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DEVELOPMENT OF A NONDESTRUCTIVE TESTING TECHNIQUE TO DETERMINE FLAW CRITICALITY

September 1970

by

P. P. Crimmins

Contract F33615-68-C-1705

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20

FORWARD

This report was prepared by P. P. Crimmins of the Advanced Technology Operations, Metallurgy and Materials Integrity Department, Aerojet Solid Propulsion Company, Sacramento, California. The research was supported by the Advanced Research Projects Agency of the Department of Defense and was monitored by the Air Force Materials Laboratory, MAMN, under Contract F33615-68-C-1705.

This report covers the period 1 June 1970 through 31 August 1970.

Effective Date of Contract: 1 July 1968
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Amount of Contract: $208,123
Principal Investigator: C. E. Hartbower
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TABLE OF CONTENTS

TABLE LIST

FIGURE LIST

ABSTRACT

A brief description is presented of the program scope for additional studies to develop a nondestructive testing technique to determine flaw criticality. The results of limited instrumentation evaluations for obtaining real time stress wave emission data are discussed. The fabrication of specimens to be tested at Aerojet and during concurrent programs under ARPA sponsorship at the University of Michigan and North American Rockwell Corporation is also discussed.

I. INTRODUCTION

This program is being conducted to develop nondestructive testing criteria which can be employed to detect and locate flaws in structures and assess their potential for reaching a critical failure condition. Two basic technologies, Stress Wave Emission and fracture mechanics are being employed to accomplish this objective.

Stress-wave emissions are generated by stressed materials as a result of the release of kinetic energy from a deformation mechanism. The region surrounding this deformation will acquire, if only temporarily, a new and more stable stress field. This new, impulsively developed, stress field will give rise to oscillations which decay due to the inelastic behavior of the material. The elastic waves propagate out from the source and are detected as small displacements on the surface of the specimen. These displacements, stress-wave emissions, can be used to locate the source of the emission and provide a means of assessing the increment of deformation and/or flaw extension.

Linear elastic fracture mechanics is an engineering method of determining the stresses in the vicinity of a stress concentration. These solutions are developed through application of elasticity theory and they determine linear relationships between stress functions and dimensional functions of the flaw. This "stress-intensity factor" which depends on the flaw's size, shape and orientation with respect to load and/or specimen geometry, is a means of defining the rate of supply of available energy for crack propagation in terms of the applied stress field within the specimen. The advantage of using the stress-intensity factor (K) is that it may be evaluated in terms of the applied stress, the crack size and the specimen dimensions and is thus reduced to a stress analysis problem. Through this engineering method, any problem solvable by linear stress analysis is capable of being analyzed from a fracture toughness point of view.

During the previous years studies under this contract[(Ref.)], it was demonstrated that the stress wave data may be parametrically related to stress-intensity factors. These relationships are being further investigated during the present study for a variety of materials and use conditions. This report covers the progress during the period of June through August 1970.

Ref.: Green, A. T. and Hartbower, C. E., Development of a Nondestructive Testing Technique to Determine Flaw Criticality, May 1970, Interim Report under Contract F33615-68-C-1705.

II. OVERALL PROGRAM SCOPE

The program to be performed to develop the Stress-Wave-Emission technology for a nondestructive inspection system is divided into three phases; a brief description of the work planned in each is shown below.

PHASE I - SPECIMEN FABRICATION

During Phase I, the specimens for testing in subsequent program phases will be fabricated. The 1100-0 and 7075-T6 aluminum alloys and the Borosilicate Glass and Borsic reinforced aluminum matrix composite materials will also be procured during this phase. The D6aC steel and 6Al-4V titanium materials are presently available from the first year's study under Contract F33615-68-C-1705, the results of which were published in Reference (1). The materials and appropriate thicknesses and conditions to be tested during the program at Aerojet are shown in Table I.

In addition to the tensile, single-edge-notch tensile and part-through-crack tensile specimens to be tested at Aerojet, standard sheet type fatigue specimens will be fabricated and delivered to the University of Michigan and North American Rockwell Corporation for their programs.

PHASE II - SPECIMEN TESTING AND DATA ANALYSIS

During Phase II, specimen testing will be performed and will be accompanied by continuous data analysis throughout Phase II. Primary emphasis will be to develop relationships between incremental fracture and failure, and significant stress wave emission characteristics which can be employed to locate and assess flaw criticality in structures for a variety of materials and use conditions. Stress wave characteristics which will be investigated include amplitude, cumulative count and rate of occurrence. These characteristics will be related to fracture behavior through fracture mechanics. It is expected that further refinement in such relationships as developed during the first year's program and shown in Figures 1 through 3 will be made. Other stress wave emission characteristics which will be studied include wave shape and frequency content.

Concurrently, stress wave emission attenuation, discrimination in high noise backgrounds, and source triangulation techniques will also be evaluated.

PHASE III - SUMMARY TECHNICAL REPORT

The Summary Technical Report including results from this and the first year's program will be prepared during Phase III.

III. TECHNICAL DISCUSSION OF WORK PERFORMED

PHASE I - SPECIMEN FABRICATION

The D6aC steel and 6Al-4V titanium sheet and plate materials were available from the first year's program while the 7075-T6 aluminum, borosilicate glass and the Borsic reinforced aluminum matrix composite materials were procured for this program. Fabrication of the tensile (Figure 4), single-edge-notch tensile (Figure 5) and part-through-crack tensile (Figure 6) specimens has been initiated and is proceeding. The borosilicate glass and composite materials have been ordered, but not received.

During the reporting period, the standard, sheet-type fatigue specimens (Figure 7) required for programs at the University of Michigan and North American Rockwell Corporation were also fabricated and delivered.

PHASE II - SPECIMEN TESTING AND DATA ANALYSIS

No tests were performed during this period using test materials specifically procured for the program. However, instrumentation evaluations were continued where possible during tests conducted as part of other studies.

The most significant of these evaluations are those being conducted to evaluate instrumentation systems which will provide a continuous, long-term monitoring capability with SWE data output which can be employed to relate the stress wave data to applied stress intensity and incremental crack area. As indicated in Figures 1 through 3, cumulative stress wave emission count appears a significant parameter for this purpose. During the reporting period, a SWE monitoring system has been assembled which will meet this requirement. The system has been employed to monitor delayed cracking in weldments. Typical data obtained from these tests which illustrates the discontinuous nature of the cracking, is shown in Table 2 and Figure 8. Additional evaluations of this system and other instrumentation components will be performed when the specimens for this program are available for testing.

TABLE I

TEST MATERIALS AND CONDITIONS

Material	Modulus	Approximate Ultimate Strength (ksi)
D6aC Steel (0.1 and 0.3-in. thick)	30×10^6	220 280
Borsic Reinforced Aluminum Composite (0.1-in. thick)	32×10^6	140
Ti-6Al-4V (0.1 and 0.25-in. thick)	16×10^6	140 17[illegible]
7075-T6 Aluminum (0.09 and 0.25-in. thick)	10.4×10^6	85
Borosilicate Glass	9.5×10^6	

TABLE II

SWAT-CONTINUOUS RECORDING OF DELAYED CRACKING HY-130 HORIZONTAL WELDMENT 1 X 18 X 36-IN.

Date	SWE Event		SWE Count		Burst of >10 ΔT (Minutes)	Burst of >50 ΔT (Minutes)	Burst of >100 ΔT (Minutes)
	Time	ΔT (Minutes)	TSWE	ΔTSWE			
20 May '70	1242	(Welding completed)					
	1630	(Counter started)					
	1637	7	103	103	7	7	7
	1639	2	105	2			
	1642	3	108	3			
	1645	3	112	4			
	1647	2	295	183	10	10	10
	1648	1	302	7			
	1650	2	307	5			
	1652	2	309	2			
	1704	12	326	17	17		
	1706	2	332	6			
	1715	9	350	18	11		
	1716	1	354	4			
	1720	4	368	14	5		
	1721	1	421	53	1	34	
	1724	3	440	19	[illegible]		
	1725	1	453	13	1		
	1730	5	806	353	5	9	43
	1734	4	817	11	4		
	1738	4	835	18	4		
	1739	1	845	10			
	1747	8	849	4			
	1756	9	863	14	18		
	1822	26	884	21	26		
	1835	13	903	19	13		
	1841	6	904	1			
	1927	46	1538	634	52	117	117
	2016	49	1539	1			
	2017	1	1723	184	50	50	50
	2107	50	1735	12	50		
	2109	2	1736	1			
	2312	123	1882	146	125	175	175
	2338	26	1887	5			
21 May '70	0005	27	1888	1			
	0237	152	1889	1			
	0257	20	3826	1937	225	305	305
	0347	50	3955	129	50	50	50
	0542	115	3957	2			
	0830	168	4029	72	283	283	
	1329	299	4203	174	299	299	582
	1644	195	4411	208	195	195	195
	2115	271	4413	2			
22 MAY '70	0406	411	4414	1			
	0619	133	4418	4			
	1130(a)	311	4441	23	1126		
	2031	541	8833	4392	541	1667	1667
23 May '70	0854	743	8834	1			
	1032	98	9113	279	841	841	841
24 May '70	0035	843	9122	9	843		
	0236	121	9123	1			
	0606(a)	210	9124	1			
	1836	750	9125	1			
	2148	192	9140	15	1273		
25 May '70	0630	>522	9140 Disconnect	-	>522	>2638	>2638

(a) Some data may have been lost between 1200 and 1630 hrs because of loss of power

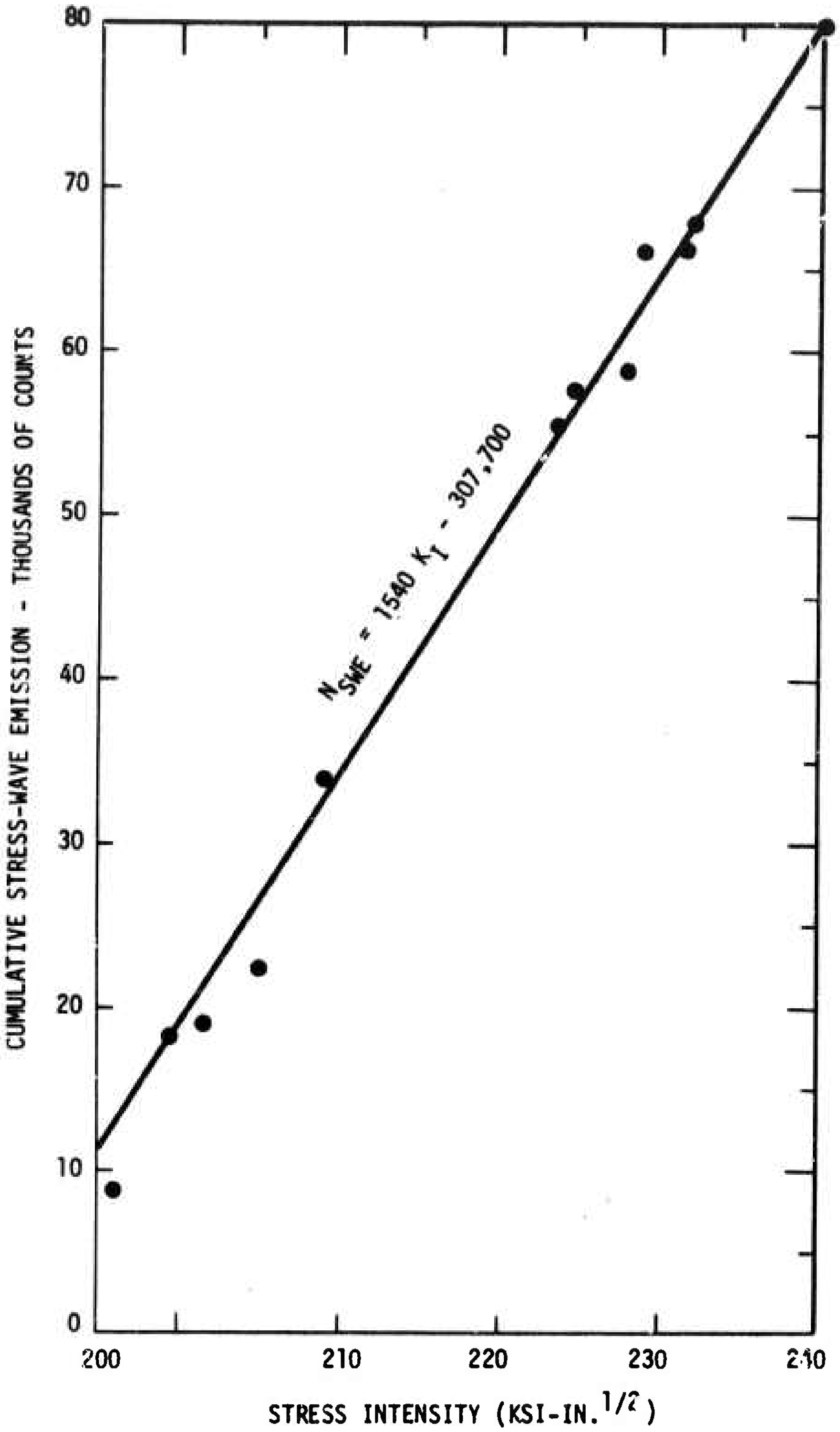


Figure 1. Relationship Between Stress Intensity Factor and Cumulative Stress Wave Count - 18% Nickel Maraging Steel in Distilled Water - Sustained Load.

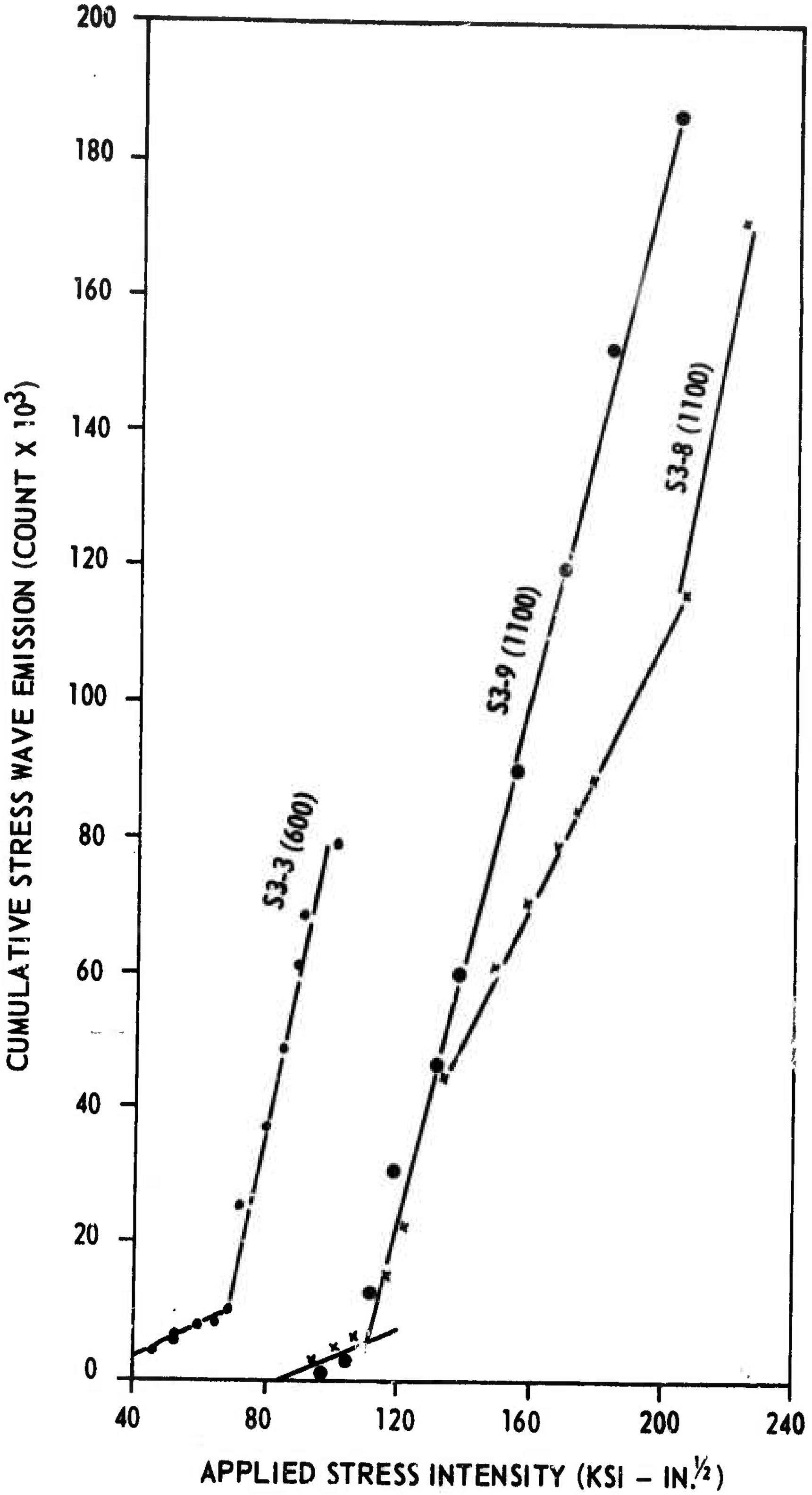


Figure 2. Total Stress Wave Emission versus Applied Stress Intensity Factor - D6AC Steel Tempered at 600°F or 1100°F - 0.29-in. thick, numbers refer to specimen identity. Rising Load to Failure.

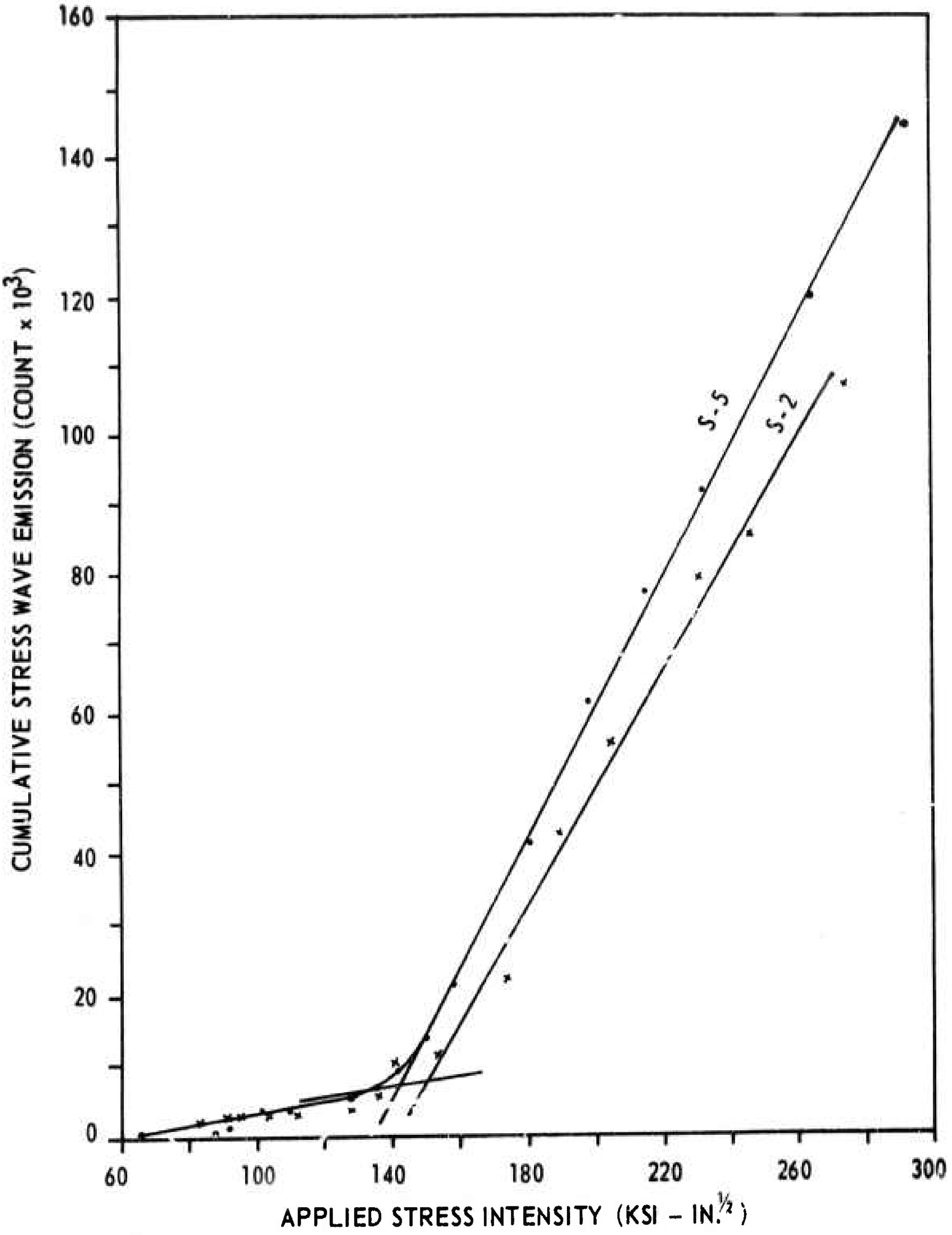


Figure 3. Total Stress Wave Emission versus Applied Stress Intensity Factor - D6AC Tempered at 1100°F - 0.10 in. - Numbers refer to specimen identity. Rising Load to Failure.

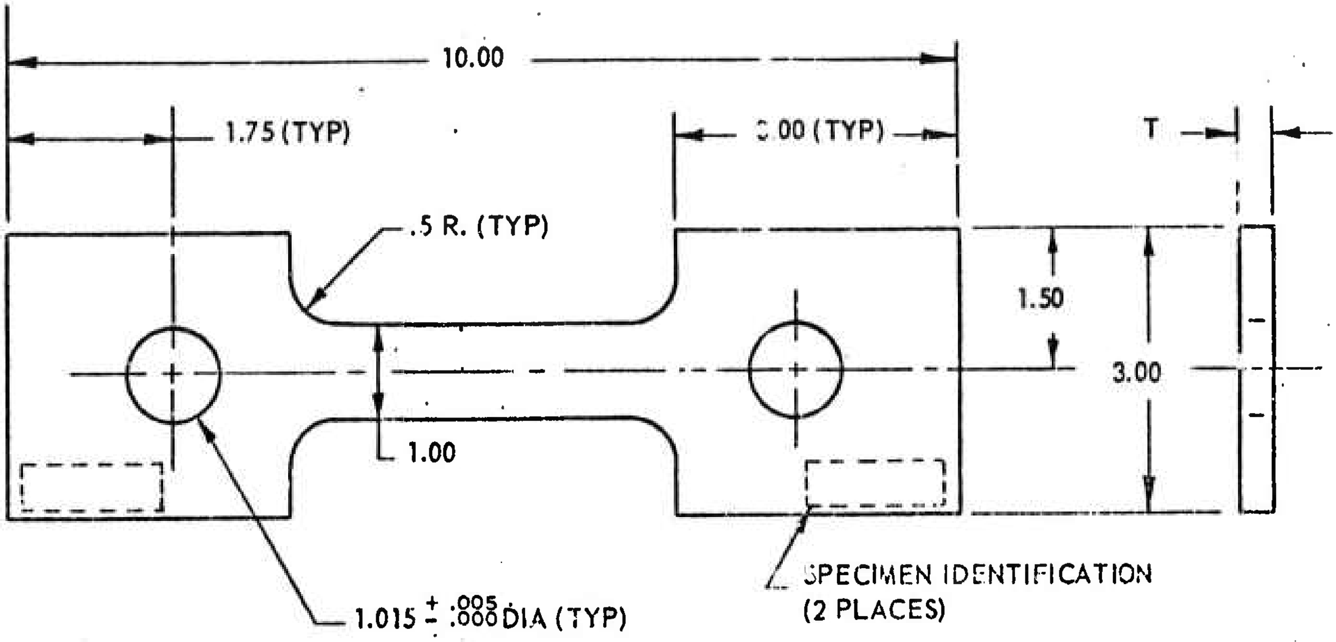


Figure 4. Unflawed Tensile Specimen for Structural Metals

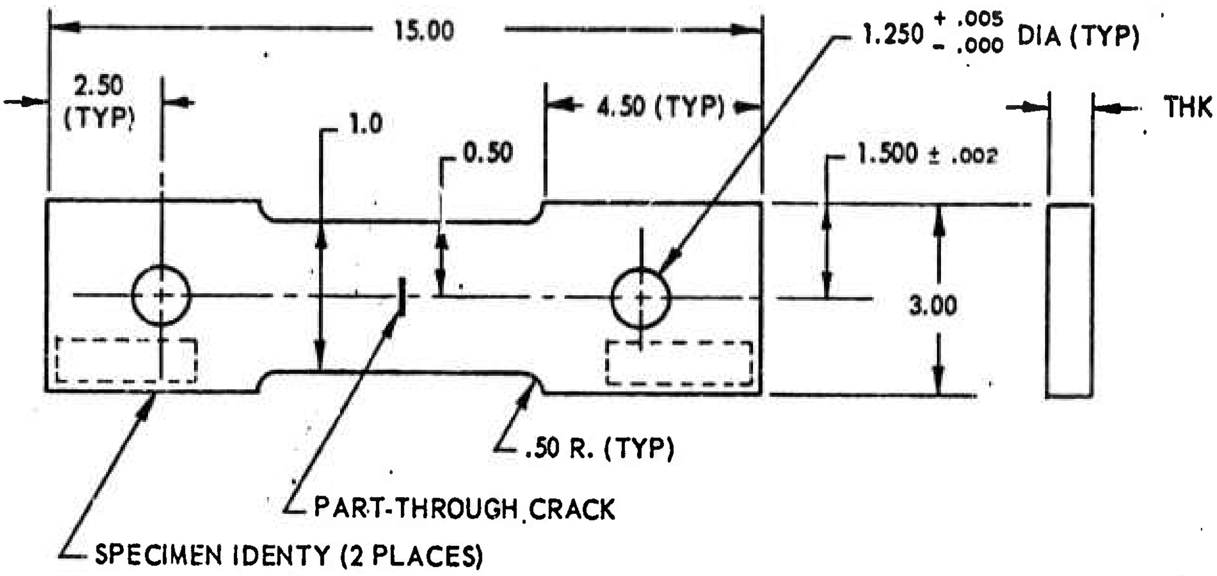
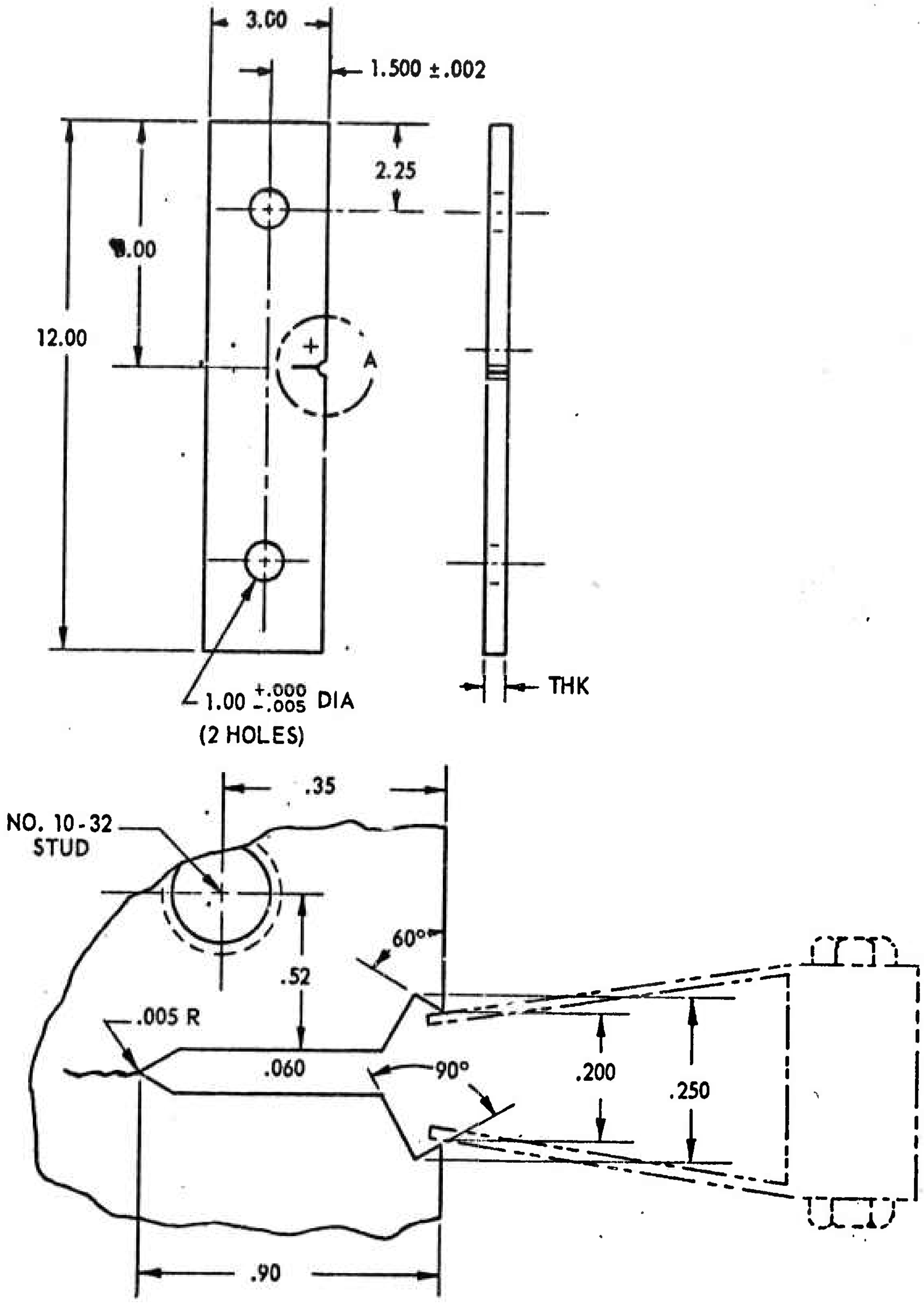
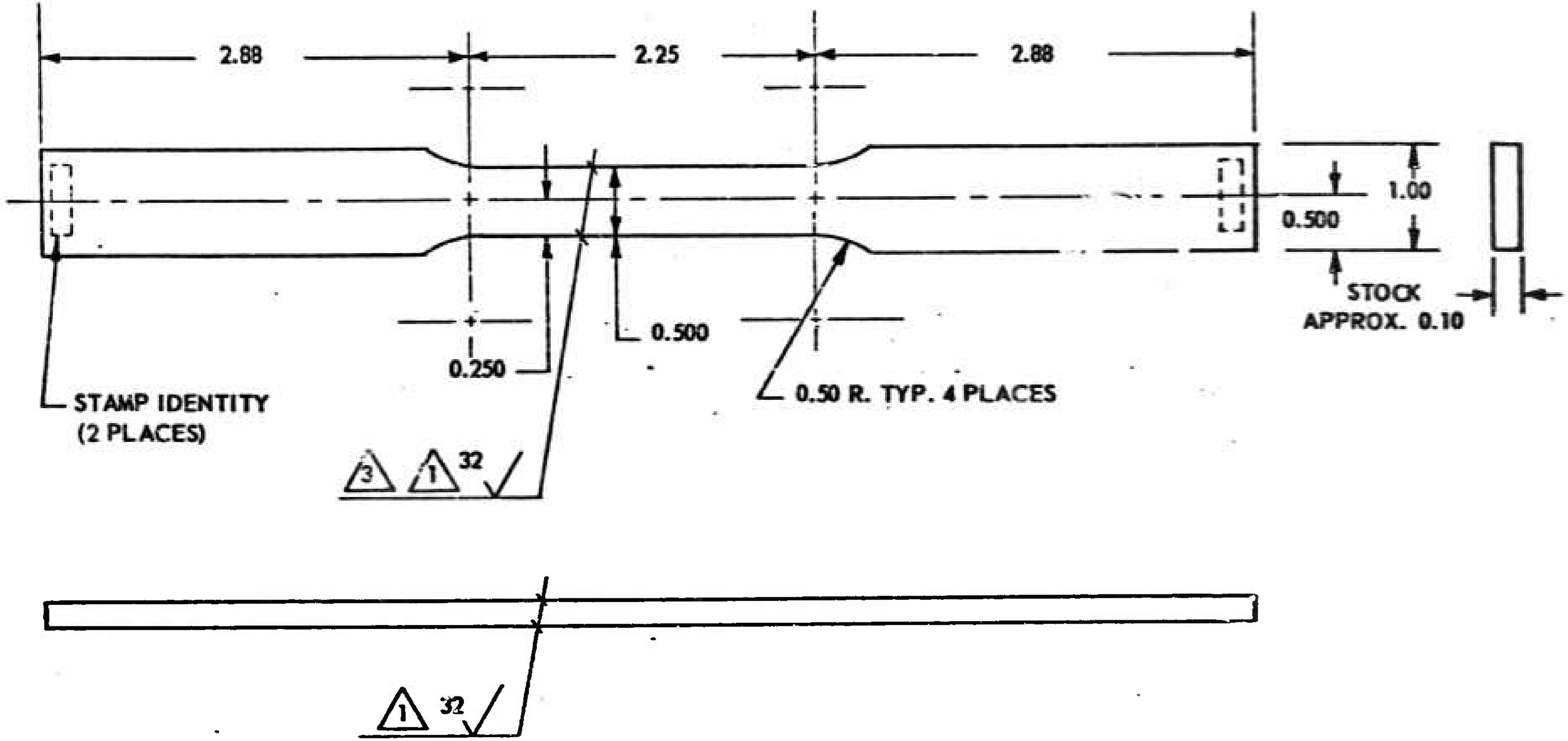


Figure 5. Typical Part-Through Crack Tensile Specimen for Structural Metals



VIEW A

Figure 6. Single-Edge Notch Specimen for Structural Metals and Crack Opening Displacement Gage



△3 THESE SURFACES TO BE PARALLEL WITHIN .005 IN 2.25 REDUCED SECTION

2 REMOVE ALL BURRS AND SHARP EDGES.

△1 NO SCRATCHES, SCRIBE LINES, OR TOOL MARKS IN THESE SURFACES.

Figure 7. Standard Sheet-Type-Fatigue Tensile Specimen

Figure 8. SWAT-Continuous Recording of Delayed Cracking HY-130 Horizontal Weldment 1 x 18 x 36-in.