted and can directly program the desired function by pressing the appropriate key.

The following are examples of instructions and functions available:

1. Movement of TCP along straight lines and in different modes can be combined with different supplementary functions, such as search; adaptive functions; and reference points. The movement takes place in rectangular coordinates or in robot-oriented coordinates. Rectangular coordinates give precise, linear movement. Robot-oriented coordinates enable rapid movement with less wear on the robot.
2. "Shift" means that a subprogram or a sequence of movements, can be programmed at one place in the working range; that same sequence of movements, with no deformation, can be performed somewhere else in the working range. Shift is then defined with a special function, reference point.
3. Adaptive functions include search, contour following, and speed control. Up to three sensors can be used simultaneously for search and contour following to ensure precise and reliable searching and following in several dimensions. The type of sensor can be selected rather freely--from simple on-off and digital sensors to fully analog sensors.
4. Pattern repetition is programmed with the aid of a subprogram. The subprogram is divided into one part for each pattern point. A register indicates which pattern point is to be executed.
5. An interrupt function allows the process or an external machine to interrupt the robot program. The execution then continues with a special subprogram that may contain instructions for dealing with errors or other service routines. When the subprogram is finished, the robot program continues from where it was interrupted.
6. Logic functions, such as conditioned jumps or conditional wait instructions, are used for interfacing and synchronizing the robot with an external process. Logic functions can be used when inputs or internal registers have assumed certain predetermined values.

Many main programs and subprograms can be stored in the robot memory. One subprogram may be used for each subsequence in the work schedule of the robot. This means that a flexible and expandable program library can be built up in the form of subprograms for standardization tasks. As one subprogram can be allocated to each subsequence, only the corresponding subprogram need be modified in conjunction with, for example, a change in layout of the peripheral equipment.

The various subprograms may call one another on several levels, which permits an efficient program structure. A floppy disk is used to store the main programs and subprograms.

It is possible to edit and check a stored program, instruction by instruction, without having to run the robot or execute the program. It is also simple to add or erase instructions or to renumber the program.

A subprogram can be amended, erased, and tested separately. The position in a positioning instruction can be modified easily, either by running the robot to the new position with the joystick or by entering a shift (in millimeters) in the x, y, or z axis with the aid of the digit keys.

With the recently developed control system, ASEA appears to be in a good position to broaden its operations and to cover more applications, such as materials handling, inspection, assembly, and machine tending.

J.F. Blackburn

SOFTWARE SYSTEMS RESEARCH AT LINKOPING INSTITUTE OF TECHNOLOGY

The Software Systems Research Center (SSRC) organizes research activities in software technology at the Linkoping Institute of Technology, Linkoping, Sweden. The purpose of the center is to develop a broad competence in various aspects of computer software, to carry out research projects relevant to industry and the society in general, and to pursue work motivated by basic research interests.

The SSRC, supported by the Swedish Board for Technical Development, is organized into three cooperating laboratories: application systems, programming environments, and artificial intelligence. A common systems group provides computer services for all the laboratories. The application systems laboratory works closely with the Department of Medical Informatics and the artificial intelligence laboratory with the Department of Mechanical Engineering. The following information was provided by the SSRC's Prof. Eric Sandewall during my June visit to the center.

The Laboratory for Application-Oriented Software Systems

The charter of the laboratory is to carry out research on specialized tools for the development of applications software, with emphasis on personal information management systems and office systems. Design principles for information management systems (IMSs) have received a great deal of emphasis over the past year. The term IMS applies to systems that maintain a collection of data and allow interactive manipulation of those data. When the systems are programmable, they provide a technique for developing computer applications as an alternative to writing a new program for each application. This offers certain advantages:

- Costs for developing software are lower because the parts of an interactive program that reappear in similar ways in several applications do not have to be reprogrammed each time.
- Documentation and extension of the software is easier because fewer parts are peculiar to the application.
- It is easier for the user to start using computer services because he can begin by learning the general purpose services in the IMS and gradually proceed to the extensions that are needed for special-purpose services.
- There is no need for the user to learn the different ways of doing the same thing in different interactive applications.

Two projects at Linkoping have provided motivation for the study of IMSs. First, an information flow model, which has been developed in the medical information system project, describes a wide class of administrative applications. The model has included a number of application experiments, implementation of experimental support systems for rapid prototyping, and implementation of applications described in terms of information flow. The IMS systems under way during the last year serve the needs of information flow models. The second project, a hierarchical editor, grew out of work on text formatting and text editing. The structure of a hierarchical editor reflects the natural structure of a document and can be a convenient, powerful, and flexible tool for information management.

The Application Systems Laboratory is organized as three project groups:

1. The Elements of Interactive Environments (ELIN) group studies architecture and design principles and develops supporting theory. Implementation experiments may assume a laboratory environment, although externally defined applications are emphasized.

2. The Advanced End-User Facilities (ED) group studies a restricted family of IMSs, emphasizing efficient implementation techniques. It is important to find out how efficient versions of IMSs should be designed. For this work, systems must be delivered to industry and tested under realistic conditions.

3. The Applications Software Development Environments (ASDE) group studies how IMS features that have proved successful in a research setting can be incorporated in commercial environments for application development in the near future.

ELIN. The ELIN group has concentrated on the theory of information management systems and their implementation, application modelling based on IMS theory, and experimental implementation.

Some common characteristics of IMS are a "create" command for introducing new items into the data base, a "print" command for showing one or more items on the screen, a "find" command, and an "edit" command. Names may vary but the functions are common.

The ELIN group believes that a theory of IMS must account for the following characteristic features: the existence of a collection of data that can be manipulated in the system; the existence of a logical cursor or point of attention in the data; a repertoire of operations on the data, usually defined relative to the logical cursor--for example, "delete" after cursor or "insert" after cursor; and conventions for displaying a segment of the data on the terminal screen.

The following basic concepts have been developed for IMS theory: (1) the data structure is viewed as a tree where each node is associated with a set of attributes; (2) the description of the display is separated from the description of the data base, the cursor, and the operations; and (3) the display mapping (from nodes in the tree to screen positions) is not specified explicitly but only as a number of constraints on the values of attributes in neighboring nodes in the tree.

The next step is to use the framework described above to model actual IMSs. The goal is to get a concise description of all the specialized phenomena that arise in an actual system.

The information flow model developed over the years defines a number of operations that can be performed along the route of information flow. The objective of ELIN's application modeling project is to provide a precise definition of the information flow operations in terms that are the same as, or are compatible with, IMS theory.

Also, several other special purpose languages that can capture an application phenomenon are needed. Some typical software products in the administrative data processing area have been studied in order to identify phenomena that could be modelled usefully. Present work is on "scalar resources"--those that have a specific amount at a fixed time. An example is the amount of money in an account or the number of items in stock of a particular article.

The experimental implementation project deals with upgrading an existing conventional office automation system with separate programs for text editing, mail, and other functions.

The first substantial step of the upgrade was to provide data structures (including array, record, and sequence) represented as permanent data in the file system, rather than as temporary data administered by the run-time system of a particular programming language. The data structures can be nested arbitrarily, and the elements can be either numbers, strings, or symbols. The system is implemented as a set of procedures that perform operations such as "create record of a given type," "inspect value in given field of given record," or "change value of given field of given record to given new contents." The system can be used as a subroutine library for implementing programs in the Pascal language, and a special interface makes the same procedures available in the Interlisp system as well.

The second step was implementation, in Interlisp, of an actual MIS based on the new IMS theory. The third step was the implementation of a manager system entirely in Pascal language and based on the previously described data structures.

ED. The ED group has been developing a generalized tool, a universal data editor, for the manipulation of text, formatted data, and pictures--assuming the use of hierarchical structuring as an aid for managing the stored information. The basic approach conforms to the IMS model, although a conservative subset of the structuring mechanisms is used. The actual work investigates how text, graphics, and forms management should be properly integrated and manipulated for the ultimate user. The structure-oriented text editor, called ED3, has been consolidated, and graphics extensions have been tested in realistic applications.

ASDE. The ASDE group has a long-term goal of contributing to the development of aids for producing applications software in a problem-oriented fashion. The approach is based on the assumption that programming language issues are less important than the software development environment, including support for an application-oriented conceptual framework and notation.

It is assumed that the software development environment has to contain at least the following components:

1. A human-computer interaction system especially for development and maintenance of application models.
2. A software data base for storage of reusable modules and program skeletons; application models, such as problem-oriented specifications of systems; program derivatives, including transformation of application models to an executable form; test plans and test data; and textual documentations.
3. A documentation system for presenting suitably selected and formatted information from the software data base.
4. A program generation and transformation system for producing optimized executable codes.

The work in the ASDE group concentrates on application-oriented aspects of the development environment. Some work has been done on components 1 through 3 above, while the work in component 4 is the responsibility of the program manipulation group in the Programming Environments Laboratory.

Specifically, development work has been on the following:

1. Models of dialogue and database query environments support multi-style human-computer dialogue interfaces and ways to organize a query system for business applications.
2. Application development tools for small businesses (in cooperation with L.M. Ericson Information Systems) are intended to reduce the effort needed for developing and maintaining standard business applications.
3. Software documentation and application-oriented specifications have assumed that programs are by-products of documentation, rather than the converse. The documentation problem within L.M. Ericson Information Systems was studied; relations between various types of

documentation were analyzed to identify common sources of information as a basis for reducing redundancy in documentation. The project produced valuable information about the documentation problem.

Programming Environments Laboratory (PELAB)

PELAB studies the architecture of a programming environment to provide powerful tools for program development. The study of properties of programming languages and their representation is another issue.

For the next few years, PELAB will concentrate on a project called DICE (Distributed Incremental Compiling Environment). The researchers are designing compiling programming environments to support incremental program development for Pascal-like languages. The integration of tools for interactive creation, editing, testing, and debugging of programs is a main objective. PELAB is trying to make the tool generators as language-independent as possible. DICE is a successor to Pathcal, which includes a Pascal interpreter, a parser for creating an internal structured program form; a structure editor; a printer; an interrupt handler and a state-saving mechanism. The system facilities are all treated as Pascal objects and are accessible from other Pascal programs. The system is implemented on a Digital Equipment Corporation DEC-20 system.

In DICE, a host-target configuration is considered. The programming environment, including a computer, resides in a host computer, and the program runs in a target computer that is connected to the host by a link of limited band width. The demand on run-time efficiency in the target is stressed, and the host compiles in target machine code. Code generation is incremental on statement level.

The method is based on a tree representation of the source program and is applicable to a wide class of languages. Editing can be done by a structure editor or a text editor coupled to an incremental parser. The editor marks new or changed nodes in the tree of the current procedure. Changed statement nodes are recompiled during a pre-order traversal of the tree. New and old machine codes are merged, and branch instructions in the old code are updated. Branch updating can be incremental on the statement level for languages with well-formed control structures on machines with go-to or control transfer instructions. The incremental compilation is consistent, and no degeneration of code quality occurs after many edit-compilation cycles. Dynamic linking is made easy by generating position-independent code and having an extra level of indirection at procedure calls.

Algorithms for fine-grained incremental compilation for the full Pascal language have been developed and are being implemented. The incremental compilation consists of two components: incremental passing and incremental code generation. The compiler is implemented in Interlisp on a DEC-20 and currently produces PDP-11 machine code of reasonable quality.

The Artificial Intelligence Laboratory (AILAB)

AILAB chiefly focuses on representation and manipulation of knowledge, problem solving, and natural language communication. The research is now being applied to mechanical engineering, partly because AI's emphasis today is on "expert systems." The objective is to analyze a human expert's behavior as information processing until a computable theory of his expertise emerges. The real difficulty is in finding out what information is involved at each point in the expert's behavior.

AILAB's work is exclusively concerned with operations planning for numerically controlled lathes. This domain contains many problems that are of great interest in AI: problem solving with highly interactive subgoals, explicit reasoning about problem-solving strategies, resource-sensitive planning, data dependencies, geometric reasoning, and highly pragmatic communication. Human experts are usually not aware of all the knowledge they use in solving a particular problem. In addition, the knowledge in question already may have been systematized for a different purpose--a textbook or manual of operation, for example.

Four specific projects are under way in AILAB. One deals with abstraction and representation in automatic planning. The central problem is how to master the huge amounts of knowledge necessary to solve realistic planning problems. Two AI working papers have been written in planning for lathe-turning. "The Lathe World" (AI-WP No. 6) contains a description of the lathe in a frame-oriented notation. "Physical Objects: A Geometric Perspective" (AI-WP No. 8) is a survey of the techniques used to represent geometry, which is of paramount importance in lathe turning.

An exploratory study with the main goal of providing participants with experience about work with expert

systems is also under way. The project now concentrates on problem solving and representation issues; communication difficulties will be studied later. Specifically, the problem of choosing the appropriate clamping method for an arbitrary work piece to be turned on the lathe is being examined. Thus far, the clamping problem has been structured into a set of sub-tasks. A set of geometric concepts that seem useful for problem solving has been hypothesized. Researchers have extracted a set of planning operators, mainly useful for determining whether inner clamping of a work piece is possible. Analysis of planning strategies has been started.

The third project is concerned with dependency nets and nonmonotonic logic. AILAB is concentrating on the design of dependency nets and on their use for knowledge representation and influence. The update algorithm is the central algorithm of a dependency net. The major result of the past year's work on this project is a completely new algorithm for the nonmonotonic update problem discussed in a report by J. Goodwin (1982). The algorithm improves performance and understanding in the following ways:

1. Time complexity is reduced; an upper bound has been proved for the first time.
2. Modularity in code and functional specification is improved.
3. Unsolvable configurations in the input are detected without extra checking.
4. Multiply solvable configurations in the input are detected without extra checking.
5. The algorithm converges monotonically toward its goal without backtracking.

The goal of the final project is to develop models of human verbal communication. AILAB's theoretical research will be accompanied by the implementation of an experimental natural language interface. With such an interface, a computer system ought to follow a user's spoken instructions. The following problem areas will be the principal focus of the work:

1. Robust parsing. Methods need to be developed to analyze the grammar of user input which is "human" in the sense that it may contain minor errors (e.g., spelling), as well as restarts and corrections.
2. Goal or plan-based interpretation of user-input. There will be an attempt to make assumptions about the sender's communicative goals and to interpret his utterances as rational actions that are part of a plan to realize one or more of the goals.

Reference

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J.F. Blackburn

ELECTRONICS

EUROPEAN MICROWAVE SEMICONDUCTOR DEVICES CONFERENCE

Heterojunctions and two-dimensional electron gas devices were of particular interest at the European Specialist Workshop on Active Microwave Semiconductor Devices. The workshop also addressed materials, unipolar devices, and bipolar devices. Held about every 18 months, the workshop is primarily intended to meet the needs of European scientists. The 1983 meeting, the eighth in the series, was organized by Prof. Peter Robson of the Univ. of Sheffield. (Prof. Robson recently was honored by Queen Elizabeth II; see the note elsewhere in this issue.)

Materials and Processing

During the past decade, many laboratories have become eager to install organometallic chemical vapor phase (OMCVD) epitaxial reactors because the devices can grow semiconducting layers with extremely sharp interfaces. Over three orders of magnitude change in carrier concentration within a 1,000-angstrom region is typical of the n+/n- interface control obtainable with the OMCVD process. Thompson-CSF near Paris has the greatest concentration of OMCVD reactors. S.D. Hersee of Thompson opened the workshop with a paper describing the first large production OMCVD reactor, known as the MR200. It is designed as a small bell jar within a larger bell jar. Twenty different 3-in.-diameter wafers can be mounted on the outer surface of the inner bell jar, where their surfaces are exposed to the reactant gases flowing between the two jars. Careful attention to design ensures a laminar flow of gases between the jars. The gases are introduced at the top surface of the inner bell jar and are symmetrically dispersed down the sides. Researchers must be particularly

careful that any change of gas flow rate and the introduction of dopant gases introduce no turbulence. Hydrogen consumption is 25 l/min and gas flow rate is 20 cm/s. Substrate heating is provided by infrared lamps.

Binary and ternary compounds of Ga, In, As, and P were grown. Reactants used included trimethyl gallium, trimethyl aluminum, triethyl indium, arsine, and phosphine. Silane was used as the dopant gas. As the OMCVD system does not have the inherent *in situ* etch capability of an $AsCl_3$ system, the growth of a buffer layer is mandatory to "cover up" the Mg, Cr, and Fe impurities that tend to pile up on the substrate surface. Growth rate primarily depends on the cation flow and is relatively independent of temperature. Temperature is held within the 600 to 750°C diffusion-limited range, and growth is typically adjusted between 0.1 to 0.3 μm/min.

Two-layer InP Gunn diodes were grown in the MR200 system. The devices exhibited 125 mW power at 84.5 GHz with 3.3% efficiency. The diode material impurity and mobility characteristics were as follows:

$N_d = 3\times10^{15}/cm^3$; μ_H=7800@RT, 40,000@77K
$N_d = 1\times10^{15}/cm^3$; μ_H=5400@RT, 60,000@77K
$N_d = 1\times10^{17}/cm^3$; μ_H=4800@RT

Other devices made with the MR200 were a two-dimensional electron gas structure (2DEG), also called high electron mobility transistor (HEMT). In it, a GaAs buffer layer was grown; it exhibited a net donor concentration of $4\times10^{15}/cm^3$. On the buffer layer a 200-angstrom undoped GaAlAs spacer layer was grown, and on that a 600-angstrom GaAlAs layer. The sheet carrier concentration in the 2DEG region of the GaAs (adjacent to the undoped GaAlAs) was controlled by the thickness of the undoped spacer layer, and at low concentrations there was evidence of trapping in the space layer. Nevertheless, 2DEG Hall mobility--162,000 $cm^2/V.s.$ at 4°K--is thought to be the highest ever obtained in OMCVD 2DEG structures and compares to mobilities of 2×10^6 obtained by molecular beam epitaxy (MBE).

As heterojunction device potential grows, the search for a stable acceptor implant gains momentum. R. Sweda (Plessey, UK) has investigated 200-keV Mg implants in GaAs annealed with a silicon nitride encapsulant. At a fluence of $10^{13}/cm^2$, 25% of the implant was lost in diffusing through the cap, and diffusion in the GaAs was significant. A mobility of 100 $cm^2/V.s.$ was achieved. It thus appears that Mg may be used for p- type implants, but its use for p+ requirements may be limited.

Although the 2DEG/HEMT structures have created a considerable amount of worldwide interest and an impressive investment in Japan, their superior performance has been mostly limited to cryogenic temperatures. Prof. H. Dämbkes of Duisburg Univ. (Federal Republic of Germany [FRG]) has studied the underlying causes of such limitation and has proposed a remedy. Using MBE fabrication, he made several 2DEG transistors characterized by 1.0-μm control gates and varying source-drain channel lengths. With transmission line measurements, he was able to separate the resistivity contributed from the contacts from that of the 2DEG sheet. He found that good ohmic contacts were exceedingly difficult to reproduce in the conventional HEMT structure, because the 2DEG is extremely thin and is easily destroyed by the alloy contact itself. The typical high-resistance contact decreases the transconductance (gm), increases the on-resistance, and may even cause a blocking contact to appear at low temperatures. By depositing a 200-angstrom n+ GaAs contact layer on top of a 600-angstrom GaAlAs layer, a contact resistance of 0.2 Ωmm was reproducibly obtained. Contact to the n+ GaAs layer was made by a 1,200-angstrom AuGe:Ni deposit alloyed for 1 minute at 500°C. Even with the low contact resistance, the channel on-resistance exceeded 7 Ω and was primarily attributed to the sheet resistance of the thin 2DEG. Using a maximum donor concentration of $10^{18}/cm^3$ in a GaAlAs 500-angstrom-layer (to avoid deleterious parallel conduction), Dämbkes theorizes that 10% of the donors transferred to the 2DEG will limit the 2DEG sheet resistivity to 1,200 Ω/□ or 12 times that of a GaAs metal Schottky field effect transistor (MESFET) with recessed gate technology. By etching through the n+ GaAs contact layer for a gate recess, Dämbkes was able to fabricate a FET characterized by a 4-μm source-drain channel length, a 300-μm channel width, and a 1.1-μm gate length exhibiting a 2.3 dB noise figure (NF) at 7 GHz with 12 dB associated gain at room temperature. He calculates that if the gate resistivity could be lowered, a 1.3-dB NF could be achieved. (Because the 2DEG is most effective only in the region immediately beneath the control gate, HEMT structures should further benefit from self-aligned gate design.)

Although self-aligned gate structures appear to be the trend, processing can be difficult as the etch used to undercut the gate metal (and thus reduce

its effective length without adverse effect upon its conductivity) typically undercuts the semiconductor as well. The undercut of the semiconductor adversely affects the transconductance and the saturated channel current. A. Centronio (Selenia Research Laboratories, Rome) has found that adverse undercutting can be greatly reduced by electrically grounding the aluminum gate metal to the active semiconductor region during etching.

Microwave FETs a la 2DEG

Much time was spent discussing a common name for FETs using the heterojunction interface to increase effective channel mobility; but participants could not agree on a common acronym. Originally, R. Dingle of Bell Laboratories proposed SDHT for selectively doped heterojunction transistor, a multilayer device now affectionately called the single Dingle heterojunction transistor. The most intense effort to develop the devices is at Fujitsu in Japan; they prefer the HEMT acronym. Thompson-CSF also is heavily committed to the device and prefers the 2DEG acronym.

T. Misugi of Fujitsu reported on several HEMT devices. Switching FETs were of the enhancement mode type, with integral nonlinear depletion mode FETs as loads. Representative characteristics were: 22 ps at 360 μW, 17 ps at 1 mW, and a record 12.8 ps at higher power. (The lowest power figure is still several hundred times that of Josephson junction logic devices).

Misugi also presented data on microwave HEMTs after first showing that HEMTs have an inherent 1.6:2.5 advantage over GaAs MESFETs in the fitting factor (K_f) of the Fukui noise equation. The Fujitsu HEMTs had a double-fed control gate measuring 0.5×200 μm. Room temperature results were:

12 GHz	1.7 dB NF	12.0 dB $G_{assoc.}$
20 GHz	3.1 dB NF	7.5 dB $G_{assoc.}$
8 GHz	1.3 dB NF	13.0 dB $G_{assoc.}$

At 77°K:

12 GHz	0.3 dB NF	12.0 dB $G_{assoc.}$

A four-stage stripline amplifier was built; it had a 3.9 dB NF with 30 dB associated gain at room temperature while operating over the 17.6 to 19.2 GHz band. The amplifier had a waveguide input and output. At 12 GHz the stripline amplifier had a 1 dB NF at room temperature and a 0.35 dB NF at 100°K. Misugi stated that Fijitsu expects further improvements by using ion implantation (and presumably self-aligned gate technology) to cut source resistance from 4 to 2 Ω. The Fujitsu devices use GaAs overlayers for ohmic contacts, but the transition is graded. Mitsugi's report may be the first on multistage millimeter wave low noise room temperature HEMT amplifiers.

N.T. Linh of Thompson-CSF reported on 2DEG FETs with gates of 0.55×300 μm recessed 600-angstroms into a 1,000-angstrom-thick GaAlAs layer. Performance obtained was:

10 GHz	1.3 dB NF	10.9 dB $G_{assoc.}$
18 GHz	2.25 dB NF	6.6 dB $G_{assoc.}$
18 GHz	2.3 dB NF	7.1 dB $G_{assoc.}$

The NF was 0.2 dB better than a commercially available NE 673 GaAs MESFET, and the associated gain was about 1 dB better. When operated at 160°C, the NF dropped to 0.25 dB at 10 GHz and exhibited an associated gain of 13.3 dB; thus it is superior to a parametric amplifier operating at the same temperature. At 105°C the GaAs carriers appear to freeze out, and the resulting reduction in carrier density offsets the enhanced mobility. A source resistance of 20 Ω was measured, and n+ GaAs overlay contacting layers apparently did not help. The NF was lowest at a drain voltage of 6 V. In contrast to Misugi, Linh reported that the fitting factor (K_f) in the noise equation should be the same for both conventional GaAs MESFETs and HEMTs. Linh did report, however, a 2.3:1.7 ratio of velocity at 77°K to room temperature velocity, but only in the region beneath the gate.

R. Sadler (Cornell Univ., NY) reported on GaAs MESFET technology using 0.75-μm lithography to produce 0.6-μm-long gates. The devices have 15.0-ps gate delay at room temperature (better than the HEMTs), but at a 5.6 mW/gate power consumption.

Heterojunction Bipolar

As lithographic resolution improves and chip density and complexity increase, the energy spent in charging and discharging the logic lines becomes a larger percentage of the total. As the transconductance of the bipolar device is much greater than that of an FET, the bipolars are receiving increased attention. European heterojunction research is under way at Plessey, The National Center for Telecommunication Studies (CNET, Paris), the Laboratory for Automation and Analyses of Systems (LAAS, Toulouse, France), the Univ. of

Lille (France), and the Univ. of Aachen (FRG).

D. Ankri of CNET provided the usual arguments in favor of heterojunction bipolar devices and some additional arguments. He stated that the heterojunction energy discontinuity must be <0.2 eV to preclude transferred electron effects; if this condition holds, then the velocity of the electrons injected into the base will be $>8\times10^7$cm/s and will experience a mean free path of 1,200 angstroms before plasmon capture. Using MBE growth and a graded interface, Ankri's devices showed a gain of 20,000 and an f_τ of 16 GHz. The base plus collector transit time was 4.9 ps.

J.P. Bailbe, (LAAS) described heterojunction bipolars fabricated by liquid phase epitaxy. The emitter had $N_d = 1\times10^{17}/cm^3$, the base was characterized by acceptor impurity concentration $N_A = 1\times10^{19}/cm^3$ and t = 0.5 μm, and a mesa structure was chosen. Performance was:

β = 20,000, I_C = 10A, f_{max} = 0.6 GHz, f_τ = 1.1 GHz, and V_{BC} = 120 V.

Y. Crosnier described how III-V heterojunction bipolars will minimize emitter current edge crowding--the fundamental limiting phenomenon for bipolar microwave power transistors.

InP Transistors

M. Armand (Thompson-CSF) described a recent record-breaking microwave power performance achieved by an InP FET operating in the accumulation mode. The devices were made by pyrolytically depositing 100-nm films of SiO_2 at 380°C. AuGe:Ni contacts define a 4.5-μm channel, while the Al gate measures 1.5×300 μm². The output power at 4-dB gain and 9 GHz was 920 mW--more than twice the power per unit gate periphery achieved by GaAs devices. A deep gate recess was used to ensure that the channel outside the gate region could handle the maximum current. Power added efficiency was 36%. Shelf life and reliability, apparently, are still unknown.

M.N. Yoder

QUANTIZING SEMICONDUCTOR LATTICE PERFECTION

The Laboratoire de Spectroscopie et d'Optique du Corps Solide is a part of the Louis Pasteur Univ. in Strasbourg, France. Although the laboratory had been noted for much work in the growth of II-VI semiconductors during the sixties and the seventies, the materials growth has largely subsided. In its place is an increased emphasis on new approaches to characterizing semiconductor materials. Among the techniques most used are Raman spectroscopy and electron paramagnetic resonance (EPR); optical carrier phonon resonance and ellipsometry are also used. Nondestructive characterization is emphasized.

Raman Spectroscopy

Raman spectroscopy is increasingly recognized as a powerful tool to determine how close a semiconductor crystal approaches perfection. The technique is based on the scattering of light from the semiconductor's surface. The scattered light of interest to the spectroscopist, however, is at a frequency different from that of the incident radiation. The frequency shift arises primarily from the coupling of the incoming photon to the vibrational properties of the crystal as carried by the optical phonons. The properties of the semiconductor thus determine the characteristics of the inelasticity scattered light. Amorphous material produces a low-intensity scattered signal over a broad spectrum, while single crystalline material scatters light characterized by high intensity peaks of narrow spectral content. Damage within the crystal shifts the response toward that of amorphous material, while electrically active impurities introduce additional spectral responses. By observing the ratio of light scattered at frequencies below the incident radiation to that scattered at higher frequencies, one can determine the surface temperature without contact. (This property has been the subject of a recent controversy relating to the actual temperature of a semiconductor bombarded with very short pulse laser beams.) The following characteristics of Raman spectroscopy have been most widely exploited: it has very high spatial resolution (e.g., 0.5-μm square), it is nondestructive, and it can be used for *in situ* measurement during semiconductor growth or processing.

C. Schwab and colleagues have introduced yet another use for Raman spectroscopy. With an argon ion laser

incident at the Brewster angle, the researchers adjusted crystal orientation and optical polarization so that there was no photon coupling to the transverse optical (TO) phonons; only the longitudinal optical (LO) phonons provided a backscattered signal. (The reason for this configuration is that the TO backscatter would occur at the same point in the spectrum where ω- plasmon coupling was of interest.) Beryllium was implanted into GaAs at fluences of 10^{14} and 10^{15} ions/cm^2. The material was annealed at 200°C, and the ω-plasmon induced shift of the LO signal was compared to that of virgin GaAs. A shift of 13/cm was found. In an iterative manner, the crystal was annealed at higher and higher temperatures, and after each annealing, the shift of the LO signal was recorded.

The unexpected was found. The LO spectral peak did not monotonically decrease approaching that of virgin GaAs. Instead, it reached a minimum (4/cm) at 450°C and then climbed very steeply, reaching a plateau between 500 and 600°C. The 10^{14}/cm^2 fluence material then rose to a higher peak at 700°C and sharply fell to near-virgin levels at 850°C. The 10^{15}/cm^2 fluence material showed a very minor increase at 700°C, after which it also fell to a minimum at 850°C. Using spectroscopic ellipsometry methods to measure crystal perfection after each temperature anneal, the researchers noted a response singularity at the temperature above 450°C at which the Raman spectroscopy LO line shift gradient was so pronounced. The interpretation now of the results is that the GaAs lattice damage (introduced by the ion implantation of Be) was almost completely annealed out at 450°C, but that electrical activation of the implanted impurity had not yet begun. During the electrical activation (at higher temperatures) lattice disorder again occurred but disappeared again at temperatures of 850°C. The experiment was repeated, and a four-point probe sheet resistivity measurement was done; the lack of electrical activation below 450°C was confirmed. This powerful new technique, if applied *in situ* during a capless annealing process using gaseous overpressure, could determine the ideal anneal/activation temperature-time profiles for any given impurity implant. The exact role of proton, boron, and oxygen implants used to render GaAs semi-insulating may also be better understood by this method.

Spectroscopic Ellipsometry

Spectroscopic ellipsometry (SE) measures the complex reflectance ratio, ρ, of light from a surface and is defined (in terms of ellipsometer readings ψ and Δ) by $\rho = r_p/r_s = \tan(\psi) \exp(i\Delta)$, where r_p and r_s are, respectively, the reflection coefficients for light polarized in the plane (interface) of incidence or perpendicular to it. If one knows the angle of incidence, θ, the dielectric constant, ε, can be determined from

$$\varepsilon = [(1-\rho)^2/(1+\rho)^2] \sin^2\theta \cdot \tan^2\theta + \sin^2\theta .$$

Comparison of ε with that of virgin crystals provides a spectroscopic determination of the structural (and possibly chemical) analysis of the material. Although SE involves a different physical mechanism than Raman spectroscopy, the two techniques have about the same sensitivity to ion implantation defects as low as those induced by a fluence of 8×10^{11} ions/cm^2. The SE results have led to conclusions similar to those of Raman spectroscopy regarding the nonmonotonic character of the lattice disorder associated with the ion implant/activation annealing.

Radiation Damage in GaAs

Although neutron transmutational doping (NTD) of silicon semiconductor material is well known and provides an extremely homogenous distribution of the phosphorous donors, the approach is not as straightforward in III-V compound semiconductors. The complications in doping compound semiconductors by neutron bombardment arise from knock-on effects. Anions (e.g., arsenic) are knocked out of their lattice site and onto an adjacent cation (e.g., gallium) lattice site. This creates an antisite defect in the crystal; the antisites, in turn, create energy levels near the middle of the bandgap. The mid-gap energy levels electrically compensate the donor electrons created by the transmutation of the cation to a column IV ion or of the anion to a column VI ion. Thus, while neutron radiation bombardment of silicon tends to increase the effective doping of n-type regions and decrease the effective doping of p-type regions, its effect on GaAs tends to compensate p-type regions, and to influence n-type regions in a manner worthy of further investigation.

The laboratory used a fast neutron flux of 7×10^{10} $^{1}_{o}$n/cm²s from the university's reactor to irradiate both semi-insulating (S.I.) and n-type GaAs. Fluences from 10^{15} to 10^{17}/cm² were used; thermal neutrons were eliminated from the flux by 2-mm-thick cadmium filters. Mean neutron energy was 2 MeV, and the energy distribution peaked at 0.8 MeV; semiconductor temperature was not significantly influenced by the neutron flux.

The neutron bombarded GaAs crystals were characterized by EPR at 9.31 GHz. Before radiation, the electrical losses in the GaAS-loaded microwave cavity were high enough (even at 4.2°K) that only the S.I. material could be measured. Relative intensity was determined at 4.2°K by comparison with a chromium-doped GaAs reference sample; absolute spin concentration was obtained by calibration against a US National Bureau of Standards ruby standard. An isotropic quadruplet signature was found in the reference material, much the same as others had found using millimeter wave EPR. The concentration in the as-grown unradiated material was 5×10^{15}/cm³. After neutron irradiation, the microwave losses in the n-type material decreased, and its paramagnetic defects became measurable. A similar defect generation rate was found for both S.I. and n-type material. The rate of defect generation was nearly linear for low fluences and slightly sublinear over the entire range of fluences, but no saturation effects were found. Samples held at 4.2°K exhibited paramagnetic defects 300 times greater than samples held at 295°K during irradiation at a neutron fluence of 1.16×10^{17}/cm². Both spectra were isotropic and exhibited similar linewidth of the quadruplet components, but the hyperfine structure clearly narrowed with increasing temperature. Subsequent temperature cycling had little effect on the spectra.

Previous measurements by other researchers were in a high-flux facility where dose rates were as much as 1,000 times faster than in the Strasbourg experiments. Since flux-induced heating effects were virtually absent in the Strasbourg experiments, the defect generation rate observed was significantly higher than in previous experiments and decreased with fluence. At 10^{15}/cm² fluence, 250 spins per absorbed neutron were observed; only 150 spins were counted at a fluence of 10^{17}/cm². Flux-dependent generation of defects and ion beam mixing effects still must be determined separately.

While the results are disturbing in that they indicate that lower flux rates (i.e., weaker or more distant neutron sources) may cause more damage to GaAs devices then do more intense but shorter duration sources providing an equal fluence, more investigations are clearly necessary.

M.N. Yoder

ENVIRONMENTAL SCIENCES

CONFERENCE ON ECOLOGY AND ENGINEERING

Can politicians, engineers, and ecologists cooperate on major construction projects along seacoasts? That was one of the issues considered during a symposium on the Integration of Ecological Aspects in Coastal Engineering Projects, held in Rotterdam, 6 through 10 June 1983.

The symposium was organized around six case studies of large-scale coastal engineering projects, either planned or under construction in Japan, the UK, Korea, Canada, Italy, and the Netherlands. Reviews of the projects were presented in plenary sessions, which were followed by two or three concurrent technical sessions on topics related to the case studies.

The individual papers presented in the technical sessions have been published as a special issue of *Water Science Technology*, Vol 16 (Rotterdam, 1983). The papers covered a wide range of topics, from very general management guidelines to straightforward civil engineering. However, there were few papers on modelling.

Opening Lecture

Prof. H.T. Odum (Univ. of Florida, Gainesville) gave the opening presentation to set the direction of the symposium. Odum was direct and animated as he tried to convince the engineers and ecologists that natural processes have "value" in terms of energy equal to or perhaps greater than the value of engineering works. But the value, he said, "can only be determined if each component of the ecosystem is evaluated in equivalent units, such as coal or solar equivalents." When this is done, he said, "the value of a salt marsh is found to be an order of magnitude greater than the marsh products that are actually sold" (e.g., fish). In other words, when environmental "commodities" are involved, money is not a good

measure of the environment's contribution. Engineers and economists rarely approach the role of ecosystems from this perspective. Consequently, he said, "most of the world's major coastal engineering works are far overvalued in terms of their long-term worth relative to a coastal ecosystem in its natural state." Odum closed his talk with the analogy that "the Egyptians had their energy sink, the Great Pyramids, and now the Dutch have theirs, their great coastal engineering works." The civil engineers who made up two-thirds of Odum's audience were not enthusiastic about his observations. However, by the end of the symposium, Odum's concepts were being discussed informally, and among the recommendations agreed upon in the summary session on the last day was that "there is a need for equal units in socio-economic-ecological parameters for balancing construction decisions."

The Case Studies

In spite of Odum's prediction that large-scale coastal engineering works will be considered our pyramids, work on such projects goes on, and without question the Dutch civil engineers are among the master builders of the world. Their efforts to control the North Sea and the Rhine/Meuse rivers date back more than 1,000 years. The Delta Project was featured at the symposium.

Without visiting the engineering works being constructed in the Netherlands, it is difficult to comprehend the magnitude of the effort to control the Rhine distributaries and North Sea storm surge. Enormous concrete structures, or caissons, are being fabricated in staging areas along the coast, floated into position by specially designed support vessels, and lowered into place across the mouths of the major Rhine distributary channels. Between the caissons, sluiceways are then constructed with gates that permit control of the outgoing flood waters from the Rhine and the incoming tidal actions and storm surge.

Planning for the Delta Project got under way soon after the severe North Sea storm of 1953. (Figure 1 shows the Delta region.) Property losses ran into the millions of dollars, and some 2,000 lives were lost. The project was, therefore, based primarily on improved safety rather than economic justification. Thus, little financial information is available, but the cost of the project is said to be more than $8 billion. For a nation of 16 million, this far exceeds the US per capita investment in the space program.

Apparently, in strict "risk analysis" terms the lives and property saved because of the enormous expenditure would be difficult to justify. This is especially apt considering the return interval for a 1953-magnitude storm. But the project has become something of a political and even a national goal to be achieved. When the Delta Project is described to visitors from other countries, there is far more emphasis on the gigantic scale of it than on the costs. Politicians might reasonably argue that dramatic projects like this contribute to national pride and worldwide recognition for the country's engineering skills, and that such values are incommensurable.

Is there significant ecological impact associated with the great flood control structures in the Netherlands? The answer is, of course, yes. Three of the barriers are "tight," resulting in a change from saline and brackish water to freshwater estuaries.

One barrier is a storm tide control structure, so the estuary behind remains saline. One of the other control structures allows enough seawater to pass so that the estuary is at least brackish.

When the issue of environmental impact is raised, one cannot avoid the conclusion expressed by most of the ecologists I talked with informally; that is, the projects are planned and justified long before any ecological implications are considered. In the case of the Delta Project, the initial planning team consisted of eight civil engineers until late in the process, when an economist was added. So the question is not should such a project be undertaken because of the environmental consequences, but rather, as the project will be carried out, what "adjustments" can be made to minimize the ecological consequences. However, the environmental adjustments (permitting circulation of seawater) in the Delta Project added more than $1 billion dollars to the final cost. Odum told me that the structures had dramatic, negative impact on just about every component of the estuary ecosystem and that it was unlikely the project could be justified if a proper energy analysis were carried out.

The second and third case studies were similar--the damming of outlets to the sea from Lake Nakanoumi in Japan and from the Nakdong estuary in Korea. The goal is to develop large freshwater reservoirs, reclaim land, and control flooding and storm surge. Both projects have questionable futures.

The last three case studies were especially interesting. To generate power, the British plan to dam the Severn Estuary, and the Canadians have a project on the Bay of Fundy. Both

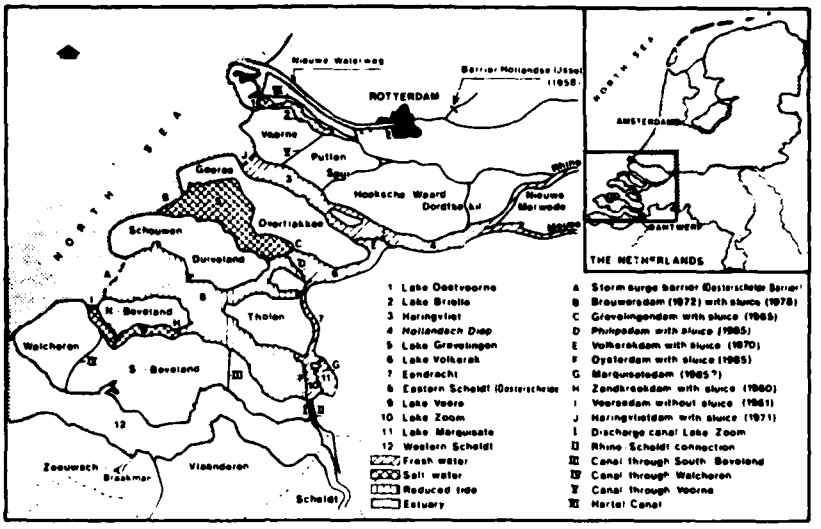

Figure 1. The Delta region; the figure refers to the situation as it is foreseen for the period after completion of the works in the Eastern Scheldt (A, D and F).

operations are well documented from the standpoint of political, physical, biological, and economic impact. The last study dealt with the control of high water levels in the lagoon of Venice, a project that has been considered for more than a decade.

The Bristol Channel in Southwest England and Wales has a tide range of 6 to 14 m. The plan to harness this tidal energy calls for an 800-MW plant that would produce about 10% of the UK's energy needs by the year 2000. In fact, a tidal power system on the Severn has been under consideration since the 1930s; however, it was the rapid rise in oil prices that moved the idea from the conceptual stage to serious planning. Even with today's slightly lower oil prices, the British engineers and economists consider the Severn a viable project.

The first question was whether it would be feasible to build a barrage or control structure across the Severn Estuary. If so, where should it be and what would be its mode of operation? A site near Weston-super-Mare was selected; then it was determined that it was feasible to enclose the estuary with a large barrier built east of a line drawn from Porlock north to the Welsh coast (Figure 2).

A tidal power scheme can be designed to operate in one of three modes:

1. With ebb generation, the rising tide flows into the reservoir through the sluices and turbines. The sluices and turbines are then closed at high water and remain closed until the difference in water level between the basin and the sea has built up sufficient head to drive the generators. The water is then allowed to flow through the system until its level is too low to turn the turbines efficiently--on the flood tide when the water in the basin is about the mid-tide level.
2. With flood generation, the water is allowed out through the sluices until low tide, then they are closed. The turbines are opened as soon as there is sufficient head to start generation, and they continue to generate power until mid-tide on the falling tide.
3. Two-way generation combines ebb and flood generation with electricity produced over a greater proportion of each tidal cycle.

For environmental and other reasons, the UK engineers decided to concentrate on an ebb generation system.

A tidal barrage or barrier affects the environment because of the physical presence of the engineering structure, changes in water levels, changes in water flow patterns and velocities and changes in the sedimentation. In the Severn project, the perimeter of the intertidal zone would be substantially

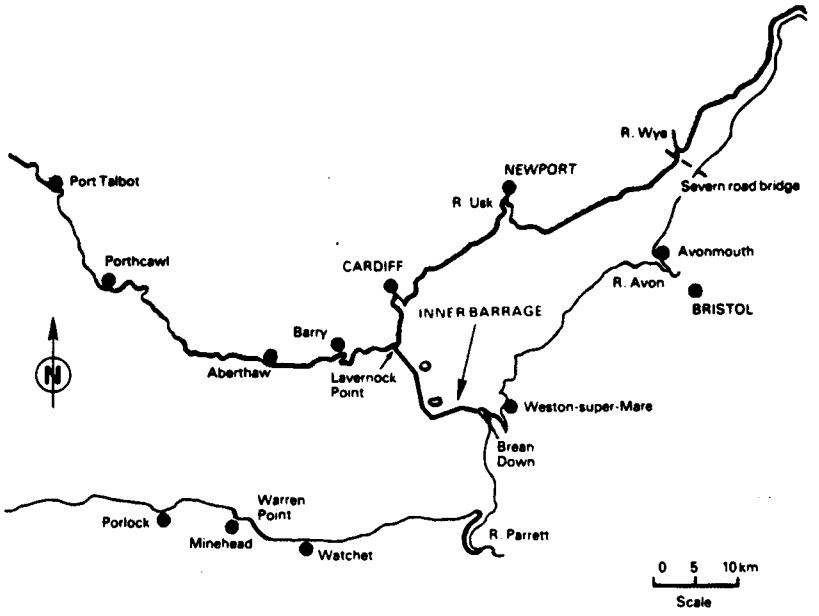

Figure 2. Bristol Channel and Severn Estuary.

altered, thus potentially increasing salt marsh areas (which might be beneficial); the salinity of the estuary would be reduced; and suspended sediment would be lower. With less turbidity, there would be more phytoplankton. In addition, migratory fish passage would be impeded and waterfowl habitat reduced.

Many government scientists, and over 40 university staff and students have been working on aspects of the project. Ten studies are in progress on geography, geology, water quality, pollution chemistry, hydrography, and ecology. Some of the work is sponsored by government research councils, including the Natural Environment Research Council (NERC).

In early 1981, the Severn Barrage Committee published a two-volume summary (available from the UK Department of Energy). Volume I ($16) describes the main findings and outlines the conclusions and recommendations. Volume II (459 pages), providing more detailed background material, lists 106 "major" reports published on the program between 1978 and 1981. Of these, 27 deal with ecology and water quality. Although an impressive amount of work was carried out over the 3 years, the two volumes are still considered a pre-feasibility study.

The main findings of the committee were as follows:

1. The project is technically feasible.
2. The economic justification will depend on a number of factors, such as the extent of nuclear generation of electricity and the price of coal and oil between the years 2000 and 2035. Such information will not be available when a decision is made about whether to continue the project. However, because the barrage would be extremely valuable if the UK faced serious energy problems in the future, the committee unanimously recommended beginning the next phase of work.
3. The environmental consequences of the project would be so wide-ranging that they must be studied in much greater depth.

The next phase of the work, a combined "Acceptability and Preliminary Design Study," will take about 4 years and will cost $30 million. Before electricity is produced, development and construction would take another 15 years. So far, the government has made no decision about the 4-year study.

For over 60 years, Canadian civil engineers have looked longingly toward a

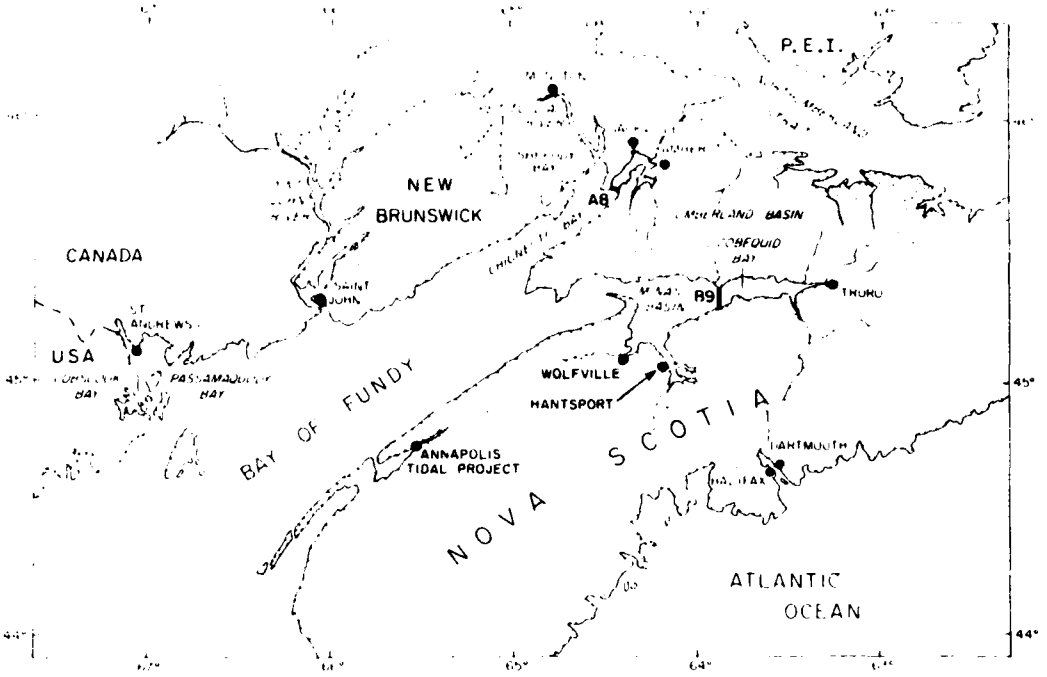

Figure 3. Bay of Fundy region.

large-scale tidal power development in the Bay of Fundy, which has the highest tide range in the world (up to 16 m). Until recently, the several tidal power proposals were routinely dropped for economic reasons. But with higher prices for energy, a project in Canada now appears feasible. The conference was told that it is now "highly Likely" that the Fundy project will proceed to the design phase. Over 100 scientists and engineers are working on the environmental and engineering aspects.

The tentative plan calls for a closure structure across the mouth of the Cobequid Bay, a span of about 8 km (Figure 3). The turbines will have 7.5-m throat diameters that rotate at 70 to 75 rpm and generate 4,000 MW. Construction will take about 12 years.

The environmental impact of the Fundy project will be significant. For example, alteration of the hydraulic regime in the upper part of the bay will cause tidal-amplitude changes of 15 cm as far away as Boston. The prediction has, as one would expect, caused concern in the US. In addition, reducing the tidal range behind the barrier will reduce not only the intertidal area (and thus primary production of benthic microalgae and saltmarsh), but also the feeding and breeding habitats for an internationally important shorebird population. Finally, the upper reaches of the bay are an important summertime feeding area for shad that migrate to the area from the entire Atlantic coast of the US. The shad could pass through the turbines, but the prediction is that many would be killed.

After completing the impact studies, the proponents will prepare an environmental impact statement. When completed, it will be reviewed by the Canadian Environmental Assessment Panel and perhaps a group in the US. The conference was told that the results of the impact assessment will influence the final design and operation procedure of the tidal power project and may influence the decision about whether to build.

The upper reaches of the Bay of Fundy are, at best, remote; one might ask how all the power is going to be used. In fact, the power will not be for expected population growth in the area or new industrialization; the consumers will be the people living in the northeastern urban corridor of the US in the year 2000. As one of the Canadian engineers said, "you people (in the US) should be interested in this project because you're going to pay for it, lock, stock, and barrel, and Canada will make a tidy profit."

The "high water problem" or occasional flooding of Venice is still with

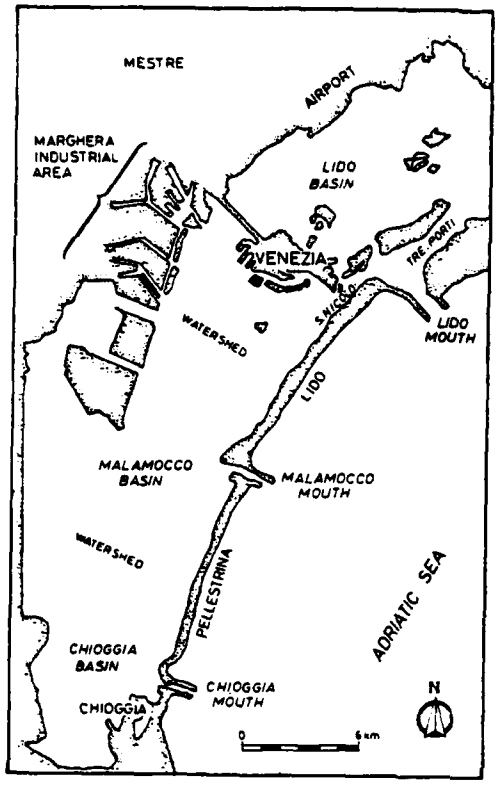

Figure 4. Lagoon of Venice.

us. For more than 20 years, Italian engineers have been debating about various structures that could prevent damaging storm surges from reaching the historical city. Apparently Venice is no longer sinking at the alarming rate of just 10 years ago. Groundwater removal from the aquifers beneath the city has been reduced, thus there has been less subsidence. But man-made alterations of the lagoon in which Venice is located have changed the hydraulic regime so much that severe surges are now occurring much more frequently.

The lagoon of Venice is 50 km long, 12 km wide, and about 0.5 m deep (Figure 4). In order to consider circulation, one can divide the lagoon into three sub-basins--the Lido, Malmaocco, and Chioggia--fed by the Adriatic Sea through the three inlets. The Lido is the largest, covering an area of 230 km^2, and includes Venice and part of the industrial zone of Porto Marghera. With an area of about 160 km^2, the Malamocco Basin accounts for the remainder of the industrial area and is crossed by the Petroli Canal, one of the main entry channels for tidal water. The canal also transports most of the pollutant load originating in the industrial zone. The southernmost basin, Chioggia, has an area of about 110 km^2; it has the best water quality and is thus used for fishing.

The way the water flows in the lagoon depends mainly on the cross section of each inlet, the depth and size of the shallow water areas, the lagoonal area affected by tidal expansion, and bottom roughness. The increased depths of the inlets, the excavation of the large navigable canals, and the reduction in lagoon area because of landfills have led to a damping of the tides inside the lagoon. Dredge and fill projects dating from the beginning of this century until 1973 have reduced tidal effects in the lagoon by about one-third.

Man's activities have affected the basin; the following problems are most serious: high tides that now occasionally flood the cities; pollution from industrial activity; rapid growth of the surrounding urban areas; increased tourism; and additional pollution from chemicals used in agriculture.

A series of transverse barriers in each lagoon inlet is now considered the cheapest and most effective way to protect Venice from "high water." Two navigable passages will be provided, each equipped with a submerged gate. The floodgate sections are unique in concept. They will consist of four or five cylindrical modules (4.80 m diameter) placed side by side at a distance of 5 m between centers and joined together to form sections 20 to 25 m long. The modules will vary in height according to the depth of the inlet and will be hinged on reinforced concrete platforms on the seaward side.

Under normal tide and wave conditions, the floodgates rest on the bottom, supported on rubber cradles in special housings. When they are needed, the floodgates are filled with compressed air, which expells the ballast water until the gates swing on their hinges to an approximately vertical position. When the storm tide subsides, a valve is opened, releasing the air and allowing the floodgate to sink back to its housing on the sea bottom. The mobile barrier will be designed to cope with a maximum sea-lagoon level difference of +1.50 m.

The lagoonal areas with the highest pollution levels are around the industrial development of Porto Marghera and inside the historical center of Venice. Unfortunately, totally closing the lagoon for only two tide cycles would

lead to a 65% increase in pollutant concentration.

The industrial pollutant load of Porto Marghera accounts for about half the entire discharge into the lagoon. Therefore, controls are being implemented to reduce future pollution by more than 90%. In addition, the high urban pollution levels will drop as the treatment plants gradually begin to operate. Plans also call for the city of Venice to reduce its discharge into the lagoon.

High water, lagoon pollution, and sinking have all been part of the Venice story for more than 30 years, and little has been done. It may take many years to start actual construction of the storm surge barriers, given the complex political and economic decision-making network.

The symposium closed on a positive note. A 2-hour summary discussion seemed to conclude simply that ecology is an important aspect of large-scale coastal engineering projects and that efforts should be made to include ecologists in the early planning teams. Several ecologists shared my observation that in every case study, ecology was a distant secondary issue. The primary consideration seemed to be a project's physical feasibility and economic justification. One Dutch ecologist summarized it this way: "It's like tuning a TV; the engineers and politicians determine the channel, then we're asked to fine tune the picture. We seldom have influence as the selection is being made."

The conference participants voted to hold another meeting in a few years, probably in Europe or North America. So interest and concern about ecology are clearly present, considering that more than half of the participants were civil engineers. The ecologists and engineers haven't quite joined hands, and any thoughts of a close union may be decades away. But a meeting like this one brings them together, at least once every 2 or 3 years.

A. Bolar

MATERIAL SCIENCES

FIBER COMPOSITE MATERIALS IN THE UK: UNIV. OF NOTTINGHAM AND FULMER RESEARCH LABORATORIES

This is the fifth in a series of articles reporting research on fiber composite materials in the UK. This month, research at the Univ. of Nottingham and Fulmer Research Laboratories is featured.

Univ. of Nottingham

Composite materials research at the Univ. of Nottingham (Nottingham, NG7 2RD) is in the Department of Mechanical Engineering, Department of Metallurgy and Materials Science, and the Wolfson Institute of Interfacial Technology. Dr. M.J. Owen, Professor of Reinforced Plastics, leads the work in the Mechanical Engineering Department, which has 19 academic staff and six research fellows. Owen has long been active in composite research, and is interested in the static and fatigue strength of glass reinforced plastics. Owen has studied the correlations between material processing, microstructure, and the properties of short fiber composites fabricated from sheet molding compounds and by injection molding and transfer molding. He will soon begin research on filament winding based on a five-axis filament winding machine with pneumatic control. The machine can wind complex patterns for objects not composed of simple surfaces of revolution. The research will focus on the correlation between filament winding patterns and surface contours, and on the development of control for the winding operations.

Owen recently concluded the final phase of an extremely extensive 10-year program for studying the biaxial strength behavior of glass reinforced polyester (GRP) resin. Over 1,200 thin-walled GRP tubes were tested for static and fatigue strength. The tubes were made of plain weave and woven roving fabrics in polyester resins, and were subjected to tension/tension and tension/compression biaxial loadings. The warp and weft directions of the fabrics coincided, respectively, with the hoop and axial directions of the tube; in-plane shear stresses do not arise in the experiments. Some flat laminates were also tested. Tensile failure occurred in the following sequence: debonding, resin cracking, and rupture. Adding a flexibilizer to the resin increased the static tensile strength at all stages of damage. The static compressive strength was controlled by fiber crimp of the fabrics: transverse fiber debonding and matrix cracking were not apparent under compressive loading. Compressive damage initiation occurred at fiber crossovers. The flexible resin system provided little improvement in compressive strength and reduced the in-plane shear strength of the fabric composites. Owen found that the glass content variations due to tube thickness

variation were significant, even on a load-per-layer basis. In fatigue testing, such variations need to be taken into account.

In the case of biaxial tube testings, the strength per layer varied with glass content and principal stress ratio. Under static biaxial loading, the usefulness of the flexibilizing additive depends on certain combinations of loading gradient and fabric type. The additive is not beneficial under biaxial fatigue loading. Owen and his coworkers have compared experiments with 14 theories for biaxial strength. The agreement between individual failure theories and experiments varies from one type of material to another. For cyclic loading, failure theories become less accurate as fatigue life increases. In addition, Owen's search for a suitable theoretical evaluation shows clearly that the existing failure theories disregard failure processes and hence cannot allow for interacting failure mechanisms--microbuckling in compression, for instance. Owen and his coworkers concluded that the modified Fischer theory provides the best overall fit for the static strength, and that the Norris distortional energy theory provides the best fit for the fatigue results. If the same failure theory is required for both static and fatigue results, the Norris distortional energy theory is the best fit overall. Finally, Owen recommended that in the absence of a biaxial test facility, designers should obtain the following data: (1) in-plane shear, (2) uniaxial tension (0 and 90 degrees), (3) uniaxial compression (0 and 90 degrees), and (4) axial stress/hoop stress = 0.5 (closed end tube).

Dr. S.J. Harris in the Department of Metallurgy and Materials Science has worked on metal matrix composites for many years. His early publications were concerned with the effects of fiber-matrix interfacial bonding, interfiber spacing, and fiber diameter on tensile and fatigue properties of metal matrix composites. More recently, Harris has been studying the stress corrosion cracking of polymer matrix composites and the fatigue behavior of continuous fiber reinforced metal, with particular emphasis on the failure modes. A scanning electron microscope study of the tungsten-copper model system has identified three types of failure: type I, fiber and matrix failure in fatigue; type II, fiber failure in tension and matrix failure in fatigue; and type III, both fiber and matrix failures in tension. The failure modes can be correlated with the composite fatigue life as follows: (1) short life specimens ($<10^4$ cycles), complete type III behavior; (2) intermediate life specimens (10^4 to 8×10^4 cycles), type II behavior at the edge and type III in the center of the section; and (3) long life specimens ($>8\times10^4$ cycles), type I at specimen edges or corners, type II in the interior, and type III at the specimen center.

Harris also concluded from the model system that reducing fiber diameter and improving interfacial bonding appear to have similar effects--improving short life fatigue performance and giving a steeper S-N plot--which downgrade long-life behavior. Furthermore, fatigue cracks initiated almost exclusively at the specimen surface, presumably by processes that have been studied in more isotropic materials. However, crack propagation in composites could be stopped at the first row of fibers, thus facilitating multiple initiation on the surface. Internal crack initiation might occur, and a broken fiber could cause internal "fretting" damage. Such damage could assist in the formation of fatigue cracks. Harris and his coworkers concluded that in composites with brittle ceramic fibers in which more random fiber breaks might occur, such damage might be more severe and significantly affect the fatigue life.

Fulmer Research Laboratories

Fulmer Research Laboratories are one of the five branches of the Fulmer Research Institute Limited, a contract research and engineering company (see *ESN* 36-9:211-213 [1982]). The Fulmer Research Laboratories provide research, development, and design and testing engineering services to industry, commerce, and government. Their activities involve engineering materials, including metals, polymers, ceramics, refractories, adhesives, and composites.

Dr. W.H. Bowyer leads the composite materials research. For nearly 10 years, Bowyer and his coworkers were concerned about the construction of damage-resistant hulls for ships. The whole project concluded about 1½ years ago, and some of the results have been published. A central concern of the research was underwater shock loading to a Mine Counter Measures Vessel (MCMV) after an explosion. MCMVs in the "Hunt" class now under construction have GRP (woven glass fiber roving/polyester resin laminated) hull structures to achieve a nonmagnetic requirement. The specific stiffness of a GRP is one-third to one-quarter that of a metal counterpart, so thick sections or selectively stiffened construction must be used when

large panels are incorporated into structures. A familiar example of such construction in a GRP is the use of top-hat section stiffeners. However, shock testing of panels revealed a tendency for the laminated-on-top-hat stiffeners to separate from the hull shell. To provide an acceptable level of damage tolerance in MCMV hulls, the stiffener flanges are through-bolted to the hull structure below the waterline; titanium fasteners are used to meet the nonmagnetic and noncorrosive requirements. The titanium bolts and their insertion are expensive because several thousand holes must be drilled through the hull below the waterline, providing many potential leakage sites. Furthermore, bolting is only a partial solution to the problem since failure usually starts far from the bolts, which then act as crack arrestors. However, the bolts do help make the hull damage-tolerant, so it maintains structural integrity following exposure to an underwater shock.

Fulmer is trying to develop improved attachment methods for stiffening frames on large GRP panels and better shock-damage resistance. Bowyer and his coworkers first investigated lower cost substitutes for through-bolting. They found that a self-tapping-screw reinforcement system can provide damage tolerance comparable to the bolted structure--up to the degree of crack propagation usually observed in shock loading tests. In another study, they concluded that using a high-toughness matrix and a stitched cloth in selected areas of the secondary bond line increases the load required to initiate bond failure by 30%. The increase is not achieved by the use of the stitched cloth and the polyester resin alone. More recently, the researchers at Fulmer have compared the shock-resistance of a chopped strand mat construction hull and a woven roving construction hull. They concluded that the performance of a composite in ship hull construction is affected by the overall structural configuration of the hull, and that the benefits of localized toughening apply to chopped strand mat construction as well as woven roving construction.

In another project sponsored by the Ministry of Defence, researchers at Fulmer are studying the ballistic impact resistance of Kevlar laminates. They used a multiple-exposure, high speed photographic method to examine the interactions between targets and projectiles. Single Kevlar-49 yarns and single and two-ply specimens of Kevlar-49 fabrics have been used as targets. The latter were tested without a matrix, in a polyester resin matrix, and in a silicone rubber matrix. Researchers have found that a standard projectile striking Kevlar-49 fabric interacts directly with six yarns. However, the fabric absorbs considerably more energy than the maximum absorbed by six yarns acting independently. The nature of the yarn crossover connections is critical in determining the fabric's capacity to absorb ballistic energy. In Kevlar-49 fabric, energy is transferred from the primary yarns to the crossover yarns by the transverse motion of the primary yarns rather than by dispersion of the longitudinal strain pulse. A polyester resin matrix affects the behavior of Kevlar fabric by enhancing the reflection of the strain front at yarn crossovers. This increases the strain gradient in the primary yarns and decreases the energy-absorbing capability of the fabric. The silicone rubber matrix used does not wet Kevlar-49 but does prevent its being displaced sideways by a penetrating projectile. The reduction in energy absorption is much less than that caused by a polyester resin matrix. Two-ply fabric laminates also were examined. Specimens that were matrix-free and those that had a silicone rubber matrix behaved as two separate and independent plies in ballistic tests. Two-ply laminates with a polyester resin matrix absorbed more energy than did two isolated single plies.

The third project described to me by Fulmer researchers is the patching of metal components by fiber composites. The goal of the work, sponsored by the Royal Aircraft Establishment, is to restore the load bearing capacity of, for instance, secondary aircraft structures damaged in battle. Major concerns in the study, which is based on wet laminate patching, are the tolerance of the matrix to contaminants, such as hydraulic fluids and aviation fuel; fatigue loading; temperature; lamination; and the thickness of the metal substrate to be patched. Woven fabrics have been tried, but the results are uncertain because in laboratory tests it is difficult to simulate the effects of battle.

Finally, it is worth mentioning that Fulmer Research Laboratories, as an independent contract research company, have been performing studies for the European Space Agency. The aim is to identify and assess long-term research goals in advanced materials. Fulmer researchers have surveyed topics such as alloys, superplasticity, metal matrix composites, nondestructive testing, thermoplastic matrices, and advanced composites in general.

References

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T.-W. Chou

SCIENCE OF CERAMICS 12

The international Science of Ceramics conference, the twelfth in a series sponsored biannually by the Association Européenne de Céramique, was held from 27 through 30 June at Saint-Vincent, Italy. P. Vincenzini (Ceramic Technology Research Institute, National Research Council [IRTEC-CNR], Faenza, Italy), president of the organizing committee, pointed out that 200 participants were registered from 22 countries for the first conference in the series to be held in Italy. The schedule included 13 invited lectures and 90 poster presentations covering the following topics: Materials Development and Processing Science, Structure and Phase Equilibria, Sintering and Microstructure, Reactions in Ceramic Systems, Mechanical and Thermal Properties, and Electrical and Optical Properties.

Bioceramics

D.J. Perduijn (N.V. Phillips Ceramic Laboratories, Eindhoven, the Netherlands) was chairman of the opening session of invited papers. G. Heimke (Friedrichsfeld GmbH, Mannheim, Federal Republic of Germany [FRG]) lectured on "Advances in Bioceramics: Present and Future Needs for Research." The emphasis was on materials for prosthetic devices used in reconstructive surgery. Although biotolerant corrosion-resistant metals are often employed in such devices, bioinert and bioactive ceramic implant materials have been developed more recently. Dense high-purity Al_2O_3 (alumina) ceramic material has been tested in clinical applications over the last 12 years. Alumina was described as the prototype bioinert material. Osteointegration of alumina ceramic has been observed in load-bearing prostheses. Anchorage of the prostheses is a critical factor. Interface observations have been made by x-radiography on the degree of filled-in bony material at the notched prosthetic column supporting a hip socket joint. Considerable rest at essentially negligible loading seems to be required for developing bony material, otherwise a soft tissue layer forms at the interface regions and progressively degrades with continued loading. Alumina ceramics are being wear tested. An advanced alumina bioceramic has been developed with a grain size less than 4 microns and a bend strength of 470 MPa.

Bioactive ceramics allow or promote the in-growth of tissue following their implantation in a bony environment. Candidate materials are hydroxylapatite-tricalcium phosphate-ceramics, calcium-phosphate-containing glasses, and alkaline silicate glass ceramics leached to give porosity in a silica-rich surface layer for the in-growth of tissue. The materials are chemically nondegradable, but their mechanical properties are limited by being porosity-controlled. Fatigue strength is a particular problem. Dental implants are a potential use for bioactive ceramics, with increasing strengths being measured for crystal phases in the order: $Ca_5(PO_4)_3OH$, ZrO_2, and Al_2O_3. Composite materials would seem to be good candidates for development, but the mismatch of thermal expansivity coefficients and elastic moduli present added problems. Posters relating to bioceramics were "Effect of Mullite Addition on the Properties of Dental Porcelain," D.M. Ibrahim and E.H. Sallam (National Research Centre, Cairo, Egypt) and F. Abdel-Gabar (Faculty of Dentistry, Cairo Univ., Egypt); and "Fatigue Properties of Pre-Stressed Calcium-Phosphate Ceramics," A.A. Driessen, P.A. Vingerling, C. de Putter, and K. de Groot (Schools of Dentistry and Medicine, Free Univ. of Amsterdam, the Netherlands).

Silicon Nitride Materials

F.L. Riley (Department of Ceramics, Univ. of Leeds, England) gave the invited lecture "Silicon Nitrides: An Overview of Research and Applications." The materials, based on Si_3N_4 and related to Si-Al-O-N (sialon) structures, are of special interest for components in advanced gas turbine and diesel engines. The microhardness properties, thermal expansivity, and resistance to oxidation and corrosion are positive features for such uses; however, the main consideration is that the refractoriness of silicon nitride potentially allows temperatures up to 1,900°C to be withstood. Research on the methods of production, microstructure, and properties of the materials

has grown nearly exponentially from 1970 to 1980, after first reports around 1961.

Hot isostatically pressed silicon nitride powder product was reported in 1977; the material contained optimally 3 mole percent of liquid forming additive. Sintering was at about 1,750°C under a pressure of 100 to 200 MPa. In 1979, post-sintered reaction bonded silicon nitride (RBSN) was produced from powder; negligible shrinkage was achieved, while full density for the product was obtained. At temperatures less than 1,410°C, silicon gas plus nitrogen gives an α-phase structure, while at greater than 1,410°C silicon liquid plus nitrogen gives a β-phase structure. In 1981, gas pressure sintered silicon nitride was produced from powder at 1,650°C containing about 5 mole percent additives and an overpressure of 2 to 10 MPa of nitrogen. The additive is extremely important because, for example, a pressure of 3 to 5 GPa is required at 1,600°C to sinter pure silicon nitride powder in a reasonable time. Additives with SiO_2, such as MgO, Y_2O_3, or Al_2O_3 plus Y_2O_3, are normally employed. A sintering temperature as low as 1,325°C was used in the latter case. Other additive systems being investigated in combination with SiO_2 are CeO_2, Sc_2O_3, ZrO_2, La_2O_3, and $BeSiN_2$ plus Be_3N_2. The additives alter the strength of the material as well. Current areas of study are densification mechanisms; microstructural optimization--in one way, by avoiding low melting eutectics; and crystallization of phases at grain boundaries.

The RBSN materials are used for thermocouple sheaths, inert gas welding torch nozzles, and hot working jigs. Hot pressed silicon nitride (HPSN) materials are used as plugs and die liners for drawing metal tubes, cutting tips, and molds for crystal growing. Advanced ceramic research programs on the materials have been under way in the US and the FRG since 1974, with expenditures thus far of approximately $200 million and $30 million, respectively. A $7.5 million program begun in Japan in 1978 was enlarged in 1981 by another program of $45 million to be completed in 1990. The European Economic Community intends to start a $50 million program in 1984.

Fifteen poster presentations dealt with silicon nitride materials being studied by researchers in France, Germany, Italy, the Netherlands, Sweden, the UK, and Yugoslavia. Phase diagram studies, sintering kinetics, transmission electron microscopy, x-ray diffraction and microprobe analysis, scanning electron microscopy, oxidation effects, and mechanical property measurements were reported, including flexural strength, fracture toughness, wear properties, stress intensities for slow crack growth, and acoustic emission effects for monitoring thermal shock and thermal fatigue resistance.

In a session chaired by P. Popper (British Ceramic Association, Stoke-on-Trent, England), D.J. Godfrey (Admiralty Marine Technology Establishment, Holton Heath) discussed "Use of Ceramics for Engines." Godfrey emphasized the importance of achieving higher engine temperatures for power and efficiency gains; for example, the available power is doubled and efficiency increased by 20% if turbine temperatures are raised from 1,000 to 1,350°C. An RBSN piston was made as long ago as 1970. The material is of interest for Wankel and diesel engines. The US Cummins Adiabatic Engine Research program has produced probably the most efficient diesel engine in the world. The cooling system, rotor, prechamber, piston, and added engine components account for a 10 to 30% heat loss in the conventional engine structure. Approximately 50% of military and civilian field failures are due to coolant system problems, which are alleviated with ceramic engine components, and lubrication is less of a problem with ceramics. Ford Motor Company was credited with inventive engineering developments for small engines of ceramic stators, rotors, and shrouds, and with the development of ceramic-metal joins for variable temperature operation. The Airesearch Division of Garrett has produced HPSN blades and RBSN stators for the TSE 331C-1 ceramic gas turbine. Garrett and Ford are cooperating on developing stator vanes, shrouds, and rotors for the AGT101 engine. The Solar Division of International Harvester, San Diego, was credited with work on energy-saving silicon nitride nozzles, shrouds, and vanes, but there has been a slow-up in the US of energy-related research.

Godfrey stated that the high temperature properties and durability of silicon carbide are also superior. The low toughness of ceramics compared to metals is the main reason for the slow growth in the use of ceramics for engines. Other difficulties are the thermal expansion mismatch with metals, degradation of properties due to oxidation, structural stability, and general lack of engineering information and experience with the newer ceramic materials. Future developments are likely to center on fiber composite materials involving silicon nitride, silicon carbide and zirconia materials.

The disk flexure test will probably replace the standard bend testing procedures.

Strength and Testing Methods

A. Majdic (Forschungsinstitut der Feuerfest-Industrie, Bonn, FRG) presented "State and Prospect of Research on Refractories in Specific Application Areas." Fracture mechanics testing has been applied to evaluating the thermal shock resistance of ceramics, particularly for use in kilns and in the steel industry, including blast furnaces, basic oxygen convertors, and electric arc furnaces. High purity oxide ceramic bricks, involving MgO-CaO-SiO_2(ZrO_2)-Al_2O_3-graphite components, are used in severe erosive, corrosive, and thermomechanical stress environments. Plasma sprayed coatings of TiN, Al_2O_3·MgO,-Cr_2O_3, and ZrB_2 are employed for special corrosion resistance. The fracture mechanics parameters are measured in three- or four-point bend tests.

K. Goebbels presented "Non-Destructive Testing of High Temperature and High Strength Ceramics, co-authored with H. Reiter, S. Hirsekorn, and W. Arnold (Fraunhofer Institut für Zerstorungsfreie Prüfverfahren, Universität Saarbrucken, FRG). The lecture updated information given in his report with Reiter at Science of Ceramics 11 in Sweden (1981). High resolution microradiography and ultrasonic methods were covered. The methods were coupled with a vibration analysis of a turbocharger rotor made from sintered silicon nitride to establish quality assurance for the component. For cracks in silicon nitride, a resolution better than 20 microns was achieved by digital image processing. Multi-angle x-ray tomography was used to determine the distribution of carbon and silicon in a carbon-infiltrated silicon nitride component of complex geometry. Ultrasonics may be employed for anisotropy and residual stress measurements as well as for crack detection. Multiple echoes were shown to be obtained from inclusions. Goebbels predicted that the use of ultrasonic microscopy and high-frequency ultrasonics for nondestructive testing of ceramics would increase in the future.

Nineteen posters were on mechanical properties and testing methods. F.E. Buresch (Institut für Reaktorwerkstoffe, Julich, FRG) presented "Relations Between Microstructure, Fracture Toughness and Thermal Shock Resistance of Ceramics." Figure 1 gives a condensed description of the model analysis Buresch has developed for macrocrack extension in microcracked dispersion-toughened ceramics. Microcracking is enhanced by the mismatch of thermal expansions or expansion anisotropy between the grains or by phase changes. The grain size and pore size distributions are important parameters. Cumulative damage from microcracking occurs from particle impacts and thermal shocking. Residual stresses are extremely important. The influence of the microcracks on Young's modulus is detected by ultrasonic methods.

R. Knehans and R. Steinbreck (Lehrstuhl für Werkstoffwissenschaften, Universität Dortmund, FRG) presented a poster on "Effect of Grain Size on the Crack Resistance Curves of Al_2O_3 Bend Specimens." The initial crack resistance was larger for smaller grain diameters over the range 25 to 2 microns determined on either a number-of-grains or areal basis. However, the increase in crack resistance with crack growth was greater for larger grain diameters, so the net resistance to crack growth after doubling the crack length was reversed to give a greater crack growth resistance for larger grain diameters. The initial behavior was attributed to the extensive energy dissipation accompanying a high density of grain-boundary-associated microcracks forming in the finer grain size material. The greater increase in crack growth resistance at larger grain sizes was attributed to an increasing interaction zone along the rougher crack faces, where the linkage of more significantly protruding grains led to a higher rate of energy dissipation--especially at small crack openings. Steinbrech and Knehans reported in another poster, with H. Blanke and W. Schaarwachter, that the crack growth resistance depended less on crack length than on crack velocity, but that relaxation measurements allowed the true kinetics to be determined and evaluated on a thermally activated (Arrhenius) basis.

Several posters were presented on acoustic emission studies: R.G. Cooke, with I.M. Pickup and B. McEnaney (School of Materials Science, Univ. of Bath), on heterogeneous ceramics and nuclear graphites; N. Ouanezar, D. Rouby, G. Orange, and G. Fantozzi (GEMPPM, Villeurbanne, France) on alumina, zirconia, and silicon nitride materials; L. Persson (Swedish State Power Board, Vasteras) on high voltage porcelain insulators; J. Ranachowski, M. Ciesla, Z. Librant, and F. Rejmund (Institute of Fundamental Technological Research, Warsaw, Poland) on cement pastes and mortars, magnesia, and metal-ceramic joints; and K. Hinrichsmeyer and U. Diederichs (Technische Universität Braunschwieg, FRG) with U.

MACROCRACK EXTENSION IN MICROCRACKED DISPERSION - TOUGHENED CERAMICS

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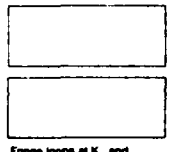
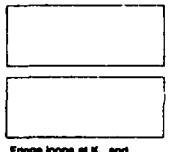
OBJECTIVES

(Micromechanisms of fracture)

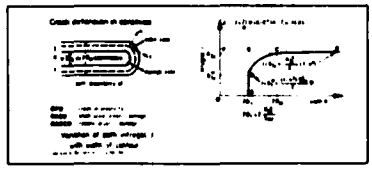
- Microcrack systems develop in stressed ceramics
- The advance of a macrocrack is a consequence of accumulations and coagulations of favorable oriented microcracks in sequences of discrete steps
- Coagulations of contiguous microcracks are a consequence of a critical microcrack-configuration that is a critical elastic strain energy density of the material inside the process zone.
- Microcracks form a crack system
- Crack systems generate a size effect of K_{Ic} and J_R
- The K_{Ic}-value of the macrocrack stress field is a function of the K_{Im}-value of the crack system of the process zone.



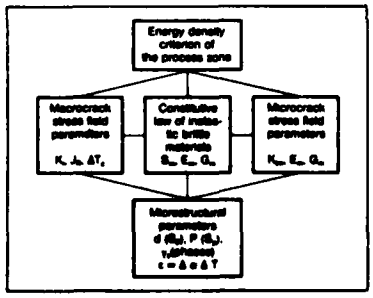
Fringe loops at K_a and after unloading in SENB specimens. Notch root radius 0.2 mm for graphite



Fringe loops at K_a and after unloading in SENB specimens. Notch root radius 4 mm for graphite



FUNCTIONAL MODELLING OF MICROMECHANICAL PROCESSES



ANALYTICAL METHODS

1. Derivation of macro- and microcrack stres-field parameters

1.1 Principle of energy density criterion of the process zone

- Dissipative energy equals change of elastic strain energy density inside the process zone of size $\pi\psi_c^2$

$$\pi\psi_c^2 \frac{\gamma_s \beta}{d} = \pi\psi_c^2 \frac{S_{mc}^2 A(\nu)}{16 E} \left(\frac{E}{E_m} - 1\right) \quad (1)$$

or with $d = a$

$$2\gamma_s l_m = \frac{S_{mc}^2 a}{8 E} A(\nu) \quad (2)$$

with

$$l_m = \sqrt{\frac{\beta E_m}{E - E_m}} \quad (3)$$

1.2 Macrocrack stress field parameters

- Notch fracture strength

$$S_{mc} = 2\sqrt{\frac{2\gamma_s E}{(2.5 - 1.5\nu - 4\nu^2)a}}\, l_m \quad (4)$$

- Stress intensity factor

$$K_{Ic} = \frac{S_{mc}}{2}\sqrt{\pi\psi_c} \quad (5)$$

- Crack resistance

$$J_R = \frac{(1-\nu^2)8\gamma_s}{(2.5 - 1.5\nu - 4\nu^2)}\, \psi_c\, l_m^2 \quad (6)$$

- Thermoshock resistance of ceramics

$$\Delta T_c = 2\sqrt{\frac{2\gamma_s}{(2.5 - 1.5\nu - 4\nu^2)\,\alpha^2 E a}}\, l_m \quad (7)$$

- Damage Parameter

$$\frac{E_m}{E} = 1 - D \quad (8)$$

$$D = \beta \frac{K_{Im}^2}{S_m^2 \pi a} \frac{1}{1 + \beta \frac{K_{Im}^2}{S_m^2 \pi a}} \quad (9)$$

$$= \beta l_m^{-2} \frac{1}{1 + \beta l_m^{-2}} \quad (10)$$

Figure 1. Fracture mechanics modelling of cracking behavior on a microstructural scale in a ceramic system.

1.3 Microcrack stress field parameters

- stress intensity factor

$$\frac{K_I}{S_m \sqrt{\pi a}} = I_m^1 = \sqrt{\frac{E - E_m}{\beta E_m}} \qquad (11)$$

- Young's modulus

$$\frac{E_m}{E} = \frac{1}{1 + \beta \frac{K_I^2}{S_m^2 \pi a}} = \frac{1}{1 + \beta I_m^2} \qquad (12)$$

1.4 Evaluation of microcrack systems

- Spontaneous microcracking

$$G_{ir} = \frac{E \epsilon^2 A^2 d}{24 (1 - \nu^2)} \qquad (13)$$

- Stress induced microcracking

$$G_i = \frac{K_I^2 (1 - \nu^2)}{E} + \frac{E \epsilon^2 A^2 d}{24 (1 - \nu^2)} \qquad (14)$$

- normalized microcrack criterion

$$A^2 d_n^* \geq 1 \qquad (15)$$

with $d_n^* = d_n / d_{max}$

A is the anisotropic factor of adjacent grains in facets with respect to the cristallographic axis for equiaxed grains (R. W. Davidge, 1981)

RESULTS

Features of crack systems such as length, density, orientation and elastic interaction of microcracks as well as the stress-intensity factor K_{Im} of the microcrack system, determine the fracture toughness K_{Ic} as well as the crack and the thermoshock resistance of ceramics (eqs (3-7) and Figs.1-6)

Stress induced microcracking can enhance fracture toughness due to crack systems of high crack density and orientation (eqs(4-11)and Figs. 9-11)

Spontaneous microcracking can lower fracture toughness as a consequence of statistically oriented microcracks (eqs(4-11)and Figs. 7,8)

The above mentioned two conclusions are in qualitative agreement with experimental results of Claussen (1982) and Green (1982)

Stress intensity factors for specific crack systems can be used to compute the corresponding Young's moduli and vice versa (eqs (11,12) and Figs. 7-12)

If the relations between microstructure, loading conditions and structural parameters of a microcrack system such as the microcrack density are known constitutive parameters of a ceramic can be evaluated. Thus the strength of a component which is microcracked by thermocycling can be evaluated by nondestructive measurements of Young's modules e.g. by ultra sonic methods.

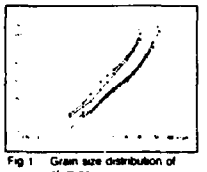


Fig 1 Grain size distribution of alumina

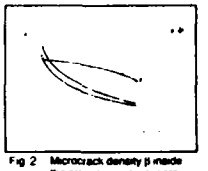


Fig 2 Microcrack density β inside the process zone v s porosity for alumina

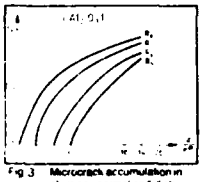


Fig 3 Microcrack accumulation in alumina normalized distribution of cracked facets for different grain facet classes for two grain size distributions v s grain size

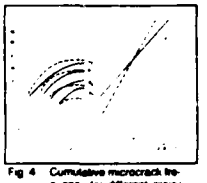


Fig 4 Cumulative microcrack frequency for different grain/facet-classes for two grain size distributions v s grain size

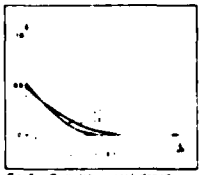


Fig 5 Cumulative crack density v s grain size for two grain size distributions

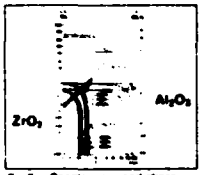


Fig 6 Spontaneous and stress induced microcracking as a function of grain size distribution for ZrO_2-Al_2O_3-composites

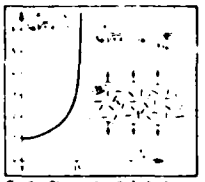


Fig 7 Stress-intensity factor for statistically oriented microcrack systems without elastic interaction (E, β-values from B Budiansky et al. 1976)

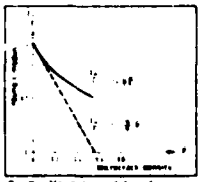


Fig 8 Young's modulus of statistically oriented microcrack systems
I B Budiansky et al. 1976
II D P H Hasselman, 1980

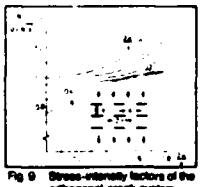


Fig 9 Stress-intensity factors of the orthogonal crack system (K_I-values from D Gross,'82)

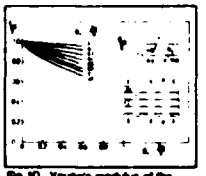


Fig 10 Young's modulus of the orthogonal crack system (K_I-values from D Gross,'82)

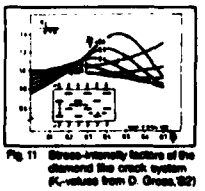


Fig 11 Stress-intensity factors of the diamond like crack system (K_I-values from D Gross,'82)

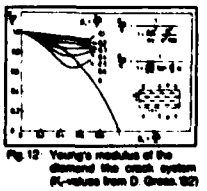


Fig 12 Young's modulus of the diamond like crack system (K_I-values from D Gross,'82)

Figure 1. (Cont'd.)

Schneider (Gesamthochschule Kassel, FRG) on cement paste, mortar, and concrete.

Fracture toughness measurements were reported in several poster sessions. G. Grathwohl, H. Iwanek, and F. Thümmler (Institut für Werkstoffkunde II, Univ. of Karlsruhe, FRG) reported a stress intensity value of 3 $MPa \cdot m^{\frac{1}{2}}$ for preoxidized SiC material sintered with different B, C, or Al additives and tested for static and dynamic fatigue behavior at 1,300°C. High resolution Auger electron spectroscopy showed monolayer chemical sensitivity for ultrahigh vacuum exposed fracture surfaces. Aluminum enrichment was observed at grain boundaries. A lateral resolution of 50 nm was obtained. In other studies, scanning electron microscopy (SEM) and transmission electron microscopy (TEM) results were closely tied to fracture mechanics and conventional strength measurements. H.W. Hennicke, R. Gorke, and W. Plentz (Institute für Nichtmetallische Werkstoffe, Technical Univ., Clausthal-Zellerfeld, FRG) had a poster on the microprocessor controlled measurement of fracture mechanics parameters. G. Simon and A.R. Bunsell (École Nationale Supérieure des Mines de Paris, Evry) gave a poster presentation of SEM and energy dispersive analysis of x-rays for characterization of NICALON silicon carbide fibers tested in tension or by creep at 1,000 to 1,300°C. A fall-off in strength above 1,000°C was associated with structural instability. Other poster sessions relating to strength properties involved materials such as W_2C, cemented WC-Co alloys, and Al_2O_3-AlON composites.

Phase Equilibria and Sintered Microstructures

E. Plumat (Free Univ. of Brussels, Belgium) chaired a session of invited papers relating to phase transformation toughening of zirconia-based materials, sintering and microstructure of nonoxide ceramics, and scanning transmission electron microscopy (STEM) and high voltage electron microscopy (HVEM) of grain boundaries in ceramics. A.H. Heuer (Case Western Reserve Univ., Ohio) described a new class of strong, tough, zirconia-containing ceramics, which derive their useful strength from the stress-induced martensitic transformation of zirconia precipitates from the tetragonal to monoclinic structures. Electron diffraction patterns and TEM images were shown of partially stabilized ZrO_2 (PSZ) containing tetragonal phase particles in a cubic matrix and of the tetragonal phase particles in a fine-grained alumina matrix. Transformation zones around crack tips and hardness indentations have been studied. Direct HVEM observations of the crack tip transformation zones were reported at the well-attended 2nd International Conference on the Science and Technology of ZrO_2, 21 through 23 June 1983, Stuttgart, FRG. An orthorhombic ZrO_2 structure has been observed as an intermediate reaction product in an MgO-containing PSZ. A stress intensity of 6 to 10 $MPa \cdot m^{\frac{1}{2}}$ was obtained in a sintered 3.5 weight percent yttria-zirconia system exhibiting a 1-nm-thick continuous yttria-alumina-silicate glass grain boundary phase. Quantitative electron microscopy analysis was shown to provide accurate information on phase boundaries in the determination of equilibrium diagrams. R.C. Garvie, M.F. Goss, and C. Urbani (Commonwealth Scientific and Industrial Research Organization [CSIRO], Division of Materials Science, Melbourne, Australia) did a poster presentation on "Weibull Modulus Studies of Magnesia-PSZ Ceramics."

H. Hausner (Technische Universität Berlin, FRG) reviewed the sintering behavior of silicon carbide and silicon nitride ceramics. In both cases, the importance of the quality of the powder constituents and additives was emphasized. Boron and carbon are the important additives for obtaining high density SiC, with a low B:C ratio needed for a fine microstructure, while MgO, CeO_2, Y_2O_3 and ZrO_2 are the additives for sintering of Si_3N_4. The oxygen content of the powder was thought to be more important than the amount of surface area. The loss in strength observed above 1,300°C for Si_3N_4 was attributed to the formation of a liquid phase at the grain boundaries.

M.P.A. Viegers (Phillips Research Laboratories, Eindhoven, the Netherlands) pointed out that modern TEM equipment operated at 100 kV gives an imaging resolution of 0.15 nm for lines and 0.30 nm for points. The chemical composition, structure, and distribution of phases are determined by TEM. Microstructural information is obtained by phase contrast (lattice) imaging and from the diffraction contrast observed in images in the bright field and dark field beams. In addition, STEM provides images of secondary electrons, backscattered electrons, and x-rays; chemical and structural information is obtained at a lateral resolution of about 5 nm. The difficulty has always been the preparation of a satisfactorily thin specimen, say 100 nm. But now with HVEM, specimens 10 times thicker (or

more) and representative of the bulk material can be studied. Examples were shown of the grain boundary structures occurring in a capacitor material composed of prefired $SrTiO_3$ subsequently infiltrated by diffusion of Bi_2O_3, PbO, and B_2O_3. Ion-milled specimens from a combination of TEM, STEM, and, most recently, HVEM observations showed that the Bi diffusion layer with a second phase layer at the grain boundaries was formed by growth from liquid solution.

About 65 poster presentations dealt with preparing materials, phase equilibria, sintering processes, microstructural characterization, and chemical reactions. G. Fernández Arroya, L. Del Olmo, J.R. Jurado, C. Pascual, C. Moure, and P. Durán (Consejo Superior de Investigaciones Científicas [CSIC] Instituto de Ceramica y Vidrio, Madrid, Spain) presented a poster "Preparation, Characterization and Properties of a Translucent Hot-Pressed $Pb_{.92}La_{.08}(Zr_{.65}Ti_{.35})_{.98}O_3$(PLZT)." X-ray diffraction and differential thermal analysis results were shown for this piezoelectric material. Other posters dealt with the thermal expansion of zirconia-based thermal barriers for diesel engines and alumina-tungsten cermets for electrical industry uses. Among eight poster presentations on phase equilibria were three Yugoslavian posters on Al_2O_3-MgO-B_2O_3, ZnO-Bi_2O_3, and SnO_2 in $BaTiO_3$-TiO_2-$Nd_2O_3 \cdot TiO_2$, respectively. R. Martinez and S. De Aza (CSIC, Madrid) showed a poster of quaternary phase diagram information relating to the compatibility of calcium monoaluminate in the Al_2O_3-CaO-SiO_2-TiO_2 system.

Sintering was the main subject of 17 posters. J. Drennan (CSIRO, Division of Materials Sciences, Melbourne, Australia) and E.P. Butler (Department of Metallurgy and Materials Science, Imperial College, London) presented excellent TEM observations of Al_2O_3 particles at grain boundaries in additive-stabilized zirconia materials. Although Y_2O_3 and Yb_2O_3 additives with SiO_2 aid sintering by forming an amorphous grain boundary phase, the second phase Al_2O_3 particles inhibit grain growth in the later stages of densification. L.K.L. Falk and G.L. Dunlop (Chalmers Univ. of Technology, Sweden), with R. Pompe (Swedish Institute for Silicate Research, Göteborg), presented a poster "Development of Microstructure during Nitridation and Sintering of Si:Si_3N_4 Powder Compacts." Pressureless sintering of Si_3N_4 material is being achieved by a two-step process involving the nitridation of Y_2O_3- and Al_2O_3-doped Si:Si_3N_4 submicron powder compacts at 1,260 to 1,400°C, followed by sintering in nitrogen at 1,800 to 1,850°C. Excellent SEM, TEM, and STEM microstructural results were presented. The work carries on from the project High Temperature Ceramics for Heat Engines supported by the National Swedish Board for Technical Development (Pompe, Hermansson, and Carlsson, 1982). Other posters dealt with the sintering of Al_2O_3, α-Fe_2O_3, SnO_2, SiC, ZnO, and $BaTiO_3$ materials. SEM, optically stimulated exoelectron emission, x-ray line broadening, dilatometry, and grain boundary grooving techniques were applied in different cases. Among the posters relating to chemical reactions were "Solid State Bonding of Noble Metals to Alumina," by R.V. Allen and W.E. Borbidge (CSIRO, Division of Chemical Physics, Clayton, Australia); "Formation of Sialons in the Systems Si_3N_4-$3Y_2O_3$ $5Al_2O_3$-$Si_2Al_4O_4N_4$ and Si_3N_4-$3Dy_2O_3$ $5Al_2O_3$-$Si_2Al_4O_4N_4$," by S. Boskovič (Boris Kidric Institute of Nuclear Sciences, Beograd, Yugoslavia); and "Glass Fibers Crystallization in the System SiO_2-Li_2O-TiO_2-Al_2O_3," by G. Scarinci, S. Meriani, B. Locardi, G. Sorarù, and D.R. Festa (Instituto di Chimica Applicata, Università Trieste, Italy).

Ceramics Research in the PRC

R. Carlsson (Swedish Institute for Silicate Research) was chairman for a session of two invited papers on the progress of ceramics research in the People's Republic of China (PRC). Guo Jing-Kun (Shanghai Institute of Ceramics [SIC], Chinese Academy of Sciences, PRC) described high temperature ceramics and composites research at the SIC. The SIC was formed in 1960 and has 408 researchers among the total staff of 947. Primary materials of concern are Si_3N_4, SiC, and AlN powder preparations, of 0.5, 0.1, and 2 to 4 micron size, respectively; Al_2O_3 materials; and fiber-reinforced ceramic composites. RBSN and magnesia-containing HPSN materials have been studied. The addition of Y_2O_3 to silicon nitride materials maintains their strength at high temperatures. High pressure silicon carbide has excellent strength properties at high temperatures. RBSN material has been used to fabricate large sealing rings. The ternary phase relations and reaction kinetics are studied for the Y_2O_3-$Al_2O_3 \cdot AlN$-Si_3N_4 system. Accomplishments described were the fabrication of a 1.3-m diameter alumina ring used for nuclear fusion studies and the development of translucent alumina for high pressure sodium lamps with 94 to 95% transmittance and lifetimes greater than 12,000 hours.

Fiber-reinforced ceramic composites research has involved carbon fibers in fused quartz or Si_3N_4 materials and SiC or BN fibers in Si_3N_4. Carbon fibers in fused quartz give good compatibility of thermal expansivity. A strength level of 600 MPa is obtained. SEM studies show that the material fails by matrix cracking and pull-out of the fibers. The relatively low thermal expansivity of the carbon fibers compared to Si_3N_4 gives a noncompatible system, which is alleviated to some extent by the addition of zirconia. A fracture mechanics stress intensity of 15.6 $MPa \cdot m^{\frac{1}{2}}$ was achieved with the modified system. Alumina was added to increase the thermal expansivity of Si_3N_4 and so prevent fracture of the SiC reinforcing material. Also, a hybrid SiC plus C fiber mixture was added to match the Si_3N_4 expansivity. The most recent system studied has been 10-mm-long BN fibers resin-bonded in an Si_3N_4 composite.

Wang Kong (SIC) described recent research on electronic functional ceramics. The main concern was with piezoelectric ceramics such as porous lead zirconate titanate (PZT). The effect of particle size distribution of the synthesized powder, sintering temperature, firing schedule, DC field sintering, cooling condition, and lead vacancy concentration have been studied. Ferroelectric domain structures were observed in the individual grains. A porous PZT composition is $0.98Pb(Zr_{.53}Ti_{.47})O_3$-$0.02Pb(Li_{.25}Nb_{.75})O_3$. Non-lead piezoelectric ceramics of interest include sodium-potassium-bismuth titanate (XNBT-[1-X]KBT with $0.73 \leq X \leq 0.95$) as a useful transducer material and $(Li_{.12}Na_{.88})NbO_3$.

Electrical and Electrochemical Ceramics

F. Cabannes (Centre de Recherches sur la Physique des Hautes Témperatures, Centre National de la Recherche Scientifique [CNRS], Orléans, France) chaired the final session of three invited papers. R. Wernicke (Phillips GmbH Forschungslaboratorium, Aachen, FRG) covered ceramic multilayer capacitors and nonlinear resistors. Miniaturized multilayer capacitors are directly soldered now in circuit boards. Palladium electrodes are sandwiched between 25-micron-thick layers of $BaTiO_3$ acceptor-doped with Mn to prevent semiconduction and keep the layers insulating. Sintering at 1,300 to 1,400°C has required Pd as the electrode material. The market is 6 billion capacitor units per year. Research has involved the design of a porous structure that will allow less-costly electrode layers to be put in after sintering. Nonlinear resistors with a temperature dependence of resistivity spanning four orders of magnitude at their Curie temperatures above 100°C, such as $(Ba,Sr)TiO_3$ and $(Ba,Pb)TiO_3$, are used in self-regulating heater elements and in degaussing units in television systems; they also are used as temperature sensors. Their properties depend on electrically active grain boundaries. Because of the grain boundary effects, microstructural control is essential. The defect chemistry and the nature of the domain structures are important areas of research; a difficulty is that thermal cycling through the Curie temperature causes embrittlement. Future prospects are for continued research to develop the materials.

S. Rinaldi (Instituto MASPEC-CNR, Parma, Italy) gave a paper co-authored with F. Licci, "Recent Advances in Hexaferrite Films." The films are ferrimagnetic materials and are promising for microwave and millimeter wave devices and for bubble memories. The crystallographically dependent magnetic anisotropy controls the bubble (domain) structures in thin garnet layers, which operate as storage devices. Materials such as hexagonally layered $Ba(Fe_{.66}Al_{.34})_{12}O_{19}$ on a substrate of $SrGa_{12}O_{19}$ are of interest because lattice matching of the film and substrate is a critical consideration. Most recently, the system $SrAl_xGa_ySc_zIn_wFe_{12-(x+y+z+w)}O_{19}$ has been studied and revealed a linear dependence of the a and c lattice parameters and Curie temperatures on composition. Polycrystalline materials were produced to confirm the linear lattice parameter dependences on composition. Millimeter-size crystals have been produced by flux evaporation from the liquid state. Results on films are encouraging, but further research is required.

B.C.H. Steele (Wolfson Unit Solid State Ionics, Imperial College, London) gave a paper on "Ceramic Materials for Electrochemical Energy Conversion Devices." The aim is to achieve fast ion conduction in ceramic electrolytes. The DC field across the electrolyte causes degradation, for example, by reducing the material to form liquid metal within it and leading to embrittlement. Polymer electrolytes may suffer less from degradation. Suitable electrolytes for oxygen and sulfur monitoring are being developed, for

example for automobile exhaust systems and carburizing furnaces. The complex impedance of AC conduction in the materials is extremely sensitive to grain boundary and grain volume resistance changes, so impedance measurements are used for microstructural studies. Secondary ion mass spectrometry is a valuable tool for assessing the surface concentrations of materials and for measuring grain boundary diffusivities. The kinetics of oxygen exchange was shown to be controlled by the surface chemistry of zirconia; only 1% of the oxygen in the gas phase was present on the surface of the material. Cation implantation has been investigated to improve the oxygen exchange. Fuel cells need a conductivity of (0.1/ohm cm) at 400 to 600°C to be competitive with conventional engines at low loads. A material of interest is $Na_{3.1}Zr_{1.55}Si_{2.3}P_{.7}O_{11}$ but the possibility of oxygen loss is a problem. Three poster presentations relating to the lecture topic were "Solid Ionic Conductor Based on High Temperature Treated Silver Zeolite $AgA \cdot AgNO_3$," by N. Petranović (Institute of Physical Chemistry, Beograd, Yugoslavia); "Control of Oxygen Partial Pressure by Solid State Electrolyte," by F. Vizethum, G. Bauer, and G. Tomandl (Institut für Werkstoffwissenschaften III, Erlangen, FRG), and "Electrical Conductivity of Solid Solutions in the Systems CeO_2-CaO and CeO_2-LnO_3 with Ln = La, Nd, Sm, Gd, Er or Y," by C. Pascual, C. Moure, G. Fernandez Arroyo, J.R. Jurado, and P. Duran (CSIC Instituto de Ceramica y Vidrio, Madrid, Spain).

The conference proceedings are to be printed before the end of the year under the editorship of P. Vincenzini. A follow-up conference this year will be the 8th International Technical Colloquium on Ceramics Processing, 29 and 30 September, Rimini, Italy. Contact Ceramurgica S.r.l., P.O. Box 174, 48018, Faenza, Italy. Science of Ceramics 13 is scheduled for 1985 at Orléans, France, under the chairmanship of F. Cabannes, Centre de Recherches sur la Physique des Hautes Temperatures, CNRS, 45045, Orléans, France.

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R.W. Armstrong

PHYSICS

NEUTRON BEAMS PROBE CONDENSED MATTER AT AERE

The Atomic Energy Research Establishment (AERE) at Harwell in Oxfordshire is the primary center for applied nuclear research and technology within the UK Atomic Energy Authority. The research and development programs are guided by the needs of the nuclear industry, and much of the work is proprietary. However, the Underlying Research Program (composing about 20% of the total AERE effort) is reported openly and provides the scientific basis for current and future R&D. The program provides innovation through longer term research for the particular needs of nuclear technology--special materials operating reliably and safely in extreme environments. Research is in the areas of radiation effects on metals and alloys, surface analysis and modification, fracture mechanisms, corrosion in aqueous environments, fluid flow, neutron reactions, nuclear measurement applications, neutron and ultrasonic analyses of condensed matter, isotope separation, and aerosol behavior.

The largest group within the Material Physics Division of AERE uses neutron beams to probe materials of interest to the nuclear power industry. The group leader, Dr. Peter Schofield, described his projects and introduced me to the accelerator and reactor neutron source facilities used in the research. This article provides some basic information about the interaction of low energy neutrons with matter, describes the neutron sources available at Harwell and elsewhere, and presents some highlights of condensed matter studies conducted at AERE.

Background

Probing condensed matter with neutrons provides unique information supplementing that obtained with x-radiation and charged particle beams. As with the other radiations, the

conventional techniques of radiography, scattering, and diffraction are used. However, the ability of neutrons to penetrate matter deeply provides many nondestructive applications associated with internal imaging, defect and void analysis, atomic and molecular structure, phase determination, and stress analysis.

The neutron's special quality for materials research is that it lacks electrical charge, interacting weakly with matter through simple, hard-sphere collisions with atomic nuclei. In contrast, ionizing radiations interact with atomic electrons through the long-range electromagnetic force. Thus, neutrons probe matter to depths of many centimeters rather than the 10^{-3} cm surface layers accessible to x-rays and charged particles. Gamma rays can also penetrate deeply but are selectively attenuated by high-atomic-number matter, whereas neutrons are attenuated by hydrogenous matter. (A neutron radiograph on display at Harwell dramatically illustrates this feature. It shows a sharply imaged waxed thread sandwiched between two lead plates.) Neutron penetration through metals, especially aluminum and steel, permits the *in situ*, time-dependent study of specimens within furnaces, cryostats, pressure vessels, stress cells, chemical reaction vessels, and magnets.

The neutron mass provides a better dynamical match to nuclei than x-rays or electrons, so vibrations in crystals and polymer chains can be efficiently excited and analyzed. The low velocity of thermal (room temperature kinetic energy, 25 meV) neutrons (2,200 m/s) permits energy discrimination by time-of-flight differences over several-meter path lengths. Additionally, neutrons have a magnetic moment, so the structure of magnetic materials and impurities can be studied nondestructively.

Quantum mechanics shows that objects usually considered particles have a wavelength that describes their distribution in space. This de Broglie wavelength is given by the Uncertainty Principle as $\lambda = h/p$, where h is Planck's constant and p is the neutron momentum. A thermal neutron has a wavelength of about 2 angstroms, which, unlike relativistic electrons or photons, scales with the inverse square root of energy. Because of this wave property, neutrons exhibit interference effects and are diffracted in accordance with the Bragg law:

$$\lambda = 2d \cdot \sin(\phi/2) \qquad (1)$$

Thermal neutrons have wavelengths comparable to d, the lattice spacing of crystalline solids, so the variation of diffracted beam intensity with scattering angle, ϕ, can be used to determine the atomic positions within crystal structures and their state of perfection. Lower energy "cold" neutrons have wavelengths in excess of the maximum 2d spacing in a lattice and so are not diffracted by ordered atomic structures in accordance with equation (1). Scattering by larger-scale disorders such as precipitates, defects, and voids therefore can be observed.

Because of increased availability of short wavelengths with accelerator-based sources and the higher resolving power obtainable with them, there has been growing interest recently in the use of "hot" neutrons (with energies up to about 1 eV) to probe matter. Using the time-structure of such pulsed sources, one can achieve a spatial resolution of 0.05 angstroms. Hot neutrons are sufficiently energetic to excite vibrational modes in matter so that measurement of the energy lost in inelastic scattering by secondary time-of-flight or crystal diffraction can yield vibrational spectra within thick specimens.

Facilities for Condensed Matter Research

Neutron beams are either extracted from fission reactors or are produced in the collision of high-energy charged particle beams with heavy targets. Research reactors have been used to probe matter for about 30 years. The highest flux sources (about 10^{15} n/cm^{2}s) are at Brookhaven National Laboratory, Oak Ridge National Laboratory, and the Inst. Laue Lengevin (ILL, Grenoble, France). High flux is important for refined experiments in which collimation and energy selection requirements limit the neutron count rate. Diffraction experiments may require many hours of beam exposure for adequate counting statistics. Rather than build its own high flux facility, the UK joined ILL about 10 years ago as a third partner with West Germany and France.

Other US reactor facilities are at Los Alamos National Laboratory, Argonne National Laboratory, and the National Bureau of Standards. Research reactors in other countries include the Chalk River Reactor in Canada and KEK in Japan. A new French reactor, Orphée, is beginning operation at about one-third the flux level of the ILL facility.

High flux reactors are now near the limit of technology in the sense that

increasing the flux by a factor of 10 would be prohibitively expensive. (The 20-year-old High Flux Beam Reactor at Brookhaven would cost about $100 million to build today.) A major problem is that the small cores required for high brightness become difficult to cool. There is also a negative public response to construction of reactors of any sort.

While reactors are fine for thermal and cold neutrons, accelerator-based sources are much more efficient in the production of sub-angstrom hot neutrons. Megavolt-energy neutrons are produced in accelerator-based sources when either high energy electron or proton beams interact with heavy targets. Protons knock neutrons from the target nuclei in a spallation process. Electrons decelerating in the target emit *bremsstrahlung* gamma rays as a source for photoneutron production.

Besides being cheaper to operate and acceptable to the public, the pulsed nature of accelerator sources have advantages with respect to energy selectivity by time of flight, improved instrumentation, and the study of time-dependent phenomena. Increased use of hot neutrons for materials research has led to construction of pulsed-neutron sources in conjuction with accelerator programs at Argonne National Laboratory and the Los Alamos National Laboratory.

The Helios electron linac at Harwell is one of the best instrumented pulsed facilities. It and the Swiss Institute for Nuclear Physics (SIN) spallation source are equivalent to medium flux reactors. The Spallation Neutron Source (SNS) now being constructed at the Rutherford Appleton Laboratory "next door" to Harwell will be a high performance neutron source, providing about 100 times the intensity of Helios.

Both reactor and accelerator sources require a moderating material to slow the neutron from megaelectronvolt energies to below 1 eV for materials research. The moderated beams have energy spreads of many decades and, with the exception of radiography, must be made monochromatic for most experiments. Pulsed sources are energy resolved by time of flight through beam lines several meters long. Velocity selection for cold or thermal neutrons can be made in reactors by mechanically chopping the beam. Instruments recording time-dependent scattering from objects at the end of the lines are then automatically parameterized with respect to neutron energy. Reactors and pulsed sources also employ Bragg reflection at specific

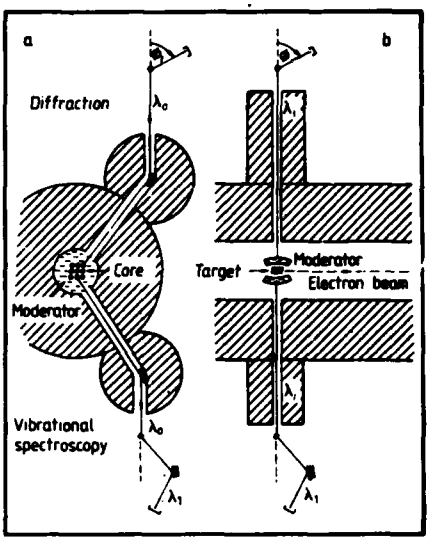

Figure 1. Materials research with (a) reactor, and (b) accelerator based neutron sources.

angles from large single crystals such as germanium and iron to select particular neutron wavelengths; see equation (1) and Figure 1. The monochromatic beam is then incident on the test specimen, which scatters it into the detector. As a testament to the dual-wave-particle nature of matter, image detectors, diffractometers, and spectrometers used to analyze the scattered beam are similar in function and application area to those used to analyze x-radiation. One difference is the larger dimensional scale required for neutron shielding and collimating.

The D_2O moderated DIDO and PLUTO reactors at Harwell began pioneering neutron diffraction research in the early sixties. I toured DIDO with D.H.C. Harris, who is responsible for operating the facility. The reactors provide 12- to 250-meV neutrons for experiments. Cold neutrons are provided by a liquid hydrogen cold source. Currently, there are only eight to 10 instruments on each reactor; most of the resources are devoted to applied materials work for industry.

A major funding source for DIDO and PLUTO is the neutron transmutation of silicon to phosphorus for semiconductor manufacturers in Germany, Japan, the US, Belgium, Denmark, and Italy. By a lucky accident of nature, 3% of silicon is the isotope ^{30}Si. After ^{31}Si is formed from ^{30}Si by neutron irradiation, it trans-

mutes to ^{31}P by beta decay. Ingots of silicon, 50 cm long by 12.5 cm in diameter, are uniformly doped in the reactors by this technique, and are later sliced for use in integrated circuits. DIDO and PLUTO are well adapted to the process because the moderator and reflector geometries provide a highly isotropic thermal neutron flux. In other facilities, ingots must be rotated on spits to provide uniform doping during the many hours of irradiation. Harwell is the world's largest producer of ingots doped this way, supplying about 15 tons per year. In the US, the process is used in the Univ. of Missouri research reactor.

Helios, an eight-section, 135-MeV electron linac with 1-A pulses of 1-ns to 5-ms duration, was shown to me by Roger Sinclair of the Materials Physics Division. Four experimental target cells can be used simultaneously with beam multiplexing: a fast neutron cell for interactions above 10 keV, a low-energy cell for photoneutron and photofission studies, a booster cell with a subcritical assembly that increases neutron yield by a factor of 10, and a condensed matter cell.

The condensed matter cell uses tantalum or uranium targets to serve up to 18 neutron beam lines. A few lines more than 100 m long provide high degrees of collimation and energy separation with time. Lines much longer than 100 m are impractical because low-energy neutrons fall in gravity over longer distances. Target yields are about 10^{12} neutrons per 5-μs pulse. Repetition rates are limited to 150 pulses/s by frame overlap--the fastest neutrons from one pulse catch up to the slowest from the previous pulse. A water moderator slows the target neutrons to energies of interest and causes the pulse to spread in time. Figure 2 shows the flux and pulse width variations with wavelength at 12 m from the target. The high flux and narrow pulse width at short λ indicate high performance in the regime where beams from reactors become weak. Nearly all of the experiments mounted on the Harwell linac make use of the shorter wavelength region of the spectrum.

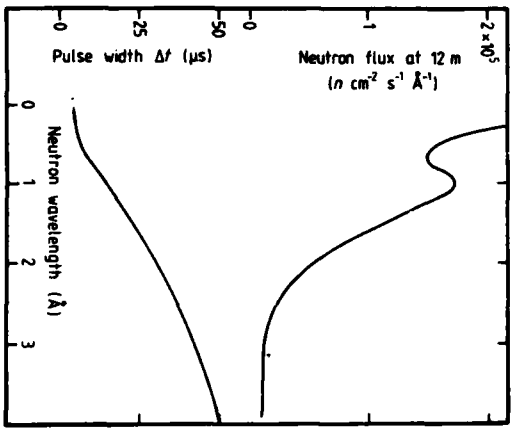

Figure 2. Flux and pulse width variations with wavelength for Helios.

Radiography

Radiography is the simplest way that neutrons are used to probe matter. As neutrons penetrate metals deeply but are heavily absorbed by hydrogenous material, the technique is particularly well suited to testing, inspection, and quality control involving low atomic number materials within metal casings. Ongoing radiography programs on DIDO and PLUTO use neutron beam lines of 14-in. diameter so that large structures can be illuminated.

Neutrons transmitted through the illuminated structure form a contact shadowgraph image behind it. For static imaging, photographic plates are covered with gadolinium foils--a rare earth element with an exceptionally high neutron absorption coefficient. Electrons emitted in response to the absorbed neutrons expose the film. Since the technique does not require velocity selection, the entire beam flux can be used, and exposures with millimeter resolution can be made in a few milliseconds. Real-time dynamic imaging can be achieved by replacing the film-foil combination with a gadolinium oxysulphide scintillator viewed by a video camera and recorder.

Two examples of static imaging were shown to me; both involved inspection for cooling channel blockage in structures. One object was an ion beam accelerator grid structure used in large numbers within the neutral beam injectors for auxiliary heating in JET (the Joint European Torus at the nearby Culham Laboratory in Abington, Berkshire). During fabrication, milled channels in a copper plate are filled with bee's wax and then copper plated over to close the channel. Neutron radiography of each grid is needed to reveal any undissolved wax that can prevent cooling water circulation. The second example involved inspection of all air-cooled turbine blades used in

Figure 3. Blocked turbine blade neutron radiograph..

the Rolls Royce RB211 helicopter--this time looking for residual core material blocking cast cooling channels. The core material is made neutron-absorbing by soaking in a gadolinium salt solution before radiography. A radiograph of a blocked turbine blade is shown in Figure 3.

Real time radiography with video monitoring is used to solve problems related to lubricant, fuel, and coolant flows in internal combustion engines. I was shown a video tape produced at Harwell in collaboration with Burmah Castrol. The tape showed oil flow and sprays within an operating Talbot Horizon car engine. Similar methods were used to study an experimental Rolls Royce helicopter engine. For safety reasons, the helicopter engine was mounted in a blockhouse surrounding a beam line outside the DIDO reactor building. The project was carried out to determine the cause of catastrophic oil consumption (gallons per minute). Radiography of the running engine pointed to oil pressure gradients in the wheel bearing assembly and a subsequent redesign.

Scattering

Cold neutrons with wavelengths longer than the Bragg limit are only scattered by defects. The defects can take many forms: porosity or voids, micro-emulsions in water, precipitates in alloys, or particles in a catalyst support. In accordance with equation (1), the scattering angle increases as the defects get smaller, so there is no theoretical lower limit to the size of the defect that can be examined. The upper limit is set by the angular resolution of detectors. Experiments are usually designed to measure inhomogeneities on the 10- to 1,000-angstrom scale. A cold beam is monochromated by mechanical velocity selection and then strikes the sample. The small-angle scattered neutron distribution is recorded with position-sensitive detectors.

On PLUTO, defect analysis is carried out using a 1-m-diameter detector, and data are collected for a few hours. The data are plotted as a Guinier plot, the logarithm of the experimental differential cross section versus Q^2, where $Q = (4\pi/\lambda)\sin(\phi/2)$. The maximum of the Guinier plot determines the separation of scatterers, the slope for large Q determines the size of the scatterers, and the Q = 0 intercept gives the defect volume fraction (Kostorz, 1979).

Small angle neutron scattering (SANS) has been used by the Materials Physics Division to study hardened alloys containing precipitates that pin

dislocations. High resolution transmission electron microscopy (TEM) is commonly used to characterize precipitates. However, diffraction and aberrations limit TEM to clusters with diameters greater than a few nanometers. The early-stage growth of smaller clusters is traced with 1-meV SANS.

The nimonic (copper-nickel) alloy PE16, used for certain important components in the Advanced Gas-Cooled Reactor, has been studied with SANS. Under heat treatment, a precipitate grows in the matrix, changing its mechanical properties. Berkeley Nuclear Laboratories, having undertaken extensive TEM and mechanical tests, prepared 11 samples of PE16 for neutron analysis. Eight of the samples were heat treated at 700°C for times varying between 16 and 10,000 hours. The remaining samples were treated at other temperatures. The precipitate size and volume fraction were determined from Guinier plots of each. A cube root increase of precipitate size with heat treatment time was demonstrated.

Another SANS experiment was designed to measure void swelling in fast-reactor core materials due to intense radiation. The precise measurement of void volume fraction and size for different dose and temperature conditions must be known to determine operational lifetimes accurately. Measurements on 316 stainless steel were chosen for study because it is the reference fuel cladding and wrapper material in the UK fast reactor program. TEM can be used for void measurements down to 2 nm in thin specimens. Neutrons can follow the growth of smaller voids in thick specimens so that average properties for the bulk material can be determined. Results showed expected trends, a decrease in void fraction with cold working and an increase of precipitate fraction with temperature.

SANS has also been used to analyze the pore and particle size distributions of nickel oxide catalyst within an alumina (Al_2O_3) substrate. The difficulty is separating the two sets of scattered neutron information associated with the voids and particles. After SANS data for an unprepared sample have been collected, the pores are filled with deuterated methanol, which has the same scattering power as the substrate. A second set of measurements then records scattering caused only by the nickel oxide particles. This contrast-match technique can then determine the void structure by comparing the two sets of results.

Inelastic forward scattering of hot neutrons from Helios is measured with the Harwell inelastic rotor spectrometer to determine vibrational energy spectra over the 50- to 200-meV range. The effects of multiphonon scattering were shown by measuring the intensity differences between two vibrational modes in sodium bifluoride ($NaHF_2$). The constant Q spectrometer uses the time variation of neutron energy on Helios to measure scattering versus energy at a fixed angle to determine the energy dispersion of phonon excitation in single crystals. The optical phonon spectrum of heavy ice was examined with the instrument.

A recent examination of the phonon spectrum of uranium oxide heated in a furnace to 2,900°K provided important information on interatomic forces and defect structure. One needs the equation of state of molten UO_2 for reactor core meltdown codes and calculations. The SANS results allow one to extrapolate to pressure and temperature regimes not accessible to laboratory experiments. The studies, supported by the General Reactor Safety Program, grew out of a more fundamental program to study lattice dynamics and disorder in fast ion conductors. The neutron data are supplemented by results of optical measurements on fast ion conductors performed at the Clarendon Laboratory of Oxford Univ. as part of a long term collaboration with Harwell.

Diffraction

For neutron diffraction analysis, the beam is finely monochromated in the short wavelengths by a large germanium single crystal. The fixed wavelength beam is then diffracted by the sample into a detector, moving in an arc around it. The neutrons are scattered by the crystal lattice planes--in accord with equation (1)--into a diffraction pattern that characterizes the atomic structure. When many crystal phases are present, diffraction can be used to determine the amount of each. Neutrons are better than x-rays for such measurements because they can be used to monitor changes as they occur during heating.

Diffraction can resolve changes in lattice spacing ($\Delta d/d$) on the 10^{-4} scale by employing a double back scattering geometry. Figure 4 shows such an arrangement on PLUTO. Very high resolution requires a highly monochromatic beam, $(\Delta\lambda/\lambda)<<1$, and high angular resolution. Differentiation of equation (1) shows that $\Delta d/d$ and $\Delta\lambda/\lambda$ vary like $\cot(\phi/2)$ for fixed $\Delta\phi$. Therefore, highest resolution is achieved for $\phi = 180$ degrees, i.e., when the beam is backscattered from both the monochrometer and specimen crystals.

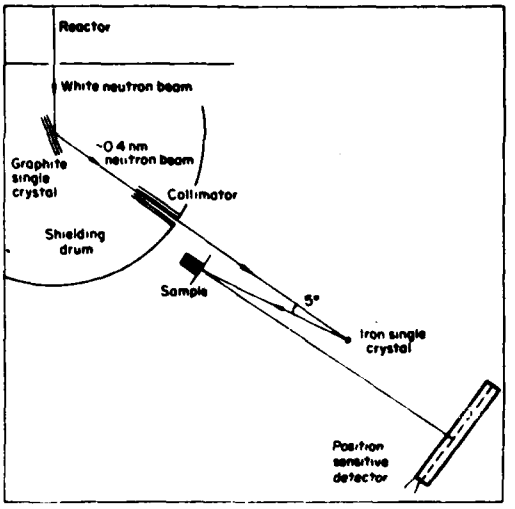

Figure 4. Double back scattering experiment on PLUTO.

Currently, the most exciting results with the back-scatter technique are measurements of internal stress. Internal stress measurements in fabricated components are of great importance but are difficult to obtain with ultrasonic and magnetic techniques because such measurements are sensitive to texture. By measuring the shift in the Bragg peaks, neutrons provide a nondestructive measure of the strain tensor within a bulk sample.

Work at Harwell is concentrated on stresses in welds. Such stresses can be a substantial fraction of the yield strength. Stress relief heat treatments help but are expensive and may introduce undesirable minority phases. Knowledge of the minimum treatment temperature and time that will reduce stresses to an acceptable level is therefore important.

A test of the method on PLUTO was provided by a 6-mm-thick steel bar subjected to a known mild stress (Allen et al., 1981). The internal stress caused an extension of the lattice spacing along the stress and a contraction perpendicular to the stress. The change in lattice spacing in a particular orientation and at a particular point in the material was measured by adjusting the apertures of the incoming and outgoing beams. The sample was then rotated about that point to define the full three-dimensional strain tensor. Results of the test showed that the d-spacing change (microscopic strain) followed the bar deformation (macroscopic strain). Additional tests have been conducted on the D1A spectrometer at ILL, where the back-scatter requirement could be relaxed because of high flux.

Most recently, the internal strain in actual welds of commercial importance has been measured before and after stress relief. For several points, the weld was oriented along six directions sufficient to define all six components of the symmetric strain tensor. It was deduced that the yield point must have been reached at places in the weld.

As indicated above, ultrasonic probing for nondestructive testing of weld materials is complicated by the dependence of ultrasound velocity on the preferred orientation of the crystallites in highly textured materials. Developing a model to predict texture effects is clearly important. Neutron diffraction measurements on DIDO were done with a 1-cm cube of austenitic stainless steel cut from weld material (Allen et al., 1983). The measurements were then used to determine the crystallite orientation distribution function. The longitudinal and transverse sound velocities in three orthogonal directions were then calculated theoretically using a number of models for the orientation distribution, and were compared with the measured values. The Voigt approximation gave the best agreement with experiment. Results should be useful for sizing defects in welds by ultrasonic techniques.

The background levels in neutron diffraction experiments can be made very low compared with x-ray diffraction. Therefore, neutron diffraction is useful for detecting small amounts of minority phases in a matrix metal. The technique was used to study heat treatment of type 316 stainless steel welds widely used for high-integrity welding applications. Microstructural instability during stress relief heating or service at elevated temperatures can lead to deterioration of mechanical properties. Electron and x-ray microanalysis of weld materials revealed the presence of undesirable, brittle minority phases. Subsequent neutron diffraction gave the volume fraction of the phases. The results allow quantitative estimates of the effects of varying the heat treatment.

Concluding Remarks

It is clear that the neutron beam is following the same evolutionary path as optical microscopy, electron microscopy, and synchrotron x-radiation--from pure scientific investigation to an important tool for materials science. Comparable progress has been made in

areas of physical chemistry using neutrons to study hydrogen bonding to surfaces. Recent investigations at Harwell include the distribution of hydrogen in catalyst materials, the distribution of water near colloidal surfaces, the sol and gel structure of cement pastes, and the sorption of polymers by porous solids.

As with the high technology sources of ionizing radiation, adequate facilities are large and beam utilization is expensive. However, the high penetration of neutrons in metals and their sensitivity to hydrogenous material provide unique insights into the structure of matter.

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D. Mosher

SPACE SCIENCE

LOW GRAVITY RESEARCH

Much of the scientific effort in space has been to explore the geospace environment, the planets, and interplanetary space. Such explorations will continue but will be complemented by major programs in astronomy and other areas of science. One new area of great promise is research under conditions of low gravity.

The European community is actively pursuing opportunities in low gravity research. Initial efforts will emphasize materials, fluids, and the life sciences. Applications will include achieving purer and more perfect crystals and developing alloys and composites. Opportunities in space will come from rocket programs; Spacelab, scheduled for a Shuttle flight (STS-9); and the forthcoming EURECA program (see *ESN* 37-4:161 [1983]). Additional low gravity research will come from theoretical studies, physical simulations, and numerical experimentation.

A low gravity environment is difficult to achieve except in space. The gravitational field varies less than about 0.1% over the surface of the earth. "Low" gravity is essentially a weightless condition which exists when a body is in a natural state of acceleration while under the action of the gravitational force. Weightlessness or near weightlessness can be achieved in free-fall in an evacuated chamber, in sounding rockets, and in satellites or space platforms. Except in space, free-fall can be maintained for only a matter of seconds and entails practical difficulties, such as coping with high terminal velocities. Sounding rocket flights are useful but last only about 4 to 6 minutes. In contrast, durations of hours to months will soon be available for experimentation in space. Remnant gravitational effects in space can be removed sufficiently to reduce the weight of an object to only a millionth (10^{-6}) of its value at the surface of the earth. Therefore, the term "microgravity research" refers generally to the low-gravity environment in space for conducting experiments or operating laboratories.

The European Space Agency (ESA) initiated its program in microgravity research in early 1982, an action that reflects developing interest in the community. The total funding planned for the first 4 to 5 years of the program is about $35 million. Initial programs will be in molecular biology, hydrodynamics, and solidification. The Spacelab facility and sounding rockets will be used.

In a related development, the European Low Gravity Research Association (ELGRA) was established in 1978 to develop a cohesive scientific community in microgravity research. The association is registered under German law and was created under the auspices of the European Space Agency and the Council of Europe. Scientific and technological research objectives are to promote and encourage European efforts to investigate gravitational effects in physical and biological systems. Particular emphasis is given to the development of microgravity experiments suitable for space flight. To accomplish their objectives, ELGRA will promote interdisciplinary cooperation among appropriate research teams; organize scientific conventions, conferences, and colloquia; and promote the exchange and dissemination of pertinent information.

ELGRA's membership covers a broad range of disciplines in science and engineering, including aerospace engineering, biochemistry, bioengineering, fluid mechanics, materials sci-

ences, microbiology, neurology, and space mechanics. To strengthen further the European microgravity community, ELGRA began a membership drive under its president, Prof. L.G. Napolitano of the Univ. of Naples. In its most recent conference activities, ELGRA cosponsored the Fourth European Symposium on Materials Sciences Under Microgravity, held in Madrid from 5 through 8 April 1983, and the International Conference on Space Physiology, held in Toulouse from 1 through 4 March 1983. In addition, ELGRA will cosponsor the Symposium on Microgravity Sciences and Processes at the International Astronautical Federation Congress in Budapest from 10 through 15 October 1983. Conference proceedings are available from the Scientific and Technical Publications Branch of ESA (Postbus 299-2200 AG Noordwijk, the Netherlands).

ELGRA is run by an elected management committee with eight members. A council with national representatives from each country in ELGRA provides nominations for the membership committee and proposes research projects and special programs for adoption. Ten nations are represented on the council: Belgium, Denmark, France, the Federal Republic of Germany, Italy, the Netherlands, Spain, Sweden, Switzerland, and the UK.

To achieve its objective in specific fields, ELGRA has established working groups. Their responsibilities are to communicate information promptly to the appropriate scientific community and to promote the development and progress of designated microgravity research projects in the European community. There are five working groups, each with one or more leaders or coordinators: Crystal Growth and Metallurgy in Space (C. Potard, France); Microgravity Fluid Dynamics (P. Monti, Italy); Physiology and Medicine in Space (F. Bonde-Petersen, Denmark); Space Biology (H. Planel, France, and A. Cogoli, Switzerland); and Radiobiology in Space (H. Bücker and E. Schopper, Federal Republic of Germany).

Microgravity activities are closely linked with European programs on the Space Shuttle. The most recent Shuttle Challenger flight (STS-7) included the deployment and retrieval of the German-built Shuttle Pallet Satellite (SPAS). During the mission, Challenger deployed, tracked, and rendezvoused with SPAS, making extensive use of the remote manipulator system. In addition, SPAS was deployed and retrieved twice. During operations, SPAS experienced electronics difficulties that impaired communications and affected both flight maneuvers and retrieval operations. Normal operations of SPAS began to fail at 115°C, about 10°C lower than expected, when the data handling system performed unreliably. The remainder of the mission was carried out successfully at lower temperatures, and the problem is under study.

SPAS was developed by Messerschmitt-Boelkow-Blohm as a commercial venture for science and technology in space from a retrievable platform. SPAS cameras provided video and still images of Challenger during the flight maneuvers. Current plans are for SPAS to fly again on STS-11, scheduled for early 1984.

The first major microgravity program in space will take place in the flight of Spacelab-1 on STS-9, scheduled for October 28. About 50 European industrial companies have contributed to the development of Spacelab, which is to date the largest cooperative venture between NASA and ESA. The refurbished Shuttle Columbia, fitted with three new engines, will conduct the Spacelab-1 mission. NASA has recently placed in geosynchronous orbit the Tracking and Data Relay Satellite (TDRS). TDRS will play a vital role in the materials and life sciences experiments that will be conducted during the 6-day Spacelab-1 flight.

R.L. Carovillano

STATISTICS

STATISTICAL QUALITY CONTROL

Quality control (q.c.) has long been an important specialty within the field of statistics; the procedures used for quality control generally involve sampling items, testing them to determine how many are defective (or measuring one or more attributes of the items to determine their "quality"), and taking some action as a result. Possible actions include: test more items, pass the current lot but change the sampling scheme for future lots, reject the lot of items sampled, or accept the lot. Various international and national groups have accepted standard q.c. plans. For example, the US Military Standard plans are widely used both by the US government and by many industrial and manufacturing groups outside the government. There is vigorous research in q.c., and several English language journals are devoted to it--for example, *Quality Assurance* (UK) and the *Journal*

of Quality Technology (US). In addition, statistics journals such as the *Naval Research Logistics Quarterly*, *Technometrics*, and the *IEEE Transactions on Reliability* regularly publish papers related to q.c.

An international meeting of prominent researchers in q.c. was recently held at the *Univ. of Kent (Canterbury*, UK). Some 30 papers were presented, covering a broad cross section of current work in q.c. During the meeting, there was considerable discussion of the strengths and weaknesses of various sampling standards. The "switching rules" used in military standards schemes caused much debate. There were discussions of economic approaches to the design of quality control plans, some using Bayesian models, others incorporating cost models and attempting to optimize cost-related measures, such as "profit." Some researchers are still producing tables, graphs, and nomograms to be used in carrying out various q.c. plans. But there is a major shift toward development of computer algorithms and computer solutions of optimization problems.

Because most q.c. models involve sequential observations (or stages), it is to be expected that dynamic programming methods would prove to be useful in solving many of the optimization problems. Until recently, the methods were computationally intractable for many "realistic" formulations of q.c. problems. Such barriers have now been lifted, as indicated by several papers that reported use of dynamic programming methods to solve q.c. problems involving optimization. Two software packages for q.c., one developed in the UK the other in Japan, were described. The packages were intended to help the q.c. engineer and technician select a q.c. procedure, to assess performances of various procedures, and to assist in carrying out a selected procedure.

There seemed to be little work on assessing the robustness of the procedures, even though strong distribution assumptions are commonly required in q.c. models. (Typical assumptions for a variables sampling plan are that observations are independent and identically normally distributed with known variance.) There were repeated admonitions that only the simplest statistics could be used in practice because individuals commonly asked to carry out q.c. procedures are not capable of more sophisticated work. For example, at one point it was suggested that randomization might be used to improve selection from a table of standard rules. The proposal was met with laughter and wide-spread comments that such a scheme is far too complex to use in practice. This attitude seems to conflict with the move toward implementation of procedures on microcomputers.

Dr. H. Rinne (Univ. of Giessen, Federal Republic of Germany [FRG]) presented "Statistical and Economic Aspects of Life Testing Plans." Rinne reviewed connections among several functions that describe random "lifetimes": the failure function, the survival function, the failure rate, the hazard rate, the cumulative hazard function, and the mean residual life function. Our ability to make inferences about life distributions and their parameters depends critically on how the life data have been observed and on the form of the life distribution; many unsolved problems remain. Rinne discussed rules described by the set $\{n, R_j, \Delta t, A_j, t^*\}$, where:

n is the number of items put on test at the beginning of the life experiment,

R_j is an indicator of whether failed items are replaced ($j = 1$) or not ($j = 0$),

Δt is the time between observations (continuous monitoring when $\Delta t = 0$, for example),

A_j is an indicator of accelerated testing, where values of A_j indicate levels of stress, and

t^* is the duration of the test.

The rules were considered when there is type I censoring (time censoring) or type II censoring (failure censoring), and multiple censoring (where there are different running times intermixed with failure times). The numerical evaluation of quantities (such as likelihood functions) related to many life testing situations turns out to be difficult or even intractable in some cases. This is one reason there has been so little progress on cost-minimal life testing plans. Another reason, Rinne says, is that such decisions usually depend on unknown parameters, which must be estimated.

In "A Sampling System for Inspection by Attributes," Dr. E. von Collani (Univ. of Würzburg, FRG) discussed approximations facilitating design of minimax-regret sampling inspection by attributes, for the case of sampling without replacement. The minimax-regret principle involves carefully modelling costs of, for example, making decisions without inspection, conducting sampling inspection, and sustaining losses

associated with acceptance and rejection actions (such as the loss associated with accepting the lot as a function of its true quality). By suitable standardization of the "avoidable" loss (i.e., the loss incurred by using the plan even if the true quality of the lot were known), von Collani obtains the regret function; he considers sampling procedures $\{N, n, c\}$, where N is the lot size, n is the sample size, and c is the acceptance number. His goal is to minimize the maximum of the regret function over all values of lot quality. According to von Collani, such plans have not been widely studied or used in the past because they tend to be somewhat intractable. Doubts have also been expressed about whether such plans make sense, because the minimax-regret principle does not use information about the expected or desired quality level. As von Collani showed, the regret function has two local maxima, one on either side of a "break-even" quality level. He introduced an approximation of the operating characteristic of the plans $\{N, n, c\}$, using a Poisson approximation. With it he defined an approximate minimax-regret plan, which turns out to have operating characteristics very close to the mimimax-regret plan. Mathematical and statistical properties of the approximate plan were discussed.

Dr. J. Kollerstrom (Univ. of Kent, UK) presented a paper entitled "OC Curves for SPRT's," in which he discussed an approximation based on queuing theory. Many q.c. plans are based on the sequential probability ratio test (SPRT). It can be viewed as a "gambler's ruin" process in which a random walk determined by the logarithm S_n of the likelihood ratio wanders between two absorbing barriers, say a and b. As soon as S_n walks outside the continuation region (a,b), sampling is discontinued and a terminal decision (accept or reject the lot) is made, according to which region contains S_n. If

$$z_i = \ln[f_1(x_i)/f_0(x_i)],$$

where f_1 (or f_0) is the density of the attribute being measured when the quality is out of control (or in control), so

$$S_n = \sum_{i=1}^{n} z_i,$$

the walk is like a gambler's ruin problem, where the z_i's are the bets and a and b are the opponent's original stakes in the game. Because of connections between the gambler's ruin problem and the GI/G/1 queue in statistical equilibrium, approximations for the limiting distribution of the waiting time for customers in the queues can be used to give approximations for the operating characteristics of the SPRT. Kollerstrom presented approximations that he has developed and discussed their use in q.c. contexts, including variance reduction techniques for simulations of the SPRT random walk.

A Bayesian approach to the design of cost optimal multistage sampling plans was presented by Drs. H. Schneider and K. Waldmann, both of the Free University in Berlin (FRG). The Bayesian approach takes into account at each stage the history of lot quality; the distribution of the relative numbers of defectives from lot to lot, the "prior" distribution, is assumed to be known. A fairly general cost model is involved (it is assumed only that the costs of inspection, accepting defective items and rejecting good items, are non-decreasing). The model provides a theoretical basis for choice among single, double, multiple, or sequential sampling plans. A solution is obtained, using dynamic programming, which demonstrates the optimality of multistage sampling procedures of the following type: let $n_0 = x_0 = 0$, and for $i>0$, let n_i be the ith sample size and x_i the number of defectives found in the ith sample. Let

$$y_i = \sum_{j=0}^{i} x_j$$

be the number of defective items found in the cumulative sample of size

$$\bar{n}_i = \sum_{j=0}^{i} n_j.$$

Define the plan in terms of the quantities z_i, L_i, U_i, such that whenever $y_i > L_i$ $(\bar{n}_i)$ the lot is accepted; whenever $y_i < U_i$ $(\bar{n}_i)$ the lot is rejected; otherwise a further sample of size $n_{i+1} = z_i$ $(\bar{n}_i, y_i)$ is taken. The problem is to determine the z_i, L_i, U_i

values such that the total expected costs of handling a lot are minimized. This can be formulated mathematically as a stationary decision model that can be solved by dynamic programming. Schneider and Waldmann presented results concerning the existence of optimal rules of the form described above. They illustrated with examples involving Polya prior distributions and simple cost functions, which led to the following general observations for the case where fixed sampling costs are high:

- For small lots and priors with small variances, accepting or rejecting without inspection is optimal.
- For lots of medium size and medium prior variances, single sampling plans are optimal.
- For lots of large size and priors with high variances, double or multistage plans are optimal. Under such conditions, the sample size at each stage should be small.

The meeting reported here is a sequel to one held 2 years ago at the Free University in Berlin. The types of papers presented suggest there is a trend to more sophistication in treatment of costs. There seems to be increasing emphasis on Bayesian models and definitely more use of optimization methods requiring sophisticated computational methods. Even so, no fundamentally new concepts seemed to be proposed; rather, it appeared that the research reported was devoted to extending and refining q.c. plans along well-established lines.

D.R. Barr

NEWS & NOTES

MINIWORKSHOPS IN POLYMER SCIENCE

Polymer scientists in the US may be interested in the format and subject matter of two specialized "miniworkshops" that the European Science Foundation has organized for 1983. "Ion-containing Polymers," organized by Prof. P. Tegssie, was held in Liège, Belgium (May 27-28); "Polymeric Supports With Chemical Functions Reagents and Catalysts" will be held at Braunschweig, West Germany (October 11-12), and is being organized by Prof. J. Klein. The organizers limit each meeting to about 10 representatives of European laboratories active in the particular field. The idea is to promote common scientific programs and to organize collaboration between the attendees. The meetings are financed by grants from the Commission of the European Communities.

V.T. Stannett

NEW FIRE-RESISTANT FABRICS DEVELOPED BY UMIST

A new fire-resistant fabric has been developed by Drs. E.F.T. White and W. Marrs of the Department of Polymer and Fiber Science at the Univ. of Manchester Institute of Science and Technology (UMIST). The fire resistance, produced by a unique partial carbonization of viscose-based textiles, is an inherent and permanent part of the fibers.

The approach has been licensed by a new company, Firotex G.B. Ltd. (Runcorn, Cheshire), which was formed to exploit the new development. The company has a large pilot facility that now includes a fully industrialized process.

A large range of woven, knitted, and felted fabrics has been developed. The fabrics preserve all the normal textile qualities of drape, handle, and ease of sewing but can resist flames of 1,500°C and give excellent thermal protection. In fact, extra protection of 90 seconds is claimed at 1,500°C. The oxygen index is 48, higher than the aramids.

There are many applications, particularly for military garments and other fabrics that might be exposed to fire. The fabric is being promoted for aircraft seating and other furniture and is already being used in some aircraft. The fabric has replaced asbestos for applications such as protective gloves and furnace shields. Blends of the partially carbonized fibers with a proportion of aramid and other fibers are also being produced. A brief account of the development has just been published (*Chemistry and Industry* [4 July 1983], 491).

V.T. Stannett

REGRESSION SOFTWARE

Multiple regression analysis is full of pitfalls for the unwary user. A team of researchers at the Univ. of Kent (UK) has been working on computer routines to check assumptions and look for problems in the data. They have now released a set of software routines called "U-REG," designed to allow even those with little or no statistical expertise to perform high-quality regression analyses. Experts, or people more familiar with the package, can select "terse" output options allowing use of the routines with short, coded prompts; commands can be "stacked" (entered before prompts appear) so the expert user can go through an analysis very quickly.

I recently had a "hands on" demonstration of the software, running on a microcomputer at the Univ. of Kent. It is extremely well designed in terms of its user-friendly characteristics and the technical quality of the routines and diversity of the options. In addition to the availability of terse prompts for the expert, the software offers the following user-friendly features: menu-driven options are available; checking of assumptions and warning of possible problems is done automatically; menu entries can be abbreviated (or even misspelled); "SOS" can be typed at any stage for help, usually in several layers of detail; "manual - (option name)" can be typed to get documentation of what the named program option does; "NEXT" can be typed to force progression to the next stage of analysis.

With each analysis, a diagnostics set is run to provide information on possible outliers, high leverage data points, need for transformations, multi-colinearity and need for associated biased estimation methods, such as ridge regression, lack of normality, and heteroskedasticity. When running the program, the user is presented a series of menus. The five main menus and some of their options provide a summary of the program options:

ALTRAN--for editing and transforming data

- Editing columns or rows
- Adding columns or rows
- Standardizing variables
- Adding qualitative variables
- Performing a wide range of transformations

EXPLORE--for exploratory data analysis

- Box plots
- Histograms
- Scatter plots of several variables
- Stem-and-leaf plots

SELECT--for selecting a regression model

- Stepwise regression
- Quadratic response surface fitting
- Properties of the solution

ASSUMPTIONS--for checking the assumptions made in the analysis

- Scatter plots of residuals
- Normal probability plot
- Box plots of residuals

BIASED--biased regression techniques

- Ridge trace
- Latent roots and vectors
- Covariance matrix of regression parameter estimators

U-REG is written in APL and is currently implemented on IBM and DEC mainframe computers and some 16-bit microcomputers. For more information, contact:

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D.R. Barr

GROWTH OF VOIDS TO PRODUCE DUCTILE FRACTURE

Prof. J.T. Barnby (Head of Dept., Metallurgy and Materials Engineering, Univ. of Aston, Gosta Green, Birmingham B 4ET, England) is involved with colleagues and students in characterizing microstructural aspects of the ductile fracture process for a number of structural steels. Recent work has centered on the void volumes in plastic zones ahead of crack tips of fracture mechanics specimens subjected to different constraints.

Barnby, A.S. Nadkarni, and B. Spencer (all of Aston) and S.L. Cresswell (Her Majesty's Nuclear Installations Inspectorate, London) have measur-

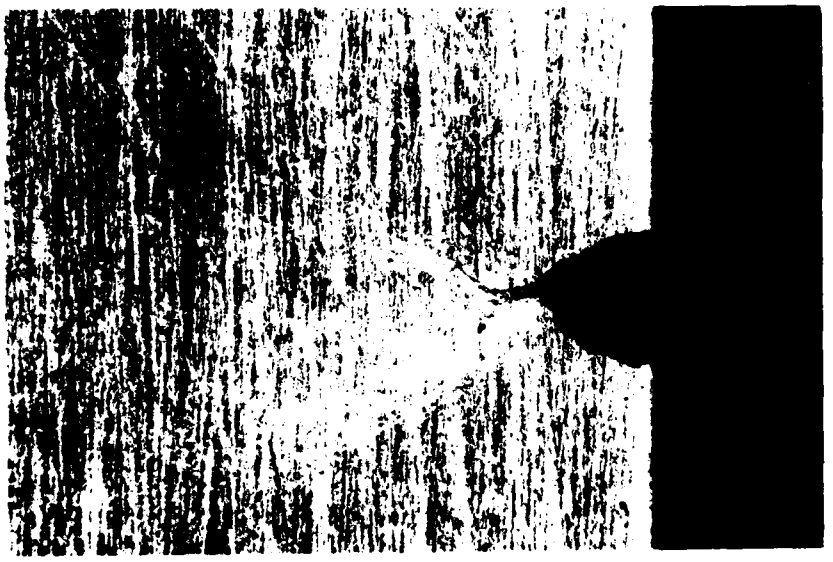

Figure 1. Surface plasticity and crack growth for a cusp-shaped crack in a longitudinally sectioned cylindrical test specimen of SA 508 CL3 pressure vessel steel.

ed critical void volumes ahead of cracks at the initiation of fracture for a pressure vessel steel tested at 100°C (1983). Longitudinally sectioned cylindrical test specimens, covering a 60-degree arc in the gauge cross section, were used with cusp-shaped cracks introduced by spark machining to allow further cracking in the plastic zones to be assessed under different states of stress triaxiality. The specimens had an effective longitudinal gauge length of 8 cm and radii of 3 and 7 cm in the transverse cross section; crack radii centered on the inner specimen circumference were 0.5, 1, or 1.5 cm. Figure 1 shows an example of the near-plane-stress plasticity and cracking at the side surface of an SA 508 CL3 steel specimen.

Sample sections containing the crack tips were carefully cut from the specimens, notched in the vertical plane, and cleaved at liquid nitrogen temperature to reveal any desired section containing the crack tip and associated voids on a cleavage surface. Scanning electron microscopy measurements were made at 2500× magnification. Conventional tensile specimens and bend specimens were also tested and voids measured in the same way. The relative void volumes were measured for different crack tip openings as a function of strain and distance ahead of the crack tip. A maximum in the void content occurred at distances of one to two crack tip opening displacements ahead of the crack tip. The result agrees with finite element modelling calculations (McMeeking, 1977), but measurements of the distribution of plastic shear strain along the extended crack plane did not agree well with the finite element calculations. Additional results are to be reported on BS4360 grade 50D steel by Barnby, Shi, and Nadkarni (1983).

References

Barnby, J.T., S.L. Cresswell, A.S. Nadkarni, and B. Spencer, "Ductile Fracture Micromechanisms in SA508 CL3 Structural Steel," Fourth National Congress on Pressure Vessel and Piping Technology (Portland, Oregon, 19 June 1983).

Barnby, J.T., Y.W. Shi, and A.S. Nadkarni, "Void Growth in a Structural Steel," International Conference on Structural Failure, Product Liability and Technical Insurance (Technical Univ. Vienna, Austria: 26-29 September 1983).

McMeeking, R.M., "Finite Deformation Analysis of Crack Tip Opening in Elastic-Plastic Materials and Implications for Fracture," *Journal of the Mechanics and Physics of Solids*, 25 (1977), 357-381.

R.W. Armstrong

QUEEN'S HONOURS IN BRITAIN

Clive Sinclair, the man who brought low cost computers to the British living room, was knighted in the Queen's Birthday Honours in mid-June. His pioneering work in providing low cost computers not only has contributed significantly to making Britain the world's most computer-literate culture, but also has been the source of hours of new-fashioned fun with video games.

The title of Commander of the Order of the British Empire was bestowed by Queen Elizabeth II upon several British subjects known by many Americans. The CBE title is given for life. Among its recent recipients are Derek Roberts (GEC Director of Research), Peter Michael (Chairman of Micro Consultants), Prof. Eric Ash (Univ. College London), and Richard Norman (Chairman, Thorn EMI Ferguson).

In the same ceremony, the title of Officer of the Order of the British Empire was given to Prof. Peter Robson (Sheffield Univ.), Peter Hickman (British Aerospace), and Roy Sanderson (Electronic Consumer Goods Sector Working Party).

M.N. Yoder

FRANCE SETS "COMPUTER YEAR"

France has named 1983 "Computer Year," according to *The Times* (London), 7 June 1983. Like Britain with its "Information Technology Year--1982" and India with its microelectronics plan (*ESN* 37-4:162-3 [1983]), France is trying to exploit the computer's economic potential. The French program will feature a series of exhibitions and conferences.

In early June, nearly 200 exhibitors participated in "The First International Software Products Fair." Held in Paris, the fair provided a showcase for companies designing and marketing software for applications such as business planning, training, and word processing.

L.E. Shaffer

SAND TRANSPORT PROBE

Dr. Andrew Salkield of the Institute of Oceanographic Sciences (IOS, Taunton, UK) has developed and field tested a sand transport probe. The device measures the impact of the moving grains on a small transducer (Figure 1).

The instrument is so promising, in fact, that Salkield is leaving the UK for the US later this summer to begin manufacturing the Sediment Transport Probe on a commercial basis. He expects to sell it to engineers and scientists working in rivers, estuaries, and marine environments. The following description was extracted from an IOS news release.

The probe is sensitive; the response allows the turbulence characteristics of the concentration field to be determined and, when taken together with simultaneous turbulent measurements, permits the flux of sediment to be calculated. The high density of sand grains gives them more momentum than the surrounding water, so they strike a transducer placed in the stream rather than follow the path of the water particles around it. This discriminates clay particles and organic matter, which do not have enough momentum to impact and be detected. The impact of the sand grain on the sensor is converted to an electrical signal; the output is a count of frequency of impacts. The sand concentration can then be derived from the impact rate and the measured water velocity. The strength of the signal is proportional to the momentum of the grain, so a crude grain size distribution can be obtained (Figure 2). To minimize multiple impacts, the sensor is only 1 cm wide and 1 mm thick.

A prototype impact sensor was calibrated 23 cm above the seabed in a tidal current; mounted next to the sensor was a nozzle through which samples were pumped. Mean concentrations derived from the impact sensor correlated well with those obtained from the simultaneously pumped samples over the concentration range of 3 to 50 ppm at the site. Grains of 40 to 800 μm were in suspension, and sieving of the pumped samples showed the minimum diameter to which the sensor agreed with the theoretical predictions. Laboratory calibration in a flume provided comparable results.

The IOS investigators conducted field measurements in the Taw Estuary to investigate the turbulent fluctuations in suspended sand concentration. The analysis indicated that the concentration field was made up of clouds of suspended sand with concentrations

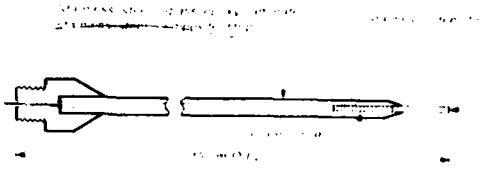

Figure 1. Sand transport probe.

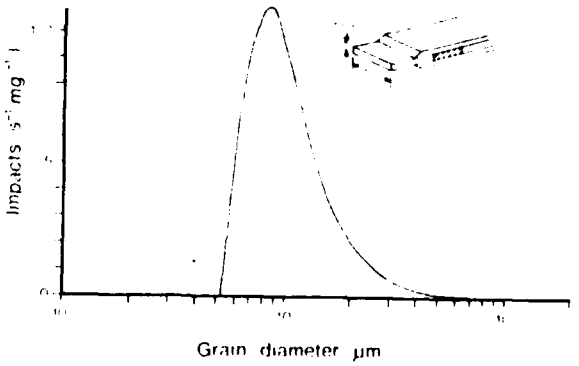

Figure 2. Grain size distribution.

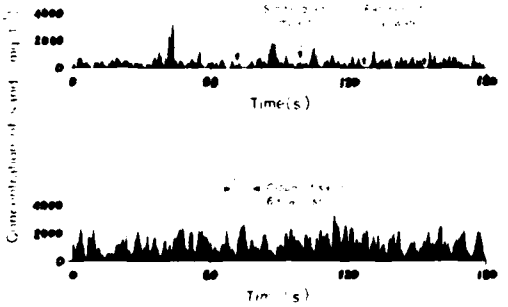

Figure 3. Suspended sand concentration.

several times the long-term mean. The clouds were separated by clear water. The clear water interludes were briefer and appeared less frequently at higher mean concentrations (Figure 3).

Previously it has been possible only to observe such detailed structures visually. The spectrum of the concentration fluctuations had a peak at a frequency corresponding to a dominant cloud size of 3 m and decayed at higher frequencies according to a -5/3 power law. This is characteristic of turbulent scalar fields and supports the hypothesis that suspended sand can be treated as such, despite the fact that the inertia of the sand grains may have caused them to be "detached" from the turbulent water motions. Thus the turbulent diffusion of sand can justifiably be treated in a manner analogous to that for heat or salt.

R. Dolan

ONRL COSPONSORED CONFERENCES

ONR London can nominate two registration-free participants in the conferences it supports. Readers who are interested in such participation should contact the Chief Scientist, ONR London, as soon as possible.

Seventh International Conference on Vacuum Ultraviolet Radiation Physics, Jerusalem, Israel, 8-12 August 1983.

IUGG Meeting Symposium 21B, "Coastal and Near Shore Zone Chemical Processes," Hamburg, West Germany, 17 August 1983.

8th European Symposium on Fluorine Chemistry (ESFC-8), Jerusalem, Israel, 21-26 August 1983.

International Symposium on Marine Science of the North West Indian Ocean and Adjacent Waters, Alexandria, Egypt, 3-7 September 1983.

Sixth International Conference on Erosion by Liquid and Solid Impact (ELSI VI), Cambridge, UK, 4-8 September 1983.

International Conference on Electronic Properties of Two-Dimensional Systems, Oxford, UK, 5-9 September 1983.

1983 International Conference on Fourier Transform Spectroscopy, Durham, UK, 5-9 September 1983.

Second International Valencia Meeting on Bayesian Statistics, Valencia, Spain, 6-10 September 1983.

Conference on Physical Chemistry of the Solid State: Applications to Metals and Their Compounds, Paris, France, 19-23 September 1983.

15th Europhysics Conferences on Macromolecular Physics, New Developments in the Characterization of Polymers in the Solid State, Hamburg, West Germany, 20-23 September 1983.

Microcircuit Engineering 83 Conference, Cambridge, UK, 26-29 September 1983.

16th European Conference on Laser Interaction With Matter, Imperial College, London, UK, 26-30 September 1983.

ONRL REPORTS

To request reports, check the boxes on the self-addressed mailer and return it to ONRL.

C-8-83: *Ultraviolet and X-ray Spectroscopy of Astrophysical and Laboratory Plasmas*, by R.D. Bleach. The meeting concentrated on four categories of studies: solar; laboratory; stellar, interstellar, and galactic; and theoretical.

C-9-83: *The 1982 International Congress of Photographic Science*, by L. Slifkin. Conference papers treated topics ranging from fundamental solid state physics of the silver halides to problems in the production of photographic products. This report describes primarily contributions closer to the chemistry and physics of crystalline solids.

C-10-83: *Fourth Europhysical Conference on Lattice Defects in Ionic Crystals*, by L. Slifkin. This report discusses conference papers that dealt with ionic defects, such as vacancies, solute ions, and dislocations.

C-11-83: *International Meeting on Lithium Batteries*, by J.J. Smith. The conference papers highlighted research results in the electrochemistry of lithium batteries; relatively little emphasis was placed on battery systems. Sessions of the conference addressed the following aspects of lithium battery technology: lithium cyclability, lithium passivation, oxide cathodes, insertion cathodes, solid electrolytes, and polymer electrolytes.

C-12-83: *The European Undersea Biomedical Society Annual Convention*, by CDR A.R. Mananlaysay, USN. The conference dealt with topics ranging from basic physiology to clinical case presentations. In additon to the scientific sessions, the conference included visits to GUSI, the new hyperbaric facility that Dragerwerk AG is building; the West German submarine escape training facility in Neustadt; and the hyperbaric works at Dragerwerk AG in Lubek.

R-5-83: *Decision Aiding in Europe: Assessment Report*, by N.A. Bond, Jr. Europeans are doing important work in medium-size decision aiding packages--unburdening, diagnostic, and structuring systems. In large military command and control configurations, European technology is appreciably behind the American state of the art.

R-6-83: *Fiber Composite Materials Research in the UK*, by T.-W. Chou. This report examines the status of basic research on fiber composites in the UK. The information is based on interviews at 15 universities, governmental laboratories, and industrial companies.

EUROPEAN VISITORS TO THE US SUPPORTED BY ONR LONDON

Visitor	Affiliation	Organization to be Visited
Dr. J. Campsie	Ocean Study Group Borgergade 34, 2-TA DK - 1300 Copenhagen K	ONR, Arlington, VA NRL, Washington, DC NSWC, White Oak, MD (September/October 1983)
Dr. G.D.W. Smith	Univ. of Oxford Department of Metallurgy and Science of Materials Parks Road Oxford OX1 3PH	Naval Research Lab Washington, DC (8 August 1983) MIT, Cambridge, MA (18-26 July 1983)

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