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CENTER FOR HIGH ENERGY FORMING

TWENTY-THIRD QUARTERLY REPORT OF TECHNICAL PROGRESS

Jimmy D. Mote

April 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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ABSTRACT

This report summarizes results during the period 1 January through 31 March 1971:

a. Die Stress Program;

b. Applications of Explosive Welding to Hardware Configurations;

c. Flange Buckling of Explosively Formed Domes;

d. Explosive Forming with Vented Dies;

e. Optimization of the Explosive Forming of Tank Ends;

f. Prediction of Edge Pull-in in Explosively Formed Domes;

g. Fracture Toughness of Explosively Formed High Strength Steel;

h. Explosive Powder Compaction;

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

j. Explosive Thermomechanical Processing;

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

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I. MARTIN MARIETTA CORPORATION

1. Die Stress Program

Principal Investigators: L. Ching, D. Bouma

A series of tests were made by varying the standoff distance and measuring die strains. In all of the tests, 0.063 inch thick 2014-0 aluminum blanks were used. These blanks were 9.5 inches in diameter and were formed in a 6.0 inch diameter die. The forming parameters such as torque, explosive charge weight, and explosive type were also held constant while the standoff distance was being varied. The test set up and die configuration were the same as reported in the Fifth Annual Report. Principle stresses have been computed from the raw data by taking the rosette gage strains at uniform times of the dynamic strain-time history and computing principle stresses and direction for each point in time. Typical examples of the principle stresses plotted as a function of time are shown in Figures 1 and 2. The difference between tests was that Figure 1 was for a one inch standoff and Figure 2 was for a 3.5 inch standoff. The time after detonation that initial die stress occurred is shown to differ for these two tests. Although all tests were similar, the time allowances were in agreement for a shock wave traveling at mach 1 through the water to the blank then traveling at mach 1 through metal to the gage location. The greatest minimum principle stress is shown to occur at about the same time for these two tests. This time coincides with the time required for a shock wave to reach the gage location traveling at mach 1 through water. Since the difference in the standoff distances was small, the difference in the time for the shock wave arrival was small.

The greatest minimum principle stress was of the most interest. It represented the major measured die load in all tests since this was the maximum compressive stress and was directed downward or axial to the cylindrical die. The angle between minimum principle stress and maximum principle stress is 90 degrees from the Mohr's circle analysis. Figure 3 is a plot of this maximum compressive die stress as a function of the ratio of the standoff distance to die diameter (L/D). Tests were conducted at six L/D ratios and the results recorded. After the data was reduced, the maximum compressive die stress was determined. The repeatability of the stress magnitude was checked by making several shots at a given L/D ratio. For these shots at a specific ratio, all parameters were kept constant. The repeatability of stress magnitude between tests is shown to have some scatter and no further

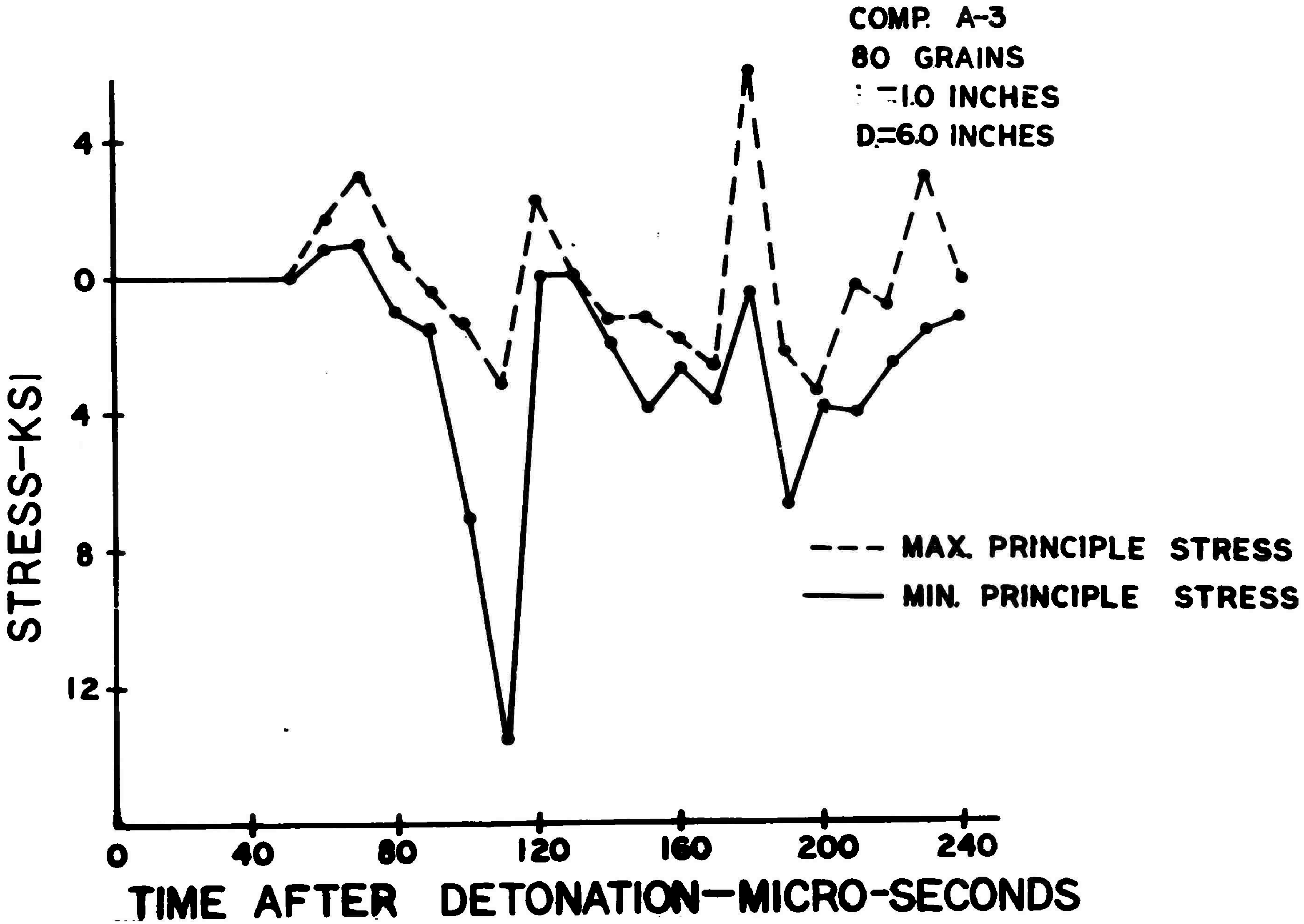

Figure 1. Principle Stresses Vs. Time (80 Grain Comp. A-3, L = 1.0, Test #085)

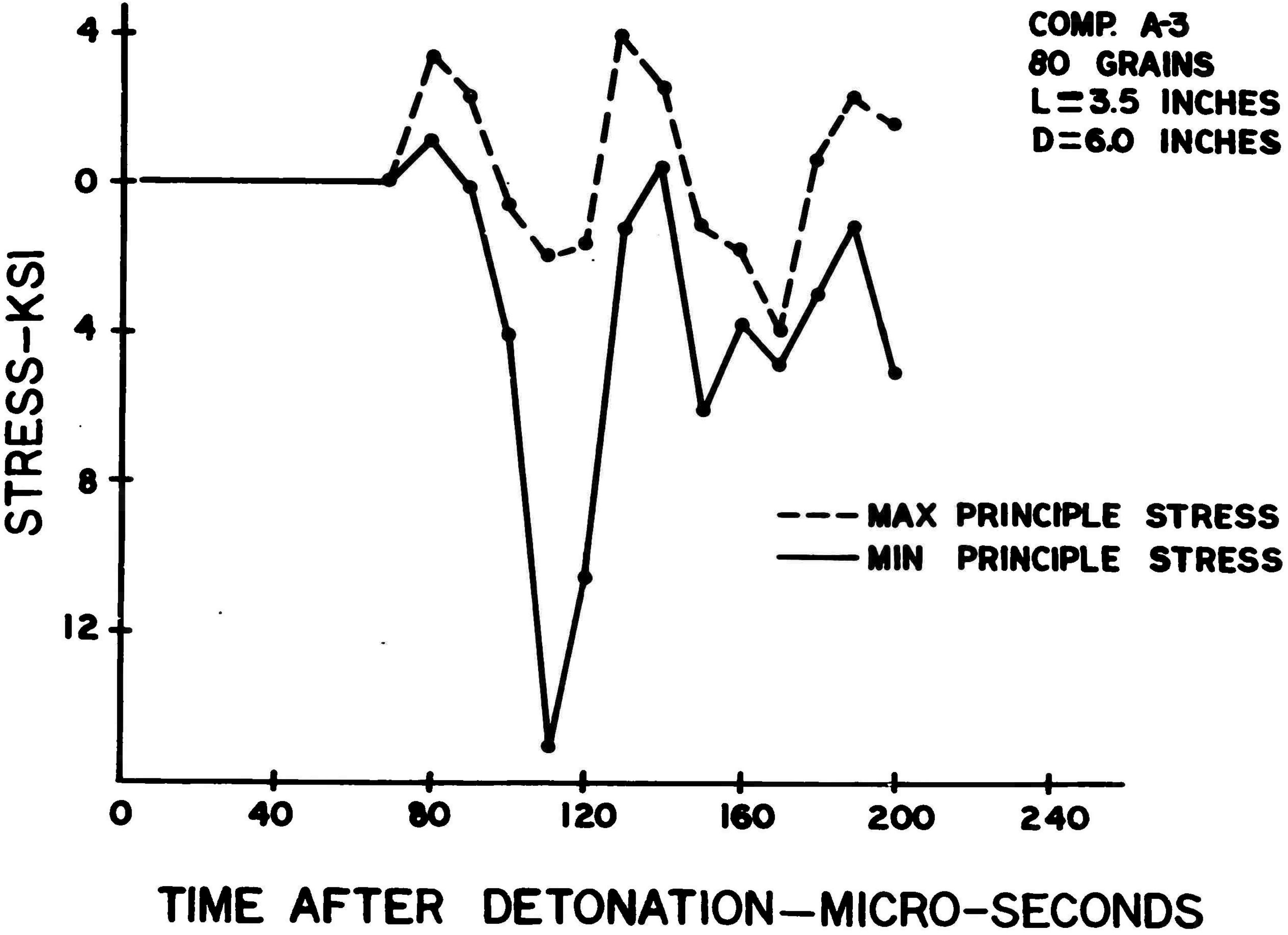

Figure 2. Principle Stresses Vs. Time (80 Grain Comp. A-3, L = 3.5, Test #058)

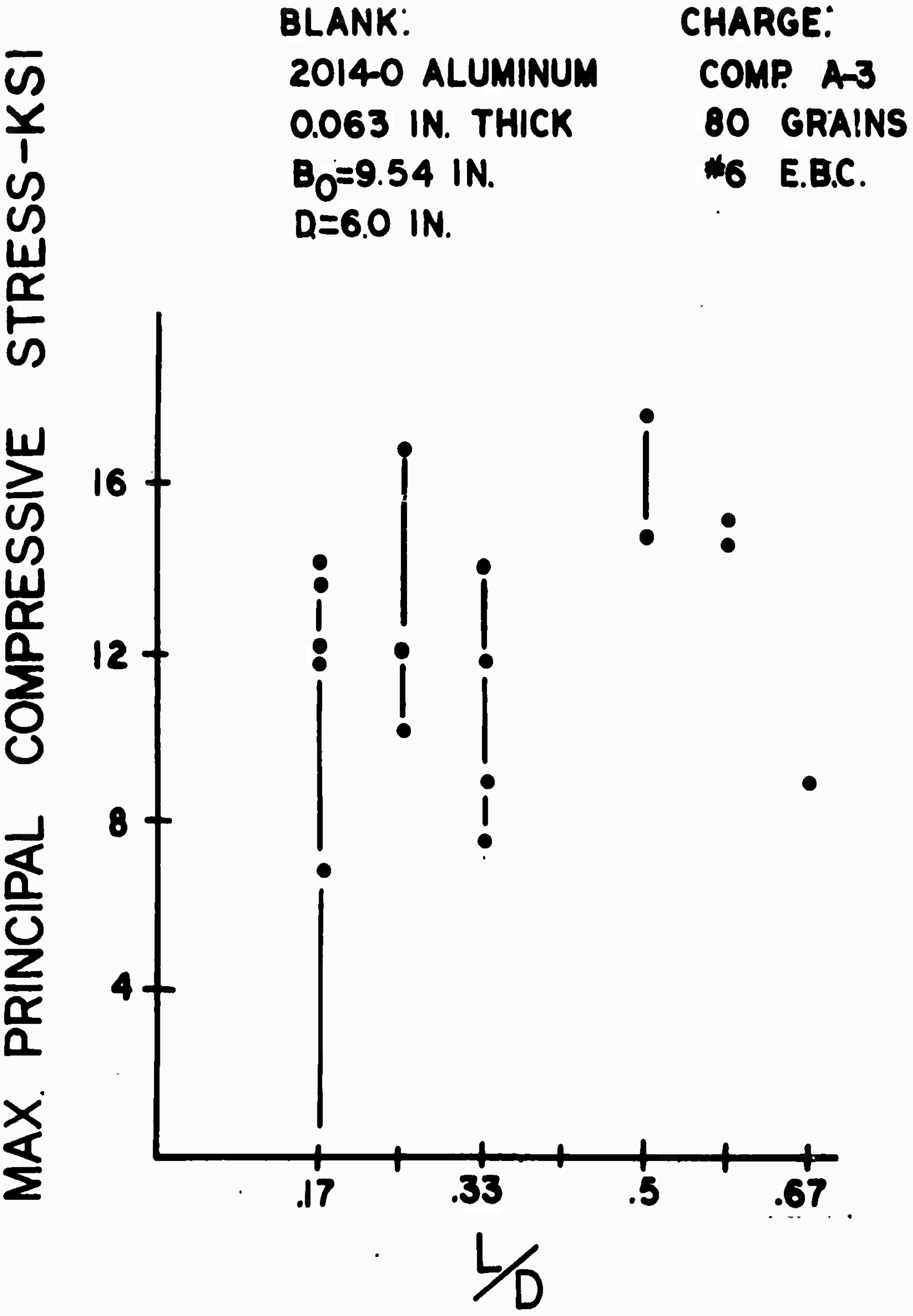

Figure 3. **Maximum Compressive Die Stress Vs. Standoff Distance**

analysis was done with the data. Testing has indicated that the load is balanced across the die. The balanced load was shown by measuring the dynamic strain of axially mounted gages which were on opposite sides of the die.

2. Applications of Explosive Welding to Hardware Configurations

Principal Investigator: W. Simon

For most tankage applications, conventional fusion welding processes provide reliable structures at the lowest cost. However, the mechanical properties of the material in the weld zone (weld metal plus heat affected zone) are usually lower than those of the parent metal. The degradation of properties occurs because of the cast metal structure in the weld zone such as large grain size, porosity, residual stresses, etc. When minimum weight becomes a design criteria, land areas must be provided to assure adequate load carrying capability in the weld zone. If the tanks are used to store highly corrosive material, even though the parent metal may be inert to the stored material, corrosive attack can occur in the weld zone causing the tank to eventually leak. This happens because of porosity, inclusions, grain boundary precipitates, etc. Other tanks applications, such as cryogenic storage vessels, wherein there may be dissimilar metal joints, also experience leakage problems due to poor bonding in the joint area. For these applications, explosive bonding provides a solution to the aforementioned problems.

Preliminary experiments have produced helium leak tight joints by explosive bonding a 17-7 PH stainless steel fitting to an A 286 stainless steel dome. These experiments will be extended to other materials and other joint configurations found in tankage.

II. UNIVERSITY OF DENVER

1. Flange Buckling of Explosively Formed Domes

Principal Investigator: M. Kaplan

Student: H. Boduroglu

The stability analysis of the flange has been finished in the case of quasi-static loading. The predicted results agree very well with the experimental critical values provided by static testing. Parametric studies have been carried out to determine the effect of the clamping system, the material properties, and geometric configuration of the flange on the critical value of pull-in. The results indicate that the clamping pressure has very little effect on the critical pull-in, i.e., the value at which buckling begins. The stiffness of the clamping system, however, plays a major role in the prevention of buckling. The results of the analysis show that clamping is a necessity if any reasonable degree of flange stability is to be attained.

2. Explosive Forming with Vented Dies

Principal Investigator: A. Ezra

Student: P. Hardee

An experimental program to determine the maximum pressures encountered in the die cavity during explosive forming with a vented die was completed. Pressure data were taken for die porosities of 0.04%, 1%, 2%, 3%, and 4%. The results of the experiments indicated that there was a point beyond which an increase in porosity failed to produce an appreciable change in the maximum pressure obtained in the process. This point occurred between 2% and 3% die porosity. This was also the point where the final domes stopped showing signs of buckling under the back pressure in the die. To determine whether or not the dome was actually buckling, a comparison was made between the pressure obtained experimentally and the calculated pressure assuming an isentropic compression of the gas to the final volume of the gas in the die cavity under a deformed dome. This comparison gave strong indication that the dome was forming most of the way and buckling rather than distorting during the forming process.

A scaling analysis of the process was done which indicated that the use of a vented die in a process which was scaled up from the experimental process would be subject to the same similitude requirements as would be found using the vacuum system.

3. Optimization of the Explosive Forming of Tank Ends

Principal Investigator: A. Ezra

Student: R. Aderohunmu

Previous results were concentrated in the range D/t = 160 to D/t = 200. This range has been extended and experiments have been conducted with blanks having a D/t = 100 and D/t = 250. Some earlier experiments were made on blanks with a D/t = 320, however, not all of these shots were successful. The results of the experiments were converted to a curve of non-dimensionalized charge weight versus D/t for both first and second shots. From this curve the approximate charge weight can be found for forming a blank of the same material with a D/t in the range covered.

Tensile tests were performed on specimens from the material (1020 mild steel) of the blanks. A true stress-strain curve was plotted. The material properties necessary for an accurate analysis, such as the yield stress and the tangent modulus, were obtained from this curve.

The die being designed is to use constant pressure clamping as in the die used for model experiments. It is semi-automatic. The clamp is held down or raised by a two-way piston cylinder system. When hydraulic fluid is pumped in one direction, with the appropriate values open or shut, the segmented clamping ring is held down. When fluid is pumped in the reverse direction the ring is raised.

4. Prediction of Edge Pull-in in Explosively Formed Domes

Principal Investigator: M. Kaplan

Student: S. Kulkarni

The quasi-static analysis was completed. The results of the analysis were used to compare thickness strain both in dome formation and bulge testing and to predict the initiation of necking in the dome. There was good agreement in all cases.

Predicted values of edge pull-in versus draw depth also agreed well with explosive dome forming data. The analysis, however, does not accurately predict the strain field in the dome, particularly in the region of the apex. Therefore, an attempt to include dynamic effects was made. The result of the dynamic study indicated that there would be no significant differences in static and dynamic forming if the blank geometries were similar at all stages of the forming operation. The reduced thin-out which occurs dynamically is a result, therefore, of the interaction between charge location, energy transfer medium, and the blank, and is not a property which is inherent in the explosive forming process itself.

5. Fracture Toughness of Explosively Formed High Strength Steel

Principal Investigator: H. Otto

Graduate Student: R. Mikesell

Charpy impact tests on AISI 4130 and 4340 and HY 80 steels were completed on both the explosively formed and cold rolled material prior to any subsequent heat treatment. An orientation dependency was shown in these tests with respect to the original rolling direction of the steel plate. In addition, differences were noted on the impact properties of specimens taken from different explosively formed domes.

Charpy tests with the 4130 steel were conducted on specimens from domes 3 and 5 which had effective strains at mid span of 0.061 and 0.057, respectively. The cold rolled steel had an effective strain of 0.066. Results of these tests are presented in Figure 4. Explosively formed specimens with a longitudinal orientation from both domes had a higher impact strength at ambient conditions than the cold rolled stock, whereas the reverse situation was true of specimens taken in the transverse orientation. The DBT temperature for all specimens fell within a range of about 20°F.

Impact tests on the 4340 steel used specimens from domes 2 and 5, in which the effective strains were 0.053 and 0.068, respectively. The effective strain in the cold rolled steel was 0.066. Results of the impact tests are presented in Figure 5. In the case of the specimens taken from dome 2, which had a lower effective strain, the DBT temperature was lower and impact strengths higher than either the specimens from dome 5 or the cold rolled stock in which the strain was about the same.

The HY 80 specimens tested were all in the transverse orientation. The cold rolled HY 80 steel had a lower DBT temperature (-180°F) than the explosively formed material (-100°F) (see Figure 6). Impact strengths of the cold rolled material were also higher at all temperatures. It is not known whether or not these results are orientation dependent, since no specimens with a longitudinal orientation have been tested.

Results have been presented in previous reports for AISI 4130 and 4340 steels in which the tempering temperature after austenitizing was 600°F. Tests were conducted on specimens in which the tempering temperature was 1000°F. In these tests specimens with a transverse orientation were used. Results of these tests are presented in Figures 7 and 8. For the 4130 steel, the cold rolled stock had a higher impact strength after heat treatment than the explosively formed stock regardless of the dome from which the specimens were taken.

Cold rolled and heat treated specimens of 4340 from dome 5 had a higher DBT and lower impact strength than the cold rolled stock, while impact strengths of specimens from dome 2 were comparable to the cold rolled material. Again, this could be an orientation effect since in previous tests on austenitized specimens tempered at 600°F, the results were reversed with specimens that were tested in the longitudinal orientation.

Several investigations have indicated that sheet and plate stock of the AISI 4000 series of steels have impact properties that are dependent upon orientation, with higher strengths being realized in the longitudinal orientation. In relating explosive forming and cold rolling to earlier investigations, the anticipated trend would be that the cold rolled stock would have higher impact strengths in the longitudinal orientation, since at the same effective strain more unidirectional strain is present in the cold rolled stock. The converse would be anticipated in the transverse orientation. Although the impact properties of the explosively formed material can be correlated with orientation effects noted by other investigators, the results with the cold rolled stock are just the opposite of what would be anticipated.

Charpy impact tests were conducted on specimens of SA 285 Grade C steel that had been subjected to the following conditions: (1) explosively free formed, (2) explosively formed in a die, (3) uniaxially strained, and (4) as-received. After machining, all of the specimens were given a stress relief anneal between

600° and 650°C for one hour, followed by slow cooling to 300°C. For comparison purposes, three specimens of the as-received stock in both the longitudinal and transverse orientations were not stress relieved. With the exception of the three specimens in the as-received condition, all of the specimens were machined with the length corresponding to the longitudinal plate direction. The effective strain in the explosively formed and pre-strained specimens was 0.053.

The results of the impact tests are presented in Figure 9. As can be seen from an inspection of this figure, the impact properties of the explosively formed stock are about the same regardless of whether a die was used. Also, the non-stress relieved as-received specimens in the transverse orientation had impact properties that corresponded to the explosively formed stock. This group of specimens had the highest impact strengths at ambient temperatures and also the lowest DBT temperature (about 0°F).

The as-received stock in the longitudinal orientation had impact properties slightly below those of the explosively formed material. The stress relief heat treatment had very little effect upon the properties of the as-received stock, and the data points in Figure 9 show no distinction between material subjected to the stress relief treatment. Static pre-straining drastically reduced the impact strength of the SA 285 steel at ambient temperatures.

Correlation of the impact tests with tensile data was impossible since after stress relief the strength (both yield and tensile) of the explosively formed and statically pre-strained material is higher than that of the as-received stock. The ductility of the as-received steel is greater than that of the strained materials. In comparing the impact data, the explosively formed and as-received stock are more similar than the pre-strained specimens which would not be indicated by the tensile data.

6. Explosive Powder Compaction

Principal Investigator: H. Otto

Graduate Students: D. Witkowsky, T. McClelland

The two areas under investigation are: (1) the compaction of steel powder for rolling and extrusion preforms, and (2) the fabrication of composites. The studies with the rolling preforms are currently using scaled-up models in which various explosives are being evaluated as the pressure source. Three dynamites are

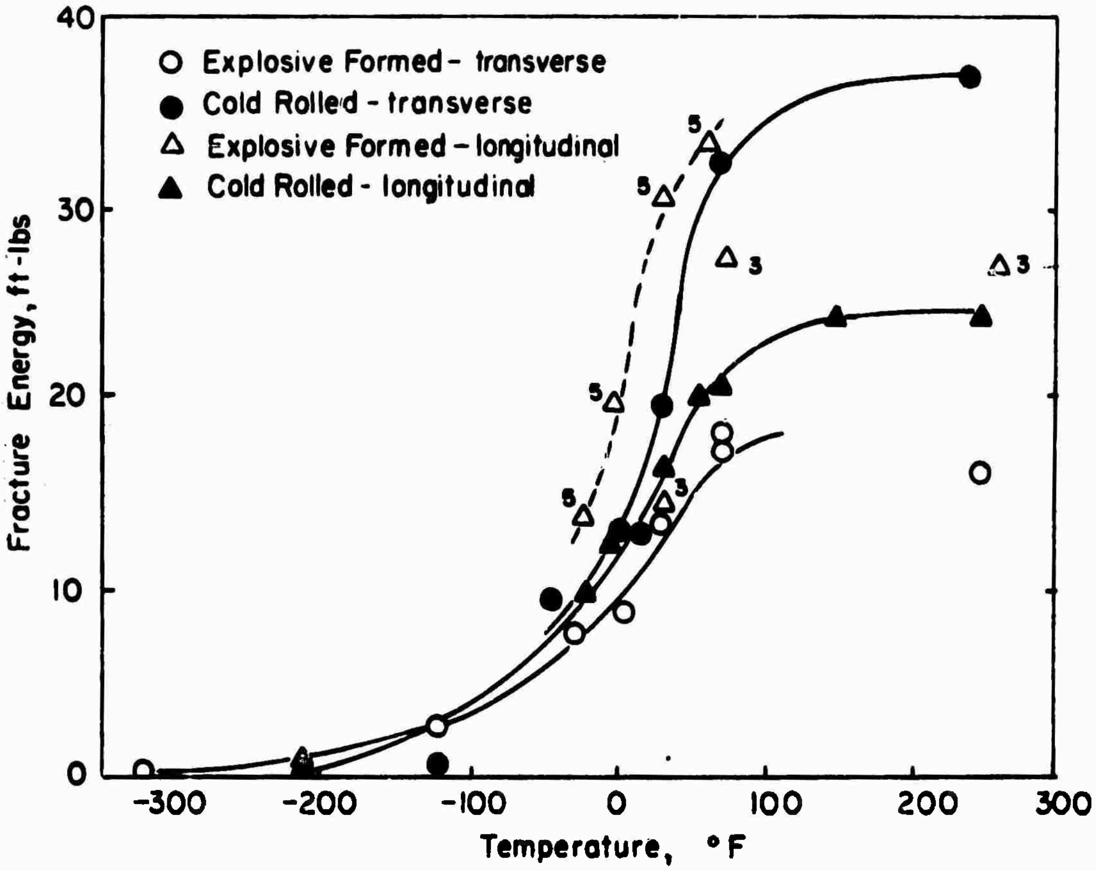

Figure 4. Results of Charpy Impact Tests on AISI 4130 Steel after Cold Rolling or Explosive Forming with No Subsequent Heat Treatment

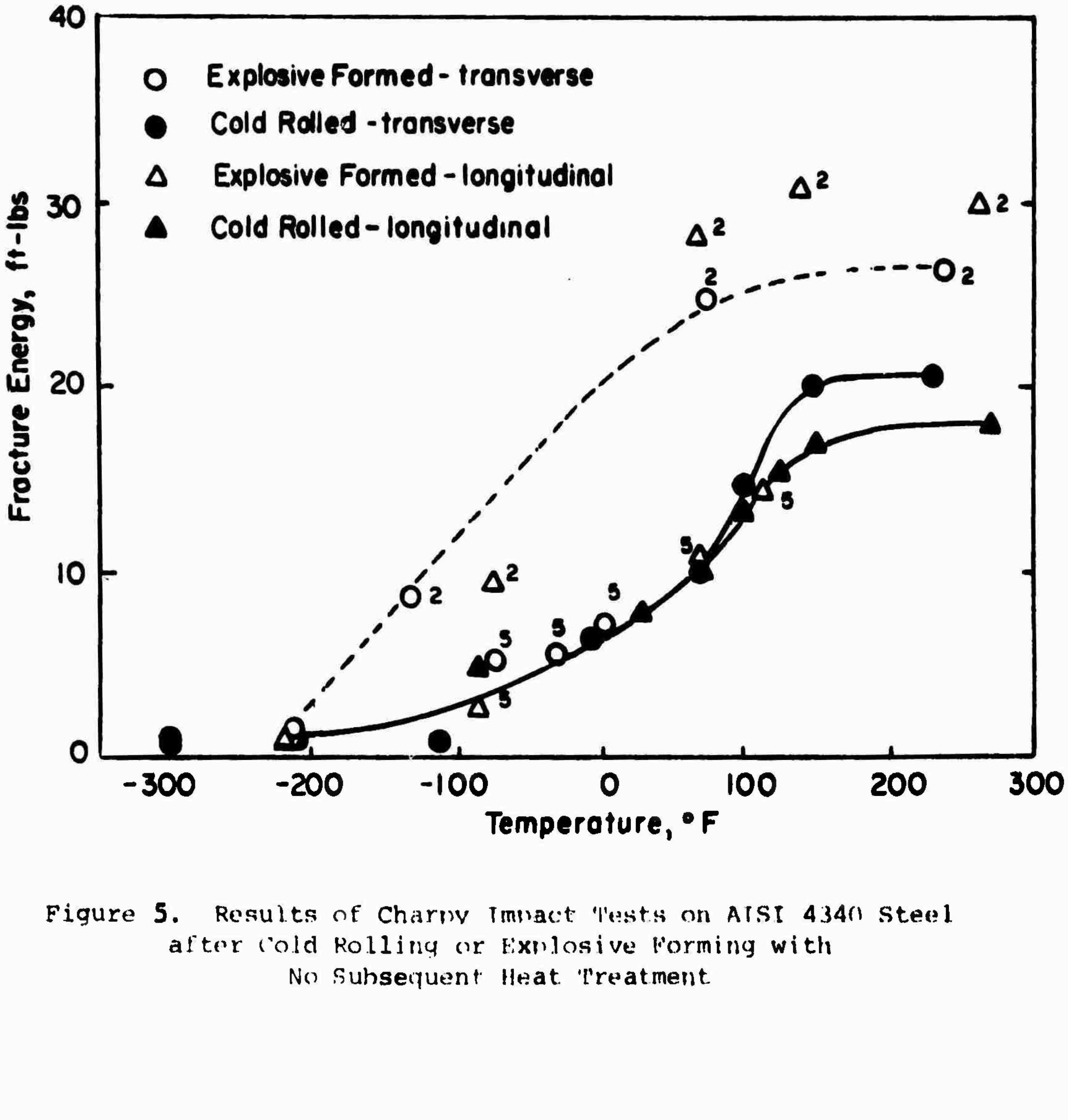

Figure 5. Results of Charpy Impact Tests on AISI 4340 Steel after Cold Rolling or Explosive Forming with No Subsequent Heat Treatment

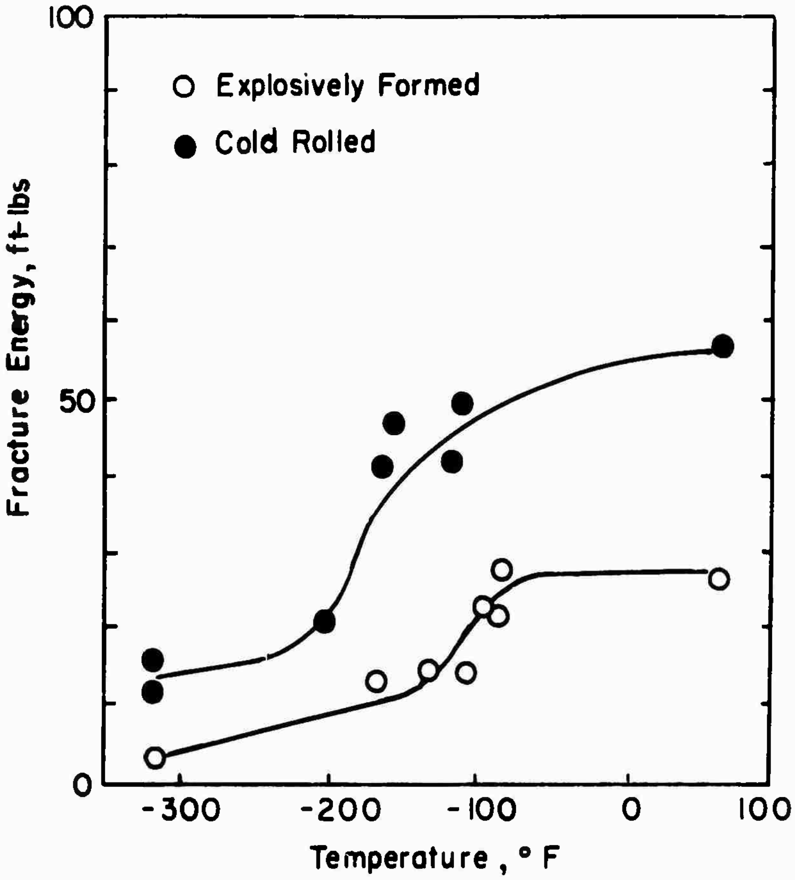

Figure 6. Results of Charpy Impact Tests on HY 80 Steel after Cold Rolling or Explosive Forming with No Subsequent Heat Treatment (Transverse Orientation)

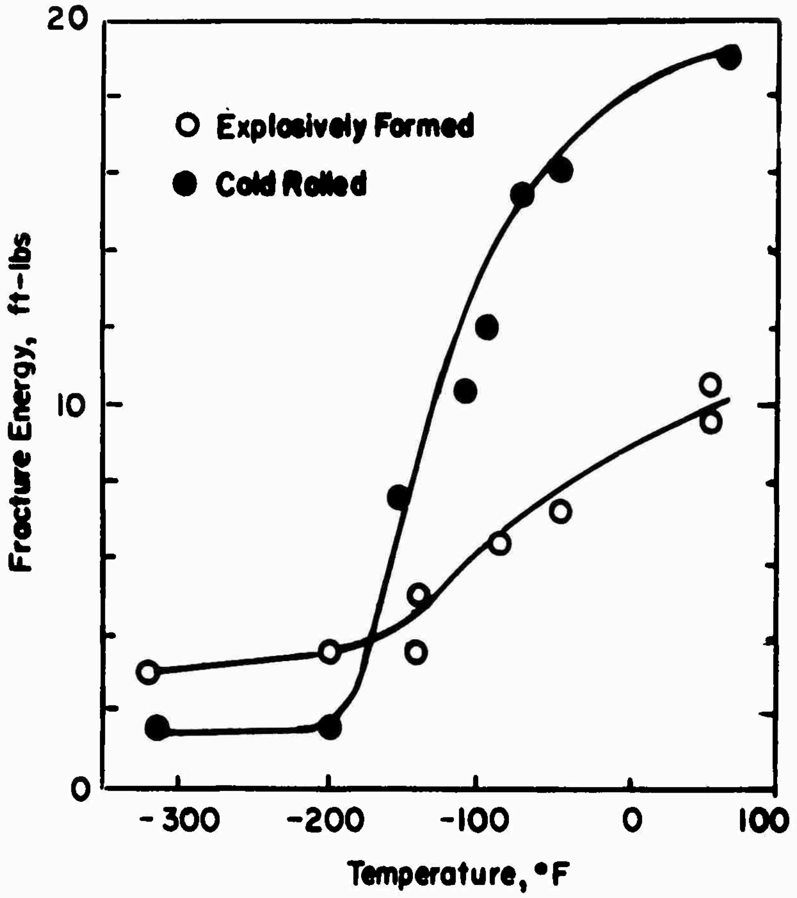

Figure 7. Results of Charpy Impact Tests on AISI 4130 Steel after Cold Rolling or Explosive Forming Followed by Austenitization and Tempering at 1000°F (Transverse Orientation)

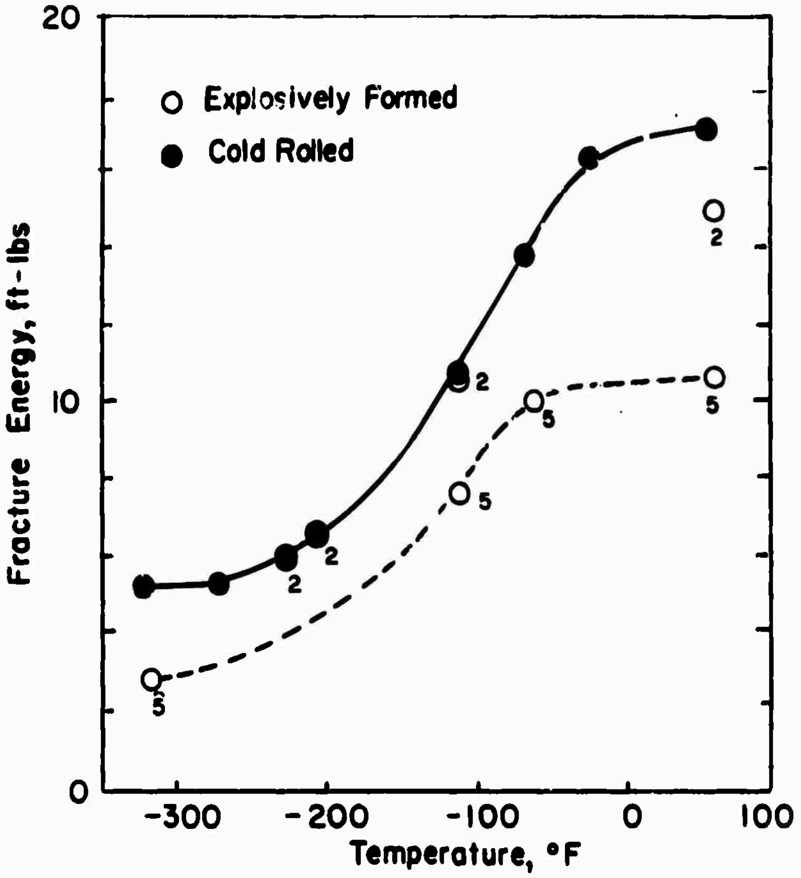

Figure 8. Results of Charpy Impact Tests on AISI 4340 Steel after Cold Rolling or Explosive Forming Followed by Austenitization and Tempering at 1000°F (Transverse Orientation)

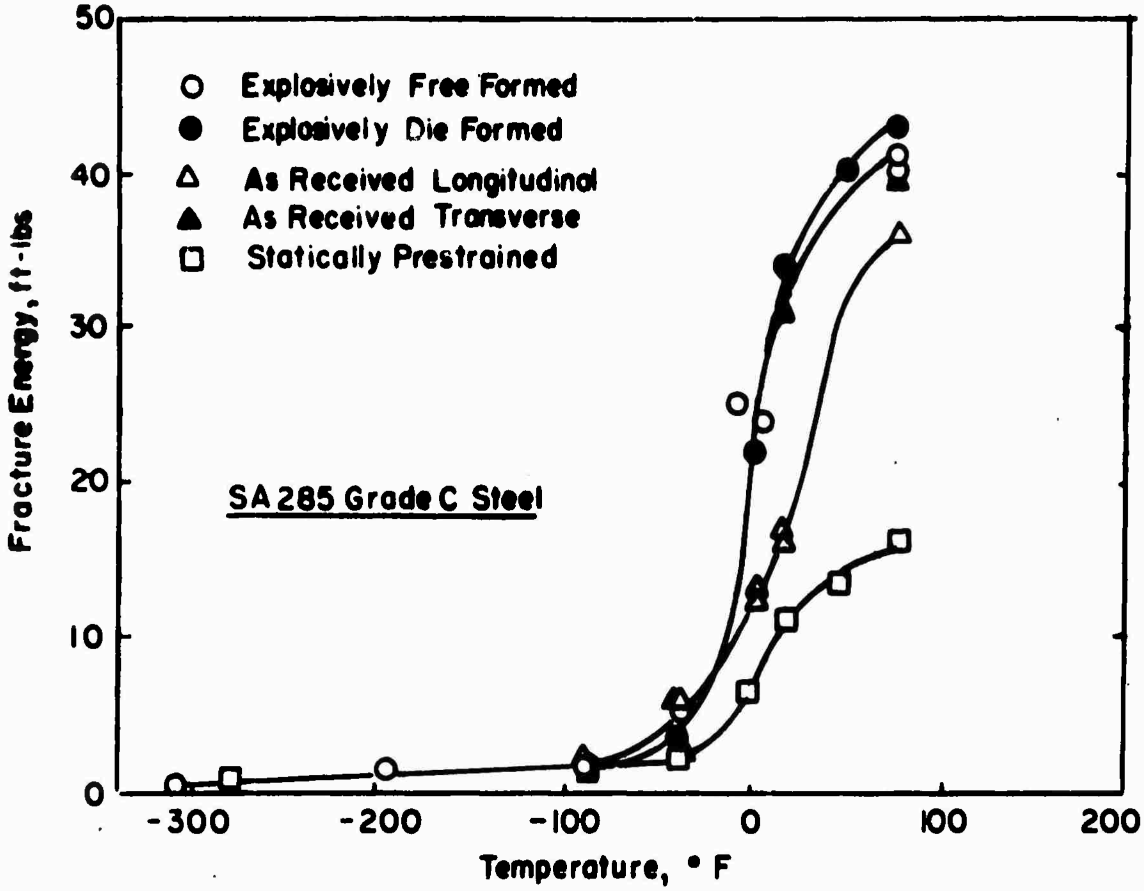

Figure 9. Results of Charpy Impact Tests Conducted on SA 285 Steel

being used: du Pont Red Cross Extra 40%, a 60% gelatin dynamite, and Trojan SWP-5. As-compacted densities of 90 to 99% are obtained, depending upon the type and amount of dynamite and the location from which the specimen is taken in from the compact. Sintering studies are underway and are being conducted at 2050°F in gettered argon atmosphere. Some oxidation has been encountered in the sintering operation which influences the subsequent rolling tests. Reductions of up to 18% have been achieved in rolling tests, but cracks have developed in oxidized areas. Sintering in a reducing atmosphere will be used to alleviate the oxidation problem.

A double piston die has been constructed for the composite tests. Harps are being used to wind the filaments. Calibration runs are currently underway to determine the amount of explosive required to compact the desired amount of powder. During these calibration tests, filaments are not placed in the compact since winding the filament harps is a time-consuming task. Once the proper amount of explosive has been determined, actual composites will be made for evaluation.

7. 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 was used to predict the residual hoop stresses produced in the experimental scale model tests. For the experimental configuration used, the computations indicated that no reyielding occurred. The experimental residual hoop stresses were generally found to be 20 to 30% below the theoretical values. However, for an experiment in which the experimental residual stress at the bore agreed closely with the theoretical value, the measured and predicted radial variations of the residual hoop stress were in close agreement.

The effect of water leakage through the end seals was also studied with the help of the computer program. For the experimental configuration and explosion pressures that were used, the effects of leakage on the pressure-time history were small and no reyielding occurred.

The computer program was also used to correlate the results that were obtained in the model tests of cylindrical forging dies.

For the geometry and material properties employed in these model tests, no reyielding was again predicted. Also, it was noticed that the amount of explosive used in the model tests was insufficient to cause the thick walled cylinder to become fully plastic. A comparison of the experimental results with theory showed that the experimental residual hoop stresses were about 40 to 50% below the theoretical values. This difference between theory and experiment is larger than in the previous case and may be due in part to the fact that the radial piston cracked or broke in these latter experiments.

Using the results obtained in these forging-die model tests, the computer program was employed to plan the tests using the full scale forging dies. The first two full scale tests produced practically no residual deformation, indicating a low initial explosion pressure even though the amount of explosive used should have produced a deformation corresponding to an initial explosion of 80,000 psi. The reason for this discrepancy was suspected to be leakage of water during the forming process. A lead seal was used in the next test and the deformations produced indicated an effective initial explosion pressure of about 75,000 psi. A further test with an improved steel seal is planned.

8. Explosive Thermomechanical Processing

Principal Investigator: N. Orava

Graduate Student: P. Khuntia

This phase of the investigation has involved two aspects of material behavior associated with explosive forming:

(1) the evaluation of the terminal strength and impact resistance of SA-285 Grade C boiler plate steel,

(2) the utilization of explosive forming as an ambient temperature mechanical stage in a thermomechanical processing or treatment schedule (ETMP) for selected precipitation-hardenable iron-based and titanium-based alloys.

With the departure of Dr. A. Dowling at the beginning of this quarter*, the supervision of the investigation of SA-285 steel was transferred to Mr. H. E. Otto, since he is responsible for similar studies on HSLA steels.

The ETMP program currently includes the study of two alloys: 17-7 PH semi-austenitic stainless steel and a beta-isomosphous titanium alloy hardened by a five alpha-phase precipitate.

A comparison of the hardness of explosively stretch-formed 17-7 PH steel with undeformed and cold rolled stock is given in Table 1. Rockwell tests were used to permit a direct comparison with the supplier's nominal values, shown in the last column. The "C" scale readings below about 20 are less reliable than "B" values; they are included for continuity.

A number of points are noteworthy. Explosive forming is less effective than cold rolling in strengthening material in Condition A which confirms previous findings for uniaxially prestrained 17-7 PH[1]. This negative rate sensitivity persists after aging at 900°F, also in agreement with the former work. One should be aware of these differences if intermediate tempers of Condition C or their age-hardened counterparts are being considered for service applications. A suitable thermal treatment to introduce more martensite can readily alleviate any relative strength deficiency. Accordingly, the above results are insufficient grounds for treating high energy rate forming as an undesirable or impractical fabrication technique for 17-7 PH stainless steel.

Although explosive forming, in Condition A, in comparison with rolling, has a small (6.8% lower at 14% strain) adverse effect on the hardness of the TH1050 condition, the reverse is true if forming is carried out in Condition T. The TH1050 hardness of material explosively formed in Condition T is raised about 15% over the undeformed control, and 7.5% over rolled stock, for effective forming strains of only 4%. The RH 950 hardness does not appear to be affected appreciably by the forming rate. Transmission electron microscopy after forming to strains of 4.6%

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*Present address: Berkeley Nuclear Laboratories, C.E.G.B., Berkeley, Glocs., England.

1. E. K. Hendricksen, et al., STP 336, ASTM, p. 104-64, 1964.

Table 1. Hardness Data for Undeformed, Cold Rolled, and Explosively Formed 17-7 PH Stainless Steel

Preforming History	Forming Method*	Effective Forming Strain (%)	Postforming Heat Treatment	Average Hardness		Nominal Hardness (Rockwell)
				R_B	R_C	
Condition A	UF	0	None	85.0	5.6	B85
	CR	4.6	None	96.4	14.2	
		14.0	None		30.7	
		50.8+	None		41.5	C43
	EF	4.6	None	91.5	10.6	
		14.0	None		21.4	
Condition A	UF	0	Condition T		32.5	C31
	CR	4.6	Condition T		32.3	
		14.0	Condition T		30.2	
	EF	4.6	Condition T		32.4	
		14.0	Condition T		30.2	
Condition A	UF	0	TH1050		42.9	C43
	CR	4.6	TH1050		43.2	
		14.0	TH1050		48.5	
	EF	4.6	TH1050		42.6	
		14.0	TH1050		45.2	
Condition A	UF	0	A 1750	103.2	26.7	B85
	CR	4.6	A 1750		26.3	
	EF	4.6	A 1750		23.1	
	UF	0	A 1750	87.0		B85
	CR	14.0	A 1750	82.9		
	EF	14.0	A 1750	90.0		
Condition A	UF	0	R-100		35.2	C36.5
	CR	4.6	R-100		33.9	
	EF	4.6	R-100		34.8	
	UF	0	R-100		36.8	C36.5
	CR	14.0	R-100		42.6	
	EF	14.0	R-100		36.0	

Table 1 (Con't.)

Preforming History	Forming Method*	Effective Forming Strain (%)	Postforming Heat Treatment	Average Hardness		Nominal Hardness (Rockwell)
				R_B	R_C	
Condition A	UF	0	RH 950		48.7	C48
	CR	4.6	RH 950		48.3	
	EF	4.6	RH 950		46.9	
	UF	0	RH 950		47.5	C48
	CR	14.0	RH 950		49.8	
	EF	14.0	RH 950		48.8	
Condition A	UF	0	CH 900	88.8	7.5	
	CR	4.6	CH 900	97.8	17.7	
		14.0	CH 900		34.4	
		44.0	CH 900		51.5	C49
	EF	4.6	CH 900	93.9	11.8	
		14.0	CH 900		25.2	
Condition T	UF	0	None		32.5	C31
	CR	4.0	None		33.6	
	EF	4.0	None		37.3	
Condition T	UF	0	TH1050		42.9	C43
	CR	4.0	TH1050		46.4	
	EF	4.0	TH1050		49.2	
A 1750	UF	0	None	87.0	6.4	B85
	CR	5.8	None	97.6	17.6	
	EF	5.8	None	89.5	8.7	
A 1750	UF	0	R-100		36.8	C36.5
	CR	5.8	R-100		TBD**	
	EF	5.8	R-100		39.0	
A 1750	UF	0	RH 950		47.5	C48
	CR	5.8	RH 950		TBD	
	EF	5.8	RH 950		46.7	

Table 1 (Con't.)

Preforming History	Forming Method*	Effective Forming Strain (%)	Postforming Heat Treatment	Average Hardness R_B	Average Hardness R_C	Nominal Hardness (Rockwell)
R-100	UF	0	None		36.8	C36.5
	CR	2.9	None		39.4	
	EF	2.9	None		42.0	
R-100	UF	0	RH 950		47.5	C48
	CR	2.9	RH 950		48.0	
	EF	2.9	RH 950		48.5	

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* UF = unformed; CR = cold rolled; EF = explosively formed
\+ Condition A plus 60% reduction yields Condition C, $R_C = 43$
** TBD: to be determined

did not reveal any significant microstructural differences between explosively formed and cold rolled Condition A material. However, the hardness difference was only 5% at this strain level. In conclusion, based on hardness data alone, the utilization of high energy rate forming to produce 17-7 PH stainless steel domes when the final state is to be TH1050 or RH 950 causes no significant change over cold rolled material.

Some difficulty was experienced in stretch forming the β III titanium alloy due to hold-down problems. However, this has been solved and a successful part produced. Large draw depths were readily obtainable when the edges were permitted to pull in, but the strain in the material was too small for meaningful evaluation. Clearly, the good cold formability claimed for β III persists to the high rates encountered during explosive forming.

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

Principal Investigator: H. Glick

Student: V. D'Souza

A theoretical study of the reloading phenomenon that occurs in explosive dome forming has begun. In this study an acoustic wave approach has previously been employed during the initial phase of the explosion up to the time when cavitation occurs near the moving blank boundary. Subsequently, the reloading phase of the flow will be analyzed assuming the fluid to be incompressible. The motion of the reloading flow is therefore obtained by solving Laplace's equation with the initial conditions given by the flow field existing at the time of cavitation. It should be emphasized that the mechanics of both the plate and the fluid are strongly coupled in the reloading phenomenon.

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Mote, Jimmy D.

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10 AVAILABILITY/LIMITATION NOTICES

11 SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Army Materials and Mechanics Research Center Watertown, Massachusetts 02172

13 ABSTRACT

This report summarizes results during the period 1 January through 31 March 1971:

a. Die Stress Program;
b. Applications of Explosive Welding to Hardware Configurations;
c. Flange Buckling of Explosively Formed Domes;
d. Explosive Forming with Vented Dies;
e. Optimization of the Explosive Forming of Tank Ends;
f. Prediction of Edge Pull-in in Explosively Formed Domes;
g. Fracture Toughness of Explosively Formed High Strength Steel;
h. Explosive Powder Compaction;
i. Theoretical Studies of Explosive Energy Transfer to a Thick Walled Cylinder Using a Radial Piston;
j. Explosive Thermomechanical Processing;
k. The Mechanics of the Reloading Phenomenon in Explosive Forming of Domes.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Energy Requirements						
Energy Transfer						
Strain Rate Effects						
Explosive Welding						
Mechanical Properties Before and After Forming						

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