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CENTER FOR HIGH ENERGY FORMING

TWENTY-FOURTH QUARTERLY REPORT

OF TECHNICAL PROGRESS

Jimmy D. Mote

July 1, 1971

Army Materials and Mechanics Research Center
Watertown, Massachusetts 02172

Martin Marietta Corporation
Denver Division
Contract DA 19-066-AMC-266(X)
The University of Denver
Denver, Colorado

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This report summarizes results during the period 1 April through 30 June 1971:

- a. Full Scale Thick Walled Tube Expansion;
- b. Applications of Explosive Welding to Hardware Configurations;
- c. Explosive Powder Compaction;
- d. Explosive Thermomechanical Processing;
- e. The Mechanics of the Reloading Phenomenon in Explosive Forming of Domes;
- f. Theoretical Studies of Explosive Energy Transfer to a Thick Walled Cylinder Using a Radial Piston;
- g. Explosion Welding;
- h. Fracture Toughness of High Strength Low Alloy Steels.

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I. MARTIN MARIETTA CORPORATION

1. Full Scale Thick Walled Tube Expansion

Principal Investigator: L. Ching

The hardware for explosive expansion of a full scale thick walled tube was fabricated. This hardware was scaled up from the hardware used on a 40% scale model. The hardware includes:

- a. 12" dia x 12" thick end plates,
- b. 1½" dia x 220" long studs,
- c. Charge holder,
- d. Radial piston 191.5" long x 3-3/4" O.D.,
- e. Mandrel for pouring plastic sleeve in the radial piston.

The actual tube expansion will be accomplished next quarter.

2. Applications of Explosive Welding to Hardware Configurations

Principal Investigator: J. Snyder

Helium leak tight joints have been produced in tube-to-end boss fittings of A286 stainless steel.

II. UNIVERSITY OF DENVER

1. Explosive Powder Compaction

Principal Investigator: H. Otto

Graduate Students: D. Witkowsky, T. McClelland

During explosive compaction of powders adiabatic heating occurs. A large amount of this heat is retained immediately after compaction and could influence the green strength of the compact. Therefore, experiments were conducted to gain an idea of the temperature. A 3" x 3" x 5/8" steel compact was made in which small pieces of "Tempilstik" temperature-indicating crayons were embedded, as well as loose aluminum shot. The Tempilstiks indicated a temperature of between 500° and 700°F is obtained during compaction. There was also an indication that the steel and aluminum reacted to give an intermetallic compound.

Tensile testing of green compacts is underway using a technique developed by Max Planck Institut für Metallforschung. Round plugs are trepanned from the compacts. These plugs are loaded in compression with the axis perpendicular to the compaction axis. Samples compacted with a dynamite to metal powder ratio of 0.8:1.0 have given the highest green yield strengths, 5700 psi, while those compacted at ratios of 1.1:1.0 and 0.6:1.0 have resulted in yield strengths of 4650 and 3420 psi.

Sintering tests are currently underway using hydrogen atmospheres to protect the compacts from oxidation. Sintering the explosively compacted specimens does increase the density by about 3%, from 94-95% to 97-98% of theoretical. The initial sintering schedule was one hour at 2050°F. Both sintering time and temperature are being varied to optimize the resulting strengths of the compacts.

The explosive compaction of steel powder-tungsten reinforced composites is being carried out using a double reaction piston which is simultaneously driven to compact the specimen. The tungsten wires are laid up in a harp placed in the assembly with one piston in place followed by adding the steel powder to effect 10%W-90% steel. The other piston is placed in the assembly and then the specimen is either precompacted in a hydraulic press or compacted directly using explosives. Explosive loadings have been varied, but a major problem appears to be delamination along one layer of tungsten wires. Explosive compaction from one side only reduced, but did not eliminate this delamination. Other process variables are being studied to eliminate this effect.

Preliminary metallographic studies of the composites before and after sintering in hydrogen for one hour at 2000°F indicate the possibility of a phase forming between the tungsten and the steel. Such a phase would be indicative of welding between the compacted steel powder and the tungsten wire.

2. Explosive Thermomechanical Processing

Principal Investigator: R. Orava

Graduate Student: J. Allen

The investigation of the relative influence of explosive or conventional forming in the solution-treated condition on aged properties is continuing. Such thermomechanical processing (TMP) schedules are being examined for 17-7PH semi-austenitic stainless steel and the titanium alloy, Beta III. During the past quarter, emphasis was placed on the latter.

Solution-treated (water quenched from 1325°F) β -III in the form of 70 mil thick sheet was uniaxially stretch formed explosively in a rectangular open die. A maximum strain of 27% was achieved by means of three successive shots. Each shot was made with one strand of 200 grain/ft Primacord at a 3" standoff distance. The hardness and tensile properties after aging at 900°F for 8 hours are given in Table 1. Data for unformed stock and for material cold rolled to equivalent effective strains were also generated and are included in Table 1 for comparison.

For forming strains approaching 10%, strengths are generally higher and ductilities lower than for material which was aged at 900°F without prior strain. The two different forming techniques did not lead to significantly different properties except that the reduction in area to fracture after explosive forming and aging was 80% higher than after cold rolling and aging. An increase in forming strain to 22% caused, on the average, a reduction in both strength and ductility over those for unformed and aged material. This decrease was greatest for explosively formed and aged β -III. Experiments are under way to ascertain the relative contributions of deformation substructure, overaging, and strain induced martensitic transformations to the preceding results.

Table 1. Hardness and Room Temperature Tensile Properties of Unformed, Cold-Rolled, and Explosively Formed Beta III Titanium Alloy After Aging (900°F for 8 hr)

Forming Method*	Effective Forming Strain (in./in.)	Hardness R_c	0.2% YS (ksi)	UTS (ksi)	True UTS (ksi)	Uniform Elong. (%)	Total Elong. (%)	R.A. (%)
UF	0	45.8	194.1	207.4	217.4	4.8	8.9	12.4
CR	7.4	46.7	198.0	217.1	227.0	4.5	5.2	5.4
EF	7.4	46.3	200.6	217.3	224.3	3.2	5.3	9.8
CR	22.0	47.0	188.4	208.9	217.7	4.2	5.3	7.1
ER	22.0	46.0	184.7	196.1	201.1	2.5	3.6	6.7

*UF: Unformed
 CR: Cold-Rolled
 EF: Explosively Formed

3. The Mechanics of the Reloading Phenomenon in Explosive Forming of Domes

Principal Investigator: H. Glick

Student: V. D'Souza

In the usual explosive dome forming process, the distance between the center of the charge and the blank is about ten times the radius of the explosive charge. The peak water pressures produced near the explosive are high enough that the compressibility of water must be taken into account. The shock wave produced, though not particularly strong, is not weak enough when it strikes the blank to justify an acoustic approach.

In order to obtain a more satisfactory description of the wave-like initial flow, blast wave theory (as developed by Sedov and Taylor to predict air explosions) was applied to underwater explosions assuming water to be a compressible medium having the Tait form of the equation of state. A similarity solution could not be found for water for the conditions of interest, i.e., for pressures less than one million psi, since water does not have a suitable shock Hugoniot relation.

The Kirkwood-Bethe theory for underwater explosions is now being studied to determine its usefulness for obtaining the desired wave-like initial flow. In particular, the accuracy of this approximate theory is being investigated since too crude an approach may produce large errors in the prediction of deformations produced by the reloading phenomenon.

4. Theoretical Studies of Explosive Energy Transfer to a Thick Walled Cylinder Using a Radial Piston

Principal Investigator: H. Glick

Student: V. D'Souza

The computer program has been employed in the design of the explosive configurations used to produce residual hoop stresses in a full scale 152mm cannon barrel and in full scale forging dies. In the case of the cannon barrel, the main aim of the computer study was to determine the rate of reduction in explosive charge in the radial piston as one goes from the breech section to the muzzle. The results of the computer program were analyzed and an explosive design configuration was transmitted to the appropriate people at the Martin Marietta Corporation.

In the case of the full scale forging dies, two dies were arranged in an end-to-end configuration and were held together by a restraining fixture. As indicated in the last progress report, the lead seal used to prevent leakage of the water was not completely effective and the observed low residual deformations were attributed to this problem. In the next test, a steel seal was used and the explosive charge was increased 10%. The residual deformations obtained with the steel seal were substantial, indicating maximum possible residual hoop stresses of about 70,000 and 90,000 psi for the two dies. The difference in the residual stresses for the two dies is presumably due to a difference in hardness. These results also appear to indicate that there was little water leakage in this last test since the apparent initial explosion pressure, p_0 , (based on residual deformations) is in good agreement with the estimated value of the explosion pressure.

One of the forging dies has been used in a production run of about 2000 forgings and the die seems to have maintained its integrity, with no indication of cracks at the inner surface. If the die had not been strengthened explosively, it probably would have failed after one or two forgings.

5. Explosion Welding

Principal Investigator: S. Carpenter

Graduate Students: M. Nagarkar, R. Wittman

The effects of the explosion welding process on the kinetics of metallurgical reactions at the weld interface have been investigated. Diffusion at the interface of explosion welded samples of Cu to Ni and Ni to Cu has been compared with that observed at the bond of commercially roll bonded composites of Cu-Ni. The diffusion widths were measured using the electron beam microprobe. Data show that the diffusion process is significantly enhanced at the interface of the explosion welded samples at temperatures above 750°C (approximately 0.7 the melting point of Cu). As a result of the enhanced diffusion, Kirkendall voids are formed at the interface giving a reduction in the strength of the weld. The enhancement of the diffusion is to be a result of the intense plastic deformation and metal flow at the interface of the explosion welded samples. Test samples of Al to steel and Ti to steel have been explosion welded to investigate the effects of the explosion welding process on the kinetics of phase formation in these systems.

During the last quarter, work was carried out to establish criteria for explosion welding of thick (above 1/2 in.) plates. To date, aluminum plates up to 1-1/2 inches thick have been explosion welded using two explosives with different explosive loadings. The two explosives have similar detonation velocities, but widely different heats of explosion. Tensile tests are in progress to determine the quality of the welds. The strengths will be correlated with the experimental parameters. A very strong dependence on sample size and edge effects has been noted.

6. Fracture Toughness of High Strength Low Alloy Steels

Principal Investigator: N. Otto

Graduate Student: R. Nikseil

Prior impact tests with HY-80 and AISI 4130 and 4340 steels had been concerned with comparing properties after forming and heat treatment. Properties of the as-received stock had not been determined. There also appeared to be a difference in the as-received stock of the 4130 and 4340, as well as orientation effects. To complete this study, the as-received properties were determined.

AISI 4130

The impact properties of stock taken from the original two plates indicated essentially no difference in properties with a transition temperature on the order of 0°F. Samples were tested with the load normal and parallel to the original rolling direction. These results are listed in Table 2.

Table 2. Charpy 'V' Notch Tests for As-Received 4130 Steel

<u>Direction</u>	<u>Temperature, °F</u>	<u>Impact, ft-lb</u>
Long.	75	20
	32	17
	-1	12
	-40	6
	-110	2
Trans.	75	34
	32	22
	0	20
	-47	9

There is a definite orientation effect with the transverse orientation having a higher impact strength and a slightly higher transition temperature.

4340

As with the 4130, the first series of tests were conducted to note any difference in impact properties between the two original plates. Specimens were tested in the transverse orientation and the results are presented in Table 3.

Table 3. Results of Impact Tests on Two Lots of 4340 Steel

<u>Lot</u> <u>Material</u>	<u>Temperature, °F</u>	<u>Impact, ft-lb</u>
1, 2, 3	75	30
	66	23
	-105	10
4, 5, 6	75	12
	32	10
	3	8
	-110	7.5

There was a definite difference in the properties with the plate from which the first series of domes was formed having a higher impact strength and a lower transition temperature. These tests invalidate some of the comparisons made earlier with some of the larger differences being attributable to the original properties. These differences will be clarified in the annual report on this program.

NY-80

Tests on the as-received NY-80 were concerned with orientation effects and are listed in Table 4.

Table 4. Results of Impact Tests on As-Received NY-80 Steel

<u>Direction</u>	<u>Temperature, °F</u>	<u>Impact, ft-lb</u>
Long.	75	55.0
	-110	58.5
	-174	45.5
	-187	40.0

(continued)

Table 4. Results of Impact Tests on As-Received HY-80 Steel (continued)

<u>Direction</u>	<u>Temperature, °F</u>	<u>Impact, ft-lb</u>
Long.	-217	23.0
	-320	15.0
Trans.	75	28.5
	-110	25.8
	-320	9.3

These results indicate the longitudinal orientation has a higher impact strength than the transverse with the original comparison.