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CENTER FOR HIGH ENERGY FORMING

SIXTH QUARTERLY REPORT

OF TECHNICAL PROGRESS

G. A. Thurston

January 1, 1967

U. S. Army Materials Research Agency
Watertown, Massachusetts 02172

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

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U. S. ARMY MATERIALS RESEARCH AGENCY
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MARTIN COMPANY
A DIVISION OF MARTIN MARIETTA CORPORATION
Contract DA-19-066-AMC-266(X)
THE UNIVERSITY OF DENVER
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ABSTRACT

The "mousetrap" type plane-wave generator has been completed. Initial shock tests have been conducted on 2024-T3 aluminum sheet, copper, 70-30 brass, iron, and maraging steel.

Accuracy of acceleration measurements to determine strain-rates in an expanding aluminum ring using a streak camera is being checked by recording known motion of a non-radial slit cut in a rotating disk.

The correlation between physical properties of metals used in explosive welding and the success of the weld is being investigated.

Checkout is continuing on a computer program to calculate strains in a blank formed into a frictionless die.

A ring cut in a chevron pattern has proved effective in controlling edge pull-in of explosively formed domes. The chevrons contract to form the ring and engage a weld bead on the rim of the blank to limit the amount of pull-in.

CONTENTS

I. UNIVERSITY OF DENVER

1. Shock Hardening

The final design studies for the "mousetrap" type of plane-wave generator were completed during this report period and the problem of "premature" triggering of the probes used for velocity and planarity measurements was solved. This was due to ionization of the shock front. Freon gas introduced into a polyethylene sack enclosing the whole assembly resolved this problem. The proper angle for planarity was readily determined after this procedure was adopted.

Specimens of 2024-T3 aluminum sheet were shocked at pressure levels of 50, 90, 120, 230 and 300 kbars. A rapid increase in hardness was noted up to a pressure of about 100 kbars, after which the increase in hardness was not as substantial for additional increases in pressure. Hardness versus pressure values are as follows:

Shock Pressure, Kbars	Hardness, DPH
0	112
50	143
90	151
120	152
230	156
300	161

No apparent change in the microstructure of the shocked specimen was observed as a function of increasing shock pressure. Transmission electron microscopy indicated that massive dislocation tangles were present that apparently increased with increasing shock pressure. No quantitative data have been obtained with respect to dislocation tangles.

Studies on copper and brass to determine the stacking fault energy as a function of pressure have been initiated. Pure copper and 70-30 brass have been shocked at pressure levels of 45, 95, and 220 kbars. Specimens for X-ray analysis and tensile tests are currently being made.

Transmission electron microscope studies of the twin formation in iron as a function of prior strain plus shock pressure are being conducted. The purpose of this investigation is to elucidate the role of twins in shock hardening behavior of armco iron, and also to study the effect of existing substructure on nucleation and propagation characteristics of these twins. Optical metallography of prestrained samples shocked to 50 and 100 kbars revealed that the number of twins decreased with increasing amounts of prestrain. Furthermore, the straight twins observed in annealed and shocked samples were replaced by bent twins on prestraining. Hardness measurements indicated that samples, prestrained (to various amounts) and then shocked were essentially identical. Also, the hardness of specimens prestrained 20 per cent in compression and those shock loaded to 100 kbars were the same. Preliminary results from substructural studies by transmission electron microscopy show that it becomes difficult for a twin to propagate in the presence of substructure.

Maraging steel (grade 250) has also been shocked at a pressure of 180 kbars and the heat treatment response studied. At 900°F., which is the recommended aging temperature for this alloy, the time to reach maximum mechanical properties was attained in about 30 minutes as opposed to four hours for the conventional heat treatment.

2. Strain Rate Experiments

Dynamic measurements of the displacement-time history of expanding ring specimens of 6061-T6 aluminum were continued. The primary purpose of these tests at the present time is to refine the measuring system in order to obtain results having the degree of resolution required to accurately establish stress-strain rate relationships.

In the initial tests where the displacement-time history was obtained by monitoring one point on the periphery of the ring, it became apparent that this information alone was not sufficient to define the overall behavior of the ring under the conditions of these tests. A slight offset in the point of initiation of the explosive charge, or a varying density in the explosive can cause unsymmetrical expansion of the ring which cannot be detected by observing only one point. For this reason the measurement system was modified so that two points on the periphery of the ring, separated 90 degrees, could be monitored and a continuous displacement-time plot obtained for each point. In addition, four probes located at 90-degree increments along the explosive-steel core interface have been included to establish the time of arrival of the detonation front. Both of these techniques will be used to determine the degree of symmetry with which the ring is expanding and establish a criterion for separating valid tests from invalid tests. This is of utmost importance since the value of stress at any time during expansion is obtained from the equations of motion for a symmetrically expanding ring, and any deviation from symmetry results in erroneous values for stress.

It was also observed that during the deceleration of the aluminum ring, the steel core repeatedly catches up with the ring thereby producing multiple impacts. Once this happens, the test is no longer valid since the aluminum ring is trying to decelerate at a faster rate than the steel core will permit. To eliminate this problem the specimen assembly is being redesigned. The configuration shown in Figure 1 has been selected for the next series of tests. In this geometry the momentum transferred to the steel from the explosive will be concentrated in much smaller elements of mass as the shock wave travels radially outward. It is believed that this will eliminate most of the wave propagation problems associated with the previous geometry, and permit the specimen ring to expand freely over much longer periods of time. This will permit extended measurements over which stress-strain-strain rate behavior can be determined.

A method has been devised wherein the accuracy of the acceleration measurements can be measured. This will be accomplished by using the streak camera system to record the motion of a non-radial slit cut in a rotating disk. The velocity and acceleration of the slit will then be determined from graphical differentiation of the recorded displacement time data. A check on the accuracy of this technique can then be made by calculating the velocity and acceleration of the slit directly from the known slit position and the angular velocity of the disk. The results of these tests will establish whether or not the technique presently being used to determine acceleration should be pursued further or if a different approach should be considered wherein acceleration is measured directly.

3. Explosive Welding

A comprehensive survey of the literature has been completed and emphasis has been placed on determining the relative importance of the material properties of the metals in the weld on the quality of explosive weld obtained. From the literature survey, data relating to forty-four welds of dissimilar metals involving thirty-one different metals have been collected. A program to analyze and investigate the correlation, if any, between the physical properties of the metals in the weld and the success of the weld is currently in progress and some preliminary results have been obtained.

Preliminary results indicate that two physical properties appear to be important for good high quality explosive welds. These are (1) the ductility of the driver plate and (2) the solid solubility between the couple, specifically whether or not the two metals form a hard, brittle intermetallic on melting. Results indicate that it is necessary to have greater than five per cent ductility in the driver plate in order to obtain a good explosive weld. To avoid failure by crack propagation large regions of brittle intermetallic should not be present in the weld interface.

Work will continue on the analysis of data generated from the literature survey. Experimental work will also be started to verify those correlations obtained from the analysis.

4. High Strain-Rate Ductility

The aims of the high strain rate, or "dynamic" ductility program were selected as follows:

a.) Substantiation of the existence and establishment of the extent of dynamic ductility;
b.) Determination of the mechanism(s) for dynamic ductility, and thereby ductility enhancement under HERF conditions; and,
c.) Establishment of guidelines for the prediction of formability at high strain rates.

From a literature survey, as yet incomplete, it was concluded that uniform strain increases with increasing strain rate, to a maximum just prior to the attainment of a critical impact velocity. This occurs, in general, with inherently ductile (FCC-base) materials only. One or more of several mechanisms could be responsible for this enhanced ductility, e.g., the onset of plastic stress wave propagation, onset of precipitation during straining, point defect production, dislocation dynamics, superplasticity effects. Both analytical and experimental studies are underway which hopefully will permit a selection of the operative mechanism(s).

II. MARTIN COMPANY

1. Strain In a Deformed Blank In Contact With a Die

The computer program being written for this analysis has been revised in two places. Originally, the program was written to accept, as input data, an initial estimate on the radial displacements. It was assumed that this initial estimate would be such that the strains over the flange, draw radius, and die cavity would be continuous. During checkout of the program, it became apparent that it was unrealistic to expect continuity in the input, so this program has been rewritten to accept input that is continuous in each of the three regions of the die but discontinuous at the junctures of the regions.

The second revision in the program is the addition of a numerical integration of the total work done by the stresses in the blank during forming. This amount of work is a useful parameter in estimating explosive charge weight requirements.

2. Increase of Ductility Due to Explosive Forming

Preliminary tests indicate that the primary cause of increased ductility in explosively formed domes is the biaxial stress state. For this reason, Martin's efforts in this area will be confined to static bulge tests in order to have effective stress-effective strain curves of sheet material to use in our computer programs for predicting strains in finished parts.

3. Blank Stabilization

R. Chihoski of our Manufacturing group has adapted some of his fixtures to produce a weld bead on the rim of our small blanks. He assures us that a fixture to lay a bead on full scale blanks would not be expensive. It could be similar to the rotating arm that held the plasma arc torch used to trim the flange from the 10 foot diameter domes explosively formed under the Titan II

Improvement Program.

A weld bead is the cheapest and most effective means that we have now to produce a rim of a blank. The rim prevents uneven draw and makes edge pull-in an independent parameter in the forming process. Controlling the pull-in helps make the forming a repetitive process.

In our past work, the rim on the blank engaged a lip machined on the hold-down ring. This has the disadvantage of leaving a gap between the undeformed blank rim and the lip. This gap allows wrinkling as the edge of the blank compresses. The gap is now avoided by cutting a ring of the final draw radius into a chevron pattern. The chevrons are extended against the blank rim as shown in Figure 2. The chevrons slide under the hold-down ring (not shown in the photograph) as the blank draws in and reform the ring to prevent further pull-in, Figure 3.

The chevrons have the further advantage that they replace the need for the lip on the hold-down ring so that they can be used without modifying our present dies.

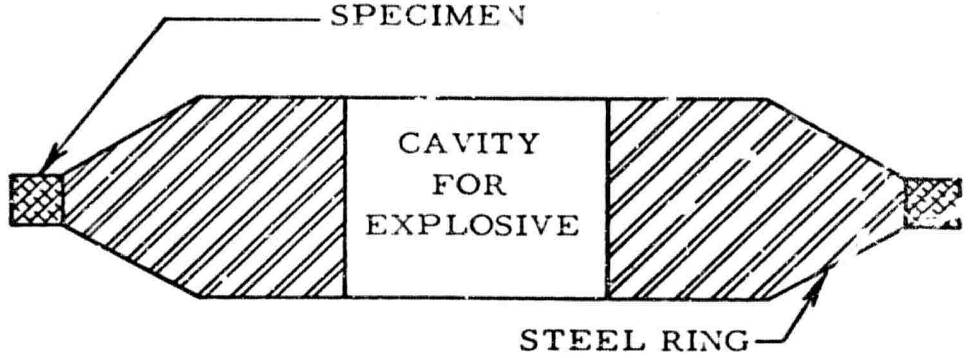

Figure 1. Revised Specimen Design

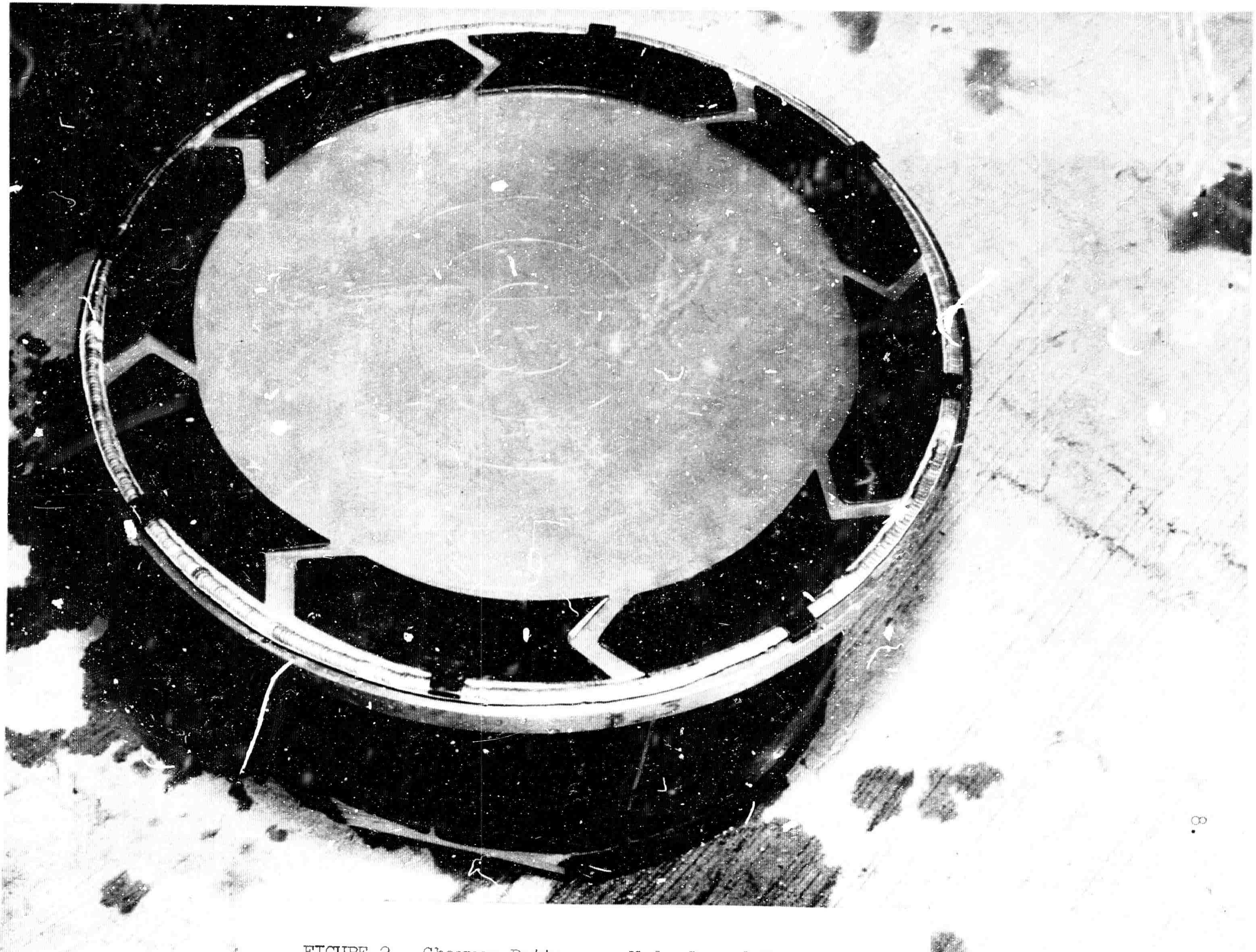

FIGURE 2. Chevron Pattern on Underformed Blank

FIGURE 3. Chevrons Formed Into Ring To Prevent Further Edge Pull-In of Deformed Part

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Plastic Strain Calculation						
Explosive Forming						
Shock Hardening						
Strain Rate Effect						

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