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TECHNICAL PROGRESS REPORT NO. 1
QUARTERLY PERIOD: 8/13/62 to 11/13/62

FABRICATION OF A 65.5 INCH DIAMETER
SIMULATED ROCKET MOTOR CASE BY
CRYOGENIC STRETCH FORMING

PREPARED FOR:
United States Air Force
Contract AF 33(657)-9638

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TABLE OF CONTENTS

	<u>Page</u>
1.0 Objective	1
2.0 Summary	2
3.0 Coordination with U.S.A.F.	3
4.0 Program Plan	4
5.0 Discussion of Activity	5
5.1 Sub-Scale Vessels	5
5.2 Material Procurement	7
5.3 Facilities and Tooling	8
5.4 Materials Evaluation	9
5.5 Full Scale Vessels	10
Appendix	

1.0 OBJECTIVE

To demonstrate the applicability of the cryogenic stretch forming process to the fabrication of large rocket motor cases of heavy wall thickness. Previous work, under government contracts, has shown the feasibility of fabricating high-strength rocket cases by cryogenic stretch forming. See references in appendix. Effort under the present contract is directed at "scaling up" the equipment and techniques to handle the size and wall thickness of a big boost motor.

1.1 Specific Contract Tasks

1.1.1 Materials Evaluation

1.1.1.1 Welding Characteristics: Determination of welding characteristics of 1/4 inch and thicker 301 stainless steel plate.

1.1.1.2 Tensile Testing: Tensile tests of welded and unwelded coupon samples prior to and after cryogenic stretching in a bath of liquid nitrogen at -320°F. Specimens shall consist of coupons representing sections cut transverse (90°) and parallel to the rolling direction of the plate.

1.1.1.3 Hardness - strength correlation: Determine relationship between weld material hardness and strength characteristics. Weldments, unstrained, strained, and in the strained-and-aged conditions to be investigated.

1.1.1.4 Charpy Impact Tests: Testing of welded and unwelded specimens at room temperature and -320°F to obtain correlative data for notch sensitivity of the weld.

1.1.1.5 ASTM Center Notch Test: Testing of specimens in the unstrained, strained, and strained-and-aged conditions to obtain correlative data for notch sensitivity.

1.1.2 Vessel Fabrication

1.1.2.1 Fabrication and testing of small scale vessels, approximately 25 inches in diameter, to verify weld and dome forming techniques.

1.1.2.2 Design and procurement of a full scale stretch forming die to control cylinder roundness and straightness.

1.1.2.3 Fabrication and cryogenic stretching of a simulated rocket motor case, 65.5 inches in diameter, with a target strength level of 275,000 psi nominal hoop yield.

1.1.2.3.1 Hydrotest of stretched vessel to determine yield point.

1.1.2.3.2 Age - After hydrotest, the vessel will be age hardened to augment strength.

1.1.2.3.3 Hydroburst - Burst test to determine yield point and ultimate strength of the cryogenically stretched and age hardened vessel.

2.0 SUMMARY

Effort during the first three-month period was directed toward program planning, budget estimating, design of vessels and test equipment, and sub-scale vessel fabrication. Procurement of raw material, certain equipment, and vessel components was initiated. Three sub-scale vessels were cryogenically stretched.

2.1 An overall program plan was generated, defining major areas of work and establishing a tentative schedule. This schedule calls for completion of all work by 25 May 1963 with a final report submitted on 21 June 1963.

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2.2 A cylindrical stretch die was designed and released for fabrication of the 65.5" vessel. The die will control the roundness and straightness of the cylindrical portion of the stretched vessel.

2.3 Designs for "dog-bone" heads were completed. This unique design is used to achieve an elliptical head when the vessel is stretched. Procurement of these parts was initiated.

2.4 Designs for specimens to be used in the materials evaluation portion of the program were completed. These designs include straight tensile specimens, notched tensile specimens, and Charpy impact specimens.

2.5 Procurement of 301 stainless steel plate stock was initiated for use in fabrication of all vessels and for metallurgical specimens.

2.6 Three sub-scale vessels, 22 inch preform diameter, were cryogenically stretched. These vessels were fabricated as part of the weld development task for the 1/4" thick material.

3.0 COORDINATION WITH U.S.A.F.

3.1 Reports: Three monthly reports were submitted during the quarter as follows:

Monthly Progress Report No. 1	13 August 1962 to 13 Sept. 1962
Monthly Progress Report No. 2	13 Sept 1962 to 13 October 1962
Monthly Progress Report No. 3	13 Oct 1962 to 13 November 1962

These reports were supplemented by informal letters and telephone conversations with the project officer.

3.2 Conferences: A conference was held on Oct. 30, 1962 at Watertown Arsenal, Mass. This was followed by a tour on Oct. 31, 1962, of Arde-Portland's plant in South Portland, Maine. The Army, Navy, and Air Force were represented. The cryogenic stretch forming programs being undertaken by Arde-Portland for all three services were reviewed. It was noted that each contract was directed at a distinct area of rocket case

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fabrication. The Air Force program is directed toward large diameter and heavy wall thickness needed for large boost motors.

4.0 PROGRAM PLAN:

A program plan was formulated outlining the work to be performed in accordance with the contract. This plan schedules the effort through to completion in June of 1963. The plan is included in the appendix of this report.

4.1 Categories of Effort

4.1.1 Sub-scale Vessels: Sub-scale vessels will be utilized to establish the type of weld for the cryogenic stretching of 1/4"-thick material. Vessels incorporating the "dog-bone" concept, as well as simple vessels, will be fabricated. These vessels will be approximately 25 inches in diameter after stretching.

4.1.2 Full-Scale Vessels: Six vessels, 65.5" in diameter are planned. One will be a simple cylindrical unit with flanged-and-dished heads fabricated to establish welding and handling techniques. Two units will include the "dog-bone" at one end to investigate dome-forming in full scale. The final three will incorporate "dog-bones" at both ends.

4.1.3 Materials Evaluation: This phase of the program will generate basic information on the properties of cryogenically worked materials of large thickness dimensions. Tensile specimens of .250", .375", and .500" thicknesses will be evaluated for cryogenic strength and room temperature response to cryogenic straining. Welded tensile specimens in .250" thickness will also be evaluated. Charpy impact specimens (pre-cracked at the root of the "V") will be tested at room temperature and -320°F. These will be both welded and unwelded.

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In addition, notch toughness data will be obtained from center-notched, pre-cracked tensile specimens in the .250" thickness.

5.0 DISCUSSION OF ACTIVITY:

5.1 Sub-Scale Vessels

5.1.1 Weld Development: Development of weld schedules was initiated for girth and longitudinal welds on sample rolled cylinders, as well as flat plate samples. Sigma welds, with and without a heliarc root pass, were investigated. Sigma is a trade name standing for "Shielded Inert Gas Metal Arc". This is a consumable electrode type of weld where the welding current is carried through the filler wire. The wire fuses as it is fed through the arc. With this type of welding, it is possible to obtain the high rate of heat input necessary to weld the thicker sections. Heliarc welds (classified as "tungsten inert gas" welds) are limited to sections of approximately .150" thickness with a single pass. For cryogenic stretch forming, welds made with numerous passes are not desirable for metallurgical reasons. These passes carry the weld zone repeatedly through the sensitizing range of temperatures for 301 stainless steel. Temperatures in this range (1000°F to 1600°F) promote carbide precipitation into the grain boundaries producing a weaker structure. Arde-Portland specifies a low carbon content (.07% maximum) in 301 stainless steel purchased for cryogenic stretch forming to minimize this effect.

Best results in Sigma welding were obtained with a "weld-prep" machined into the joint. The prep is basically a chamfer on each of the parts being joined, forming a "V" groove with a butted land (see figure 1). As an alternate to the pure sigma approach, a weld was developed in which the land is first consumed with a heliarc fusion pass (no filler wire).

The remaining "V" groove is then welded by this sigma process. This is referred to as a sigma/heliarc-root weld. Its advantage lies in the fact that the weld nugget is smaller than in the pure sigma weld since it does not have to penetrate to the bottom of the land. To achieve penetration through the land, the pure sigma weld must stay molten longer, with more filler added, making for a substantially wider overhead. The advantage of the smaller nugget in the sigma/heliarc root weld is offset somewhat by the fact that it is a two-pass weld with the inherent sensitization mentioned above. Actual stretching of these two weld types, in vessels, is the best means for selecting the one to be used.

5.1.2 Vessel Fabrication: Sub-scale vessel 2102 (22 inch preform diameter) utilizing hemispherical end closures, was assembled with sigma/heliarc-root welds. In this particular unit, the longitudinal cylinder weld was ground flush to the parent metal, at both overhead and underbead. The grinding was incorporated to eliminate notch-like junctures between the weld bead and the parent metal. Subsequent vessels, discussed below were left un-ground for comparison. The vessel was cryogenically stretched to burst. The burst pressure was 4750 psig representing a cryogenic stress level of 245,000 psi. The failure was not weld associated but was attributed to a deep gouge in the sheet and traced to cylinder forming rolls. This condition in the rolls was subsequently eliminated. Figure 2 shows the vessel after burst. Note the two fracture lines which come together near the center of the cylinder. The rolling gouge was found at this point. Sub-scale 22 inch diameter vessels, 2100 and 2101 were fabricated to evaluate the pure sigma weld, that is, without heliarc root pass. These ruptured at low stress levels during cryogenic stretch. The failures were definitely weld-associated.

The failure pattern was consistent in both vessels, passing through the entire length of the longitudinal weld. Vessel 2100 burst at 3220 psig (157,000 psi hoop stress) and vessel 2101 burst at 3040 psig (147,000 psi hoop stress). Figure 3 shows vessel 2101 after burst. In these vessels, the longitudinal weld was left un-ground, in contrast to vessel 2102 where it was blended flush on both sides. The fractures in vessels 2100 and 2101 both passed directly through one of the weld-to-parent metal junctures at the underbead of the longitudinal weld. This notch-like juncture was blended away in vessel 2102 and the failure stress was 60% higher and remote from the weld. It is felt that blending of the critical longitudinal weld, at least at the underbead, may be the key to a successful weld for cryogenic stretching of thick vessels. During the next report period, a vessel will be fabricated with sigma/heliarc-root welds. The weld beads will be left unaltered. The unit will be stretched to burst. A premature failure of the type observed in the pure sigma welded vessels 2100 and 2101 will verify the weld-notch theory and the weld-blending approach can be explored further.

It should be noted that these early weld development vessels were fabricated and tested with Arde-Portland development funds. Contract funds will be used for all future vessels.

5.2 Material Procurement: Heat number E72550 was rolled by the vendor in .250" thick plate. The material was provided for both vessel work and materials evaluation. This is in accordance with the contract which states "Materials for all .250" coupons will be taken from the sheets from which the simulated cases will be fabricated." A small quantity of the heat was obtained in .060" thick sheet stock. Tensile specimens in this thickness were pulled during the report period to provide a stress-strain curve at -320°F and evaluate room temperature

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strength at various cryogenic prestrains. This type of evaluation will be part of the materials phase to be performed with thick plate specimens. A comparison, for the same heat, between cold-rolled sheet and hot-rolled plate will thus be available when the program is complete. The cryogenic stress-strain curve and response data is presented in Figure 4. Note that the heat also exhibits an excellent response to aging after prestrain, a key property for this program where the final case will be aged. During the next report period, a small vessel will be built from the .060" sheet stock, on one of Arde-Portland's development programs, to provide some rapid data on the properties of the material in actual vessels. The chemical analysis of the heat is included in Table I of the appendix.

5.3 Facilities and Tooling

5.3.1 Forming Die: The full-scale 65.5" diameter vessel will be stretched in a cylindrical die to assure roundness and straightness. The die is a simple, stainless steel, roll-and-weld cylinder of dimensional tolerances commensurate with this type of construction. The inside diameter is such that the vessel will "spring-back" to the desired 65.5 inch diameter when the stretching pressure is released. The die has been released to procurement and is scheduled for receipt during the next report period.

5.3.2 Stretch Facility: Arde-Portland is erecting a new stretch facility designed to meet the requirements of larger vessels and higher stretch pressures. The pit will accommodate a vessel up to 65" in diameter and 160" long. The pit is actually an insulated forming tank installed permanently in the ground. For vessels in the 65" class, the entire pit is used as a container for liquid nitrogen. When smaller vessels are stretched,

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a smaller forming tank, supported in the pit, is used for obvious reasons of economy with the liquid nitrogen. The facility will be equipped with two cryogenic pumps. One is a 4000 psig pump of high capacity to permit rapid stretching of large vessels where the pressure requirement is not high. The other pump is a 30,000 psig unit of lesser flow capacity, intended for smaller vessels where heavy wall thickness could make for a very high pressure requirement.

Stretch operations will be conducted from the same block-house as before. Many of the valves in the system will be remote-operated by electric solenoids. The pumps will also be located remote from the block-house and near the stretch pit so that a minimum length of pressurizing line will be used. Pressure instrumentation will be of the transducer type with direct reading indicator at the control panel in the block-house.

5.4 Materials Evaluation

Design work for the initial 301 material tensile specimens was completed during the report period. These are the unwelded specimens in .250", .375" and .500" thicknesses which will be fabricated parallel and transverse to the rolling direction in the large plate. Quotations for fabrication of these specimens are now being received. Designs for the welded tensile specimens, center-notched tensile specimens (welded and unwelded), and Charpy impact specimens (welded and unwelded) have also progressed and will be completed during the next report period. The test program cannot be conducted at Arde-Portland's facilities due to the very high loads required to pull thick heavy-section tensile specimens. Thiokol Chemical

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Corp., Wasatch Division, possesses suitable equipment and has been selected for the job. Negotiations for a sub-contract are now in progress and should be complete during the next report period. All specimen designs previously referred to have been coordinated with Thiokol Chemical for compatibility with their test machine. The cryostat design was completed during this report period and released for fabrication. This is the rig which refrigerates the specimen during test. It consists basically of a container for the liquid nitrogen, a clevis attachment for the tensile specimen, and a mechanism for inserting and retracting the clevis pin while under the liquid-nitrogen bath. The cryostat is scheduled for completion early in the next report period.

5.5 Full-Scale Vessels

5.5.1 First Simple Vessel: The first 65.5" vessel will consist of a cylinder combined with simple closure heads. This unit will be built mainly to develop tooling and techniques for machining, welding, and general handling of vessels of the 65.5" class. Sound welds for cryogenic stretching of thick material will be the main objective in this first attempt at scaling-up from small to large size. This first vessel will consist of 302 stainless steel ASME-type flanged and dish heads welded to a cylindrical shell. The heads are on order and will be received early in the next report period. The large 301 stainless steel plate (Heat No. E72550) from which the cylinder will be rolled has been released for shearing

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to size. The plan will be to machine the weld-prep chamfers on the edges of this plate prior to rolling. This will preclude the need for machining operations on a large diameter cylinder. A corresponding savings in tooling cost and set-up time will be realized.

5.5.2 Designs for Elliptical Head Vessels: Designs incorporating the various "dog-bone" concepts and elliptical head shapes were completed. It should be noted that these designs will be tried in sub-scale size first, and when proven in test, will be "scaled-up" for the 65.5" case. The "dog-bone" head nomenclature is derived from a unique type of preform closure which resembles the end of a dog bone. The closure shape is such that a portion of it is larger than the cylinder diameter. During the cryogenic forming operation, the cylinder will stretch more than the larger diameter of the "dog-bone" and will result in a straight vessel. Data obtained from another program indicates that corner welds can result in premature failure. Therefore, the final design eliminates the original cone and disc dog-bone plan and incorporates formed parts avoiding the troublesome sharp corner welds.

APPENDIX

References

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| Table I | Chemistry of Heat No. E72550 |
| Figure 1 | Sketch of Weld Preparation for Sigma Weld |
| Figure 2 | Vessel 2102 After Burst |
| Figure 3 | Vessel 2101 After Burst |
| Figure 4 | Mechanical Properties of Heat No. E72550 |

Program Plan

REFERENCES

1. Arde-Portland final report, "Development of Ultra High Strength Rocket Motor Cases by Cryogenic Stretch Forming," U. S. Army Ordnance Materials Research Office, contract DA-30-069-ORD-3099 Task A, February 15, 1962.
2. Arde-Portland final report, "Cryogenic Stretch Forming of Rocket Motor Cases," Navy Bureau of Weapons, Contract NOW 60-0263-C, May 15, 1961.

TABLE I

Chemical Composition of 301 Stainless Steel Heat No. E72550
(% by Weight)

C	.066
Mn	1.43
Si	.61
Cr	17.35
Ni	7.51
S	.012
P	.020
Cu	.26
Mo	.24
Co	.03

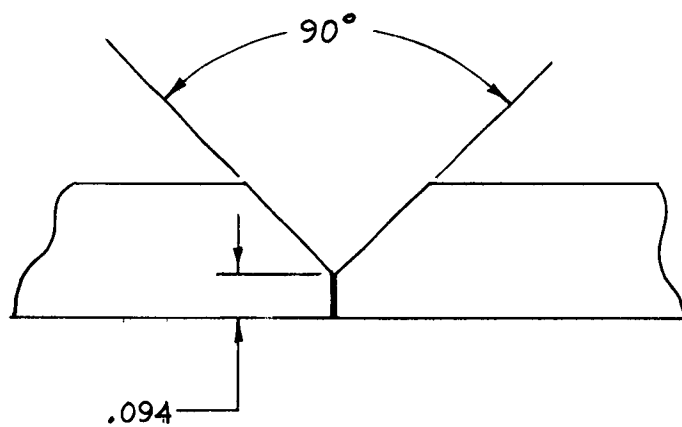


FIGURE 1 Weld Preparation for
Sigma Weld

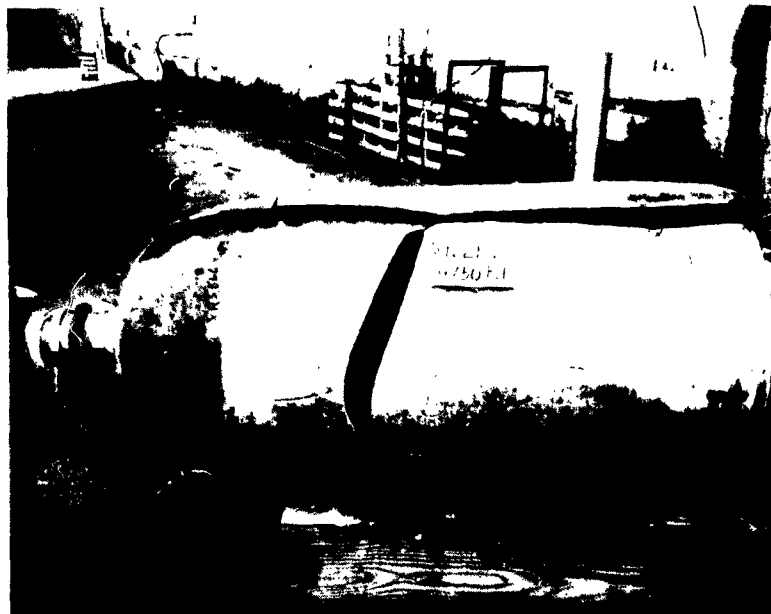


Figure 2 - Vessel #2102 After Burst

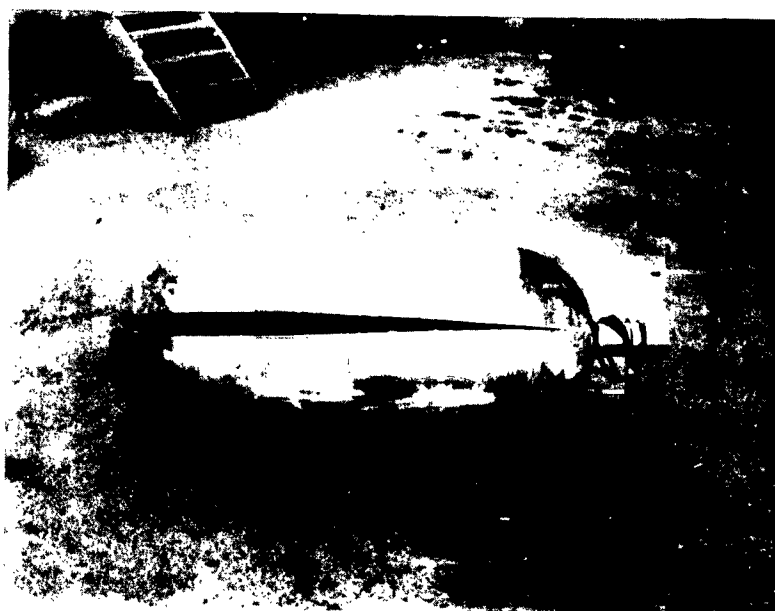
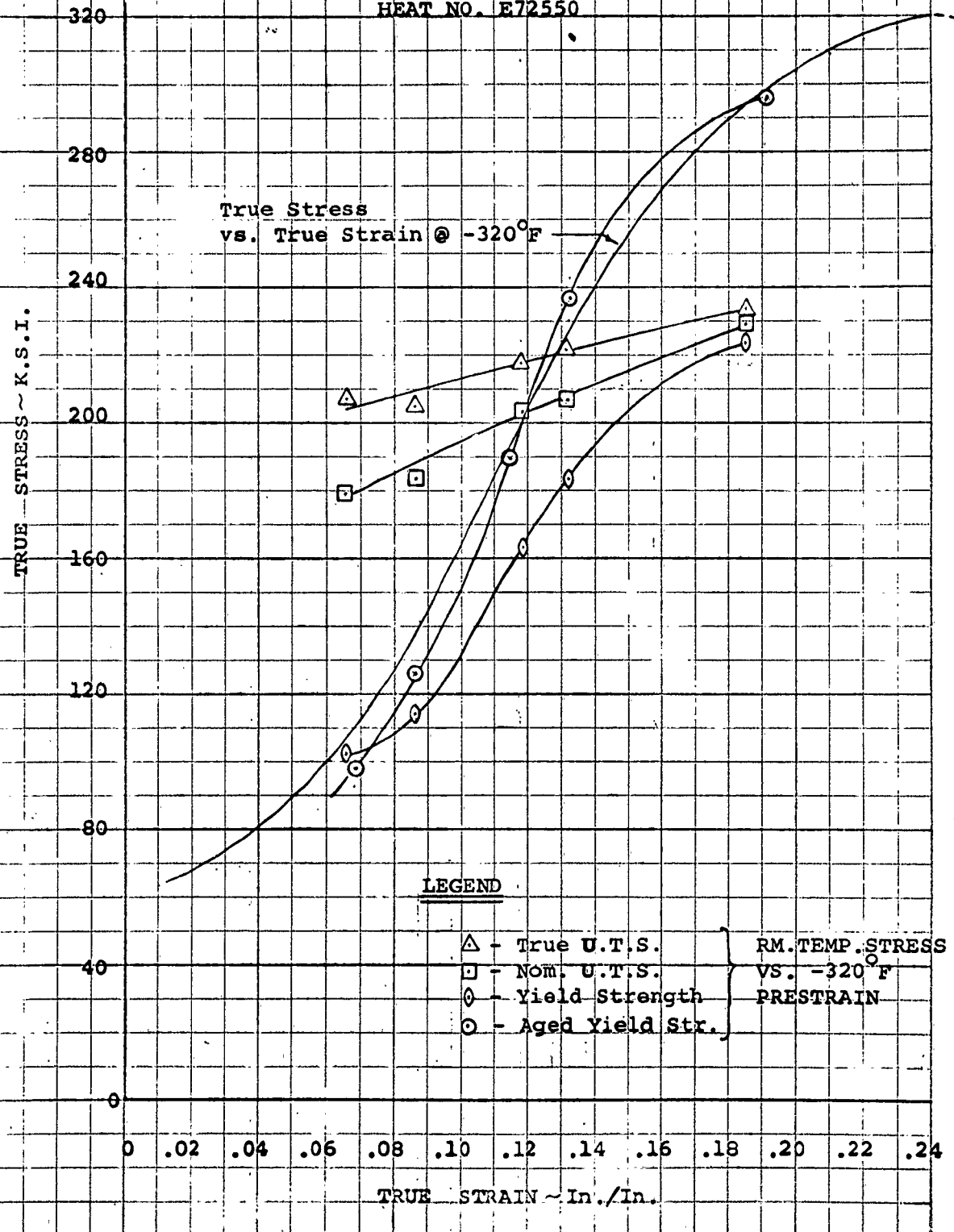


Figure 3 - Vessel #2101 After Burst

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A. J. HARRIS & SONS, INC.

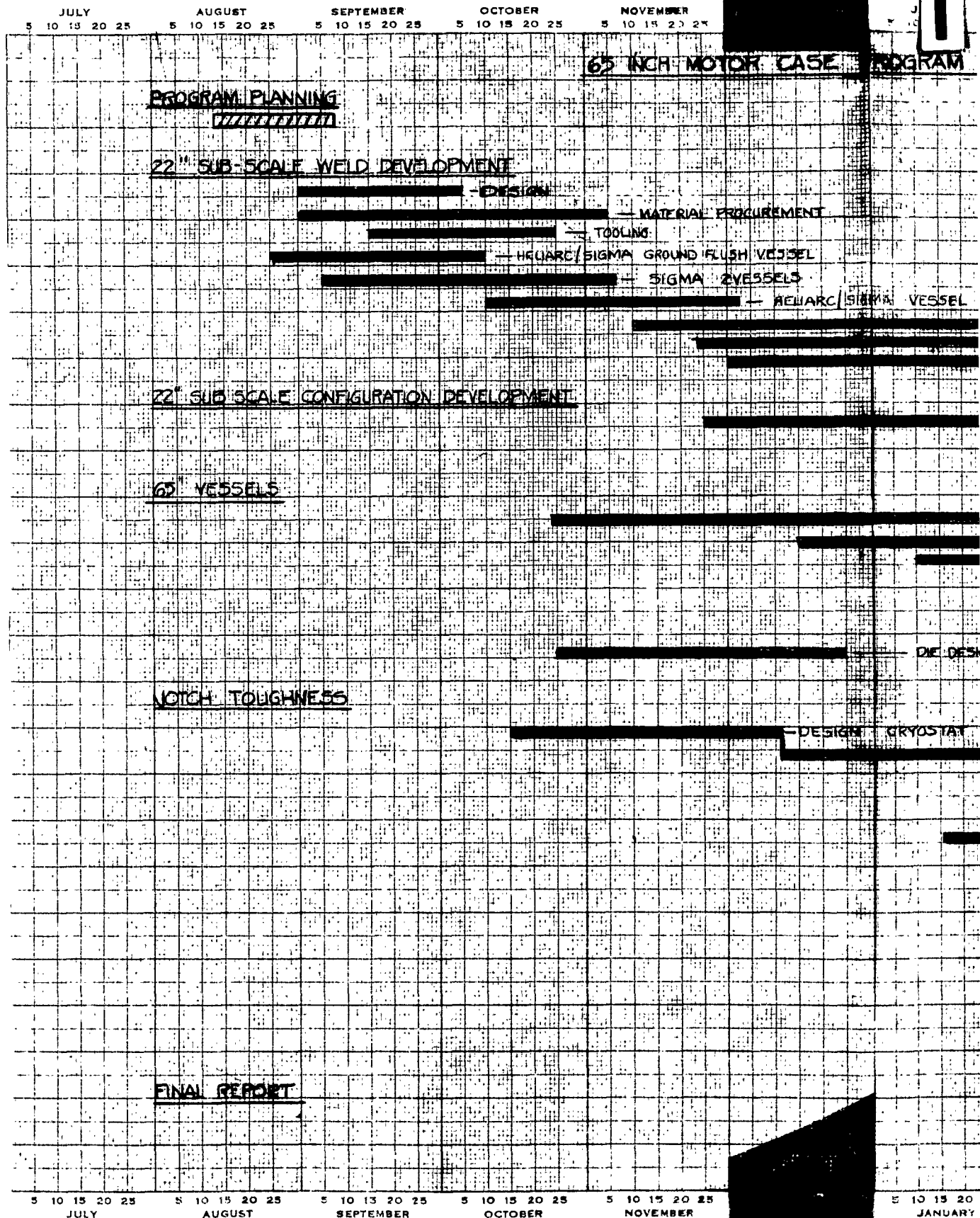
FIGURE 4

MECHANICAL PROPERTIES OF 301 STAINLESS STEEL
HEAT NO. E72550



1962

1



1963

2

