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LABORATORY EVALUATION OF 4-3/4-INCH FLASH-WELDED ALLOY STEEL ST--ETC(U)
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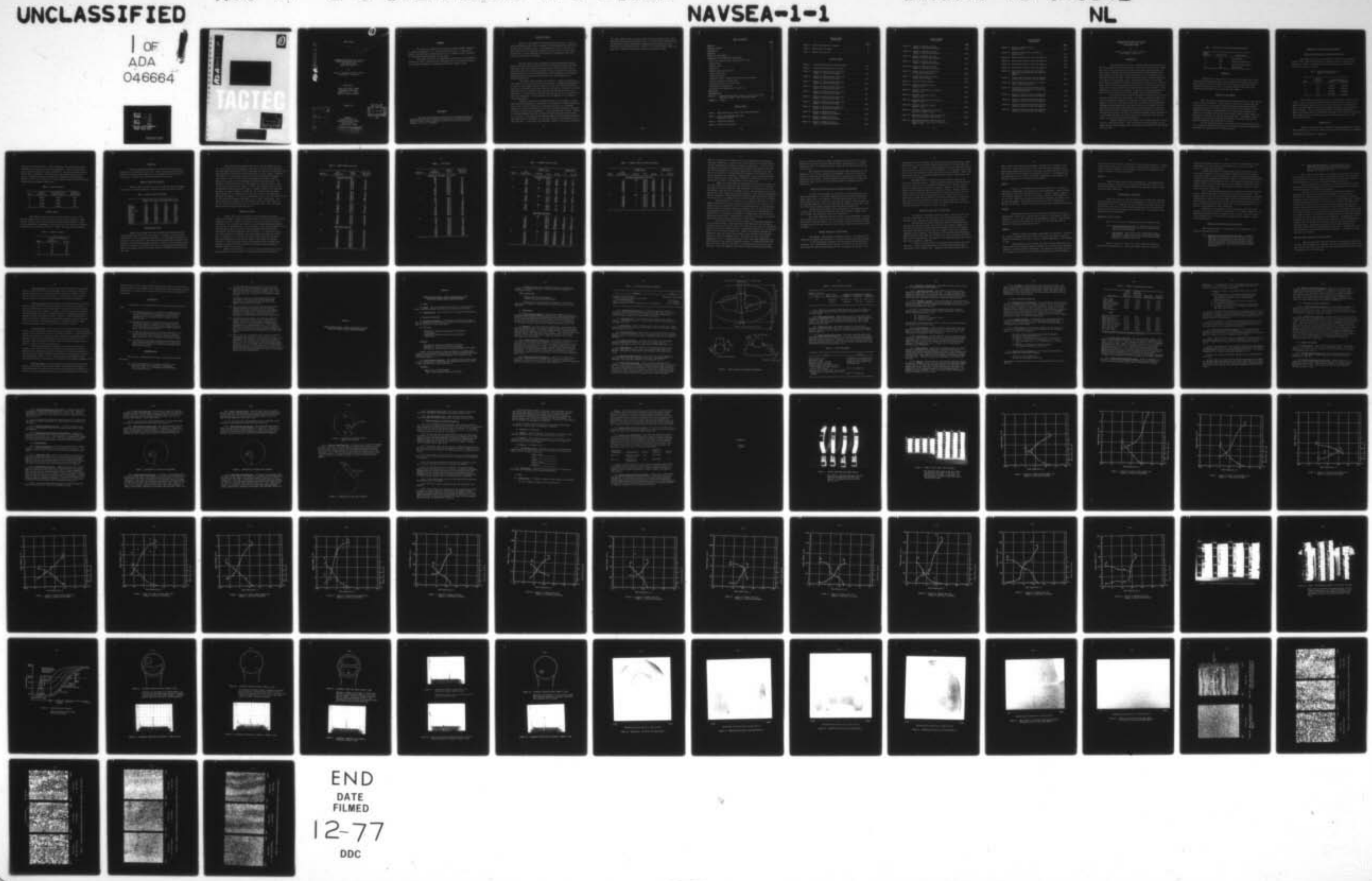

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FINAL REPORT

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LABORATORY EVALUATION OF 4-3/4-INCH FLASH-WELDED ALLOY STEEL STUD LINK ANCHOR CHAIN
(Report No. NSSC 1-1)

by

David C. Doerschuk, Robert J. Eiber,
and Thomas P. Groeneveld

Sponsored by

NAVAL SEA SYSTEMS COMMAND
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FOREWORD

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DISCLAIMER

EXECUTIVE SUMMARY

There is a considerable cost-saving potential for the U. S. Navy in using flash-welded anchor chain as opposed to die-lock-manufactured chain which has been used for almost 50 years. For example, the cost of 4-3/4-inch die-lock anchor chain for the Navy's new CVN-70 aircraft carrier, currently under construction, is nearly $800,000, while equivalent flash-welded chain would cost less than one-half that amount.

The first step of this investigation involved developing guidelines and procedures for the manufacture of 4-3/4-inch flash-welded alloy steel stud link anchor chain which would be representative of the best state-of-the-art practice presently in use and would enable the Navy to procure chain that would satisfactorily meet its service requirements. These guidelines and procedures, along with quality-assurance testing requirements, were summarized in an *Interim Specification.*

The present report contains the results of a laboratory evaluation of four samples of 4-3/4-inch flash-welded anchor chain. Although the manufacturers of the four chain samples were not required to follow the *Interim Specification* guidelines and procedures precisely, since the time and cost involved in retooling and modifying their operations would have made this impractical for the very small amount of chain required, their current practices are in very close accord with those delineated in the *Specification* and the samples can be considered truly representative.

The major program effort involved evaluation of the samples in accordance with the metallurgical, nondestructive, and mechanical testing requirements as set forth in the *Specification.* The primary objective was to determine whether the 4-3/4-inch flash-welded anchor chain currently produced by these manufacturers would meet Navy requirements. It was concluded that it would. However, it was also determined that the *Specification* needed some minor modifications, e.g., revision of the procedure for obtaining some of the metallurgical specimens and eliminating the requirement for ultrasonic testing of the flash-weld area of each chain link. In the case of the ultrasonic testing, it was found that defects

were often indicated where, in fact, none existed, which would result in good chain being rejected and considerable waste. It was therefore recommended that the ultrasonic testing requirement be eliminated since several other non-destructive and metallurgical tests called for in the *Specification* reveal the same types of defects for which the ultrasonic tests were intended.

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LABORATORY EVALUATION OF 4-3/4-INCH FLASH-WELDED ALLOY STEEL STUD LINK ANCHOR CHAIN

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INTRODUCTION

The CVN-70 aircraft carrier, currently under construction for the Navy, will require 4-3/4-inch anchor chain. Since the Second World War the Navy has used die-lock-type chain for all anchor-chain applications requiring this size. Recent technological advances have resulted in flash-welded-type chain which appears to be suitable for naval applications and is considerably less expensive than die-lock chain. Flash-welded-type chain is presently being used by a number of foreign navies and for anchoring most offshore oil platforms. Recent studies at Battelle's Columbus Laboratories have indicated that 4-3/4-inch anchor chain can be flash-weld manufactured to meet U. S. Navy requirements by using certain technical guidelines and procedures developed by Battelle. These guidelines and procedures are contained in Appendix A, "Interim Specification: Chain, 4-3/4-Inch (120.5 mm) Stud Link, Anchor, Steel, Flash-Butt-Welded".

The guidelines and procedures represent the present state of the art for chain manufactured by flash welding. This report contains the results of a series of laboratory evaluations to determine the material characteristics of samples of 4-3/4-inch flash-welded anchor chain produced by four manufacturers. Although the chain samples were not produced strictly in accordance with the guidelines and procedures established in the *Interim Specification*, since the time and cost involved in retooling and modifying their operations would have been prohibitive for the very small test quantities needed, current practices are so very nearly identical with those called for by the *Specification* that the samples can be considered truly representative.

Samples consisting of one triplet and two single links were received from four chain manufacturers. Table 1 shows the size and type chain of each sample and the letter designation for each manufacturer that will be used throughout this report.

TABLE 1. CHAIN SAMPLE SIZE, QUALITY, AND LETTER DESIGNATION

Sample Designation	Sample Size, mm	Sample Quality
A	120	Oil-Rig Quality
B	120.5	Extra High Strength Grade 3
C	132	Extra High Strength Grade 3
D	120	Oil-Rig Quality

OBJECTIVE

The objective of this study was to collect and document data on the material properties/characteristics of four samples of 4-3/4-inch anchor chain and to evaluate them in accordance with specific quality-assurance testing guidelines and procedures in order to determine whether flash-welded chain presently being manufactured will meet Navy requirements.

APPROACH TO THE PROBLEM

Each chain sample was subjected to the complete series of tests outlined in the *Interim Specification*. These included a proof load, breaking load, and destructive test of the triplets, using the 5-million-pound testing equipment at Lehigh University; link surface, flash-weld surface, and flash-weld interior examinations, and physical measurements of one single link; and chemical composition, link interior, fusion-zone microstructure, tensile, Charpy impact, and bend tests of specimens cut from the other single link. In addition, a series of dynamic tear tests were conducted on specimens cut from the link used for physical measurements and nondestructive testing.

All testing was performed in accordance with the *Interim Specification* or the respective ASTM standard method. The testing procedures are described and the results are presented in the following section.

DISCUSSION OF TEST PROCEDURES AND RESULTS

Proof Load, Breaking Load, and Destructive Tests

Each sample triplet was proof loaded to 1,700,000 lb, then loaded to 170,000 lb and inspected for fractures or tendency to open at the weld, and measured for stretch. All samples performed satisfactorily in these tests. The results are shown in Table 2.

TABLE 2. PROOF LOAD, BREAKING LOAD, AND DESTRUCTIVE TEST RESULTS

Sample	Stretch at 170,000 lb, percent	Breaking Strength, lb	
		Tested	Anticipated
A	0.00	2,540,000	2,780,000
B	2.01	2,455,000	2,204,000
C	0.23	3,110,000	2,568,000
D	0.39	2,570,000	2,780,000

Each sample was then pulled to break. All fractures occurred in link corners. Table 2 shows the recorded breaking strength for each sample and the expected breaking strength in accordance with the respective size and quality chain. Note that samples B and C were stronger and Samples A and D were weaker than anticipated. Also, it should be noted that the breaking strength of Sample D was greater than the 2,550,000-lb requirement of the *Interim Specification* even though it was 0.5 mm smaller than the 120.5-mm chain called for in the *Interim Specification*.

Tensile Tests

Figure 1* shows the 0.505-in. round bar tensile specimens after testing. The specimens were cut from the unwelded portion of the chain samples in accordance

*All figures are presented in Appendix B.

with the *Interim Specification.* Table 3 summarizes the mechanical properties determined by the tensile tests at room temperatures. The 0.2 percent offset yield strengths ranged from 61,200 to 70,600 psi. The tensile strengths ranged from 92,300 to 102,000 psi. The reduction in area ranged from 64.6 to 70.0 percent. Samples B and D did not surpass the 99,600-psi ultimate strength required by the *Interim Specification.* These samples showed 94,300 and 92,300 psi ultimate tensile strengths, respectively.

TABLE 3. TENSILE TEST RESULTS

Sample	Tensile Strength, psi	0.2 Percent Offset Yield Strength, psi	Reduction in Area, percent
A	100,800	67,700	66.1
B	94,300	69,500	68.8
C	102,000	70,600	64.6
D	92,300	61,200	70.0

Hardness Tests

Each sample was given two Brinell hardness tests, one at 0.10 in. below the sample external surface and the other at a point one-half the radial distance from the center of the unwelded area opposite the flash weld. These data are presented for supplementary information only, since there is no hardness requirement in the *Interim Specification.* Table 4 shows the recorded hardness.

TABLE 4. HARDNESS TEST RESULTS

	Brinell Hardness, BHN	
Sample	0.10 In. Below Surface	At 1/2 r
A	187	199
B	181	192
C	269	201
D	188	185

Bend Tests

All of the specimens passed the *Interim Specification* bend-test requirement of 120 degrees with no crack. There was some localized yielding evident in the weld region; however, no crack extended across the surface of the specimen. Figure 1 shows the bend specimens after testing.

Chemical Composition Analysis

Sample material was taken from the base metal of each chain sample. The results of a chemical analysis in percent by weight are shown in Table 5.

TABLE 5. CHEMICAL COMPOSITION OF SAMPLES

	Chemical Composition of Sample Designated, percent			
	A	B	C	D
Silicon	0.21	0.22	0.27	0.31
Manganese	1.72	1.83	1.81	1.59
Phosphorus	0.026	0.008	0.032	0.022
Sulfur	0.019	0.035	0.020	0.031
Carbon (total)	0.34	0.22	0.33	0.24
Nickel	0.04	0.12	0.04	0.13
Chromium	0.04	0.09	0.03	0.17
Molybdenum	0.01	0.01	0.01	0.02
Copper	0.01	0.09	0.03	0.21
Vanadium	0.006	0.061	0.005	0.091
Aluminum	0.029	0.027	0.021	0.009
Nitrogen	0.008	0.012	0.008	0.004
Niobium	<0.01	<0.01	<0.01	<0.01

Charpy Impact Tests

Charpy V-notch impact tests were conducted on flash-weld and base-metal specimens from each of the four samples. As called for in the *Interim Specification*, all of the specimens were taken at the same radial distance from the center of the chain link. The V-notches were located along the radius on all specimens. The flash-weld specimens were first etched to locate the weld and the notch was then made in the center of the weld. All specimens were machined and tested in accordance with the procedures outlined in ASTM A370; Type A V-notches were used.

The six flash-weld specimens from each of the four samples (A, B, C, and D) were tested over a temperature range from 0 to 120 F with two specimens from each sample being tested at 32 F to determine the shape of the transition curve. Eleven base-metal specimens were taken from each of the four samples. Specimens from Samples B, C, and D were tested at -60 to +60 F; specimens from Sample A were tested at from -30 to +90 F; and three specimens from each of the four samples were tested at 32 F to determine the shape of the impact curve. All specimens, together with their test temperatures, are shown in Figure 2. Data for the tests are presented in Table 6. Plots of the transition curves for the flash-welded specimens are shown in Figure 3 through 6; those for the base-metal specimens are shown in Figures 7 through 10. For the flash welds the Charpy impact energies at 32 F averaged 45, 52, 65, and 26 ft-lb for the flash-weld specimens from Samples A, B, C, and D, respectively, and 53, 122, 107, and 127 ft-lb for the base-metal specimens from Samples A, B, C, and D, respectively. The Charpy impact-energy requirement at 32 F given in the *Interim Specification* is 36 ft-lb for the flash weld and 43 ft-lb for the base metal. Thus, flash-weld Sample D did not meet the requirement at 32 F.

Dynamic Tear Tests

Dynamic tear tests were conducted on flash-welded and base-metal samples in an attempt to obtain less variable impact data than are usually obtained in Charpy-type tests. However, the dynamic tear test data showed even greater variability. It is believed this was due to a relationship among specimen size, notch radius, and flash-weld size. The flash weld is only a few thousandths of an inch thick while the notch radii of Charpy and dynamic tear specimens are, respectively, ten and one thousandth inch, therefore, it is more difficult for the testing technician to precisely locate the dynamic tear notch at the flash weld. In addition, it is difficult to obtain specimens with the flash weld perfectly perpendicular to the specimen length. This results in a greater variation of actual flash-weld location from desired location in dynamic tear specimens as opposed to Charpy specimens, as the dynamic tear specimens are markedly larger in cross section.

Results of the dynamic tear tests for both the flash-welded and base-metal specimens are given in Table 7. The transition curves are shown in

TABLE 6. CHARPY IMPACT TEST DATA

Specimen	Test Temperature	Energy, ft-lb	Shear Area, percent
	Flash-Weld Specimens		
A	0	39.5	45
	+32	46.0	51
	+32	44.0	48
	+60	63.5	78
	+90	72.0	92
	+120	85.0	100
B	0	49.0	43
	+32	52.5	71
	+32	50.5	43
	+60	58.0	71
	+90	78.5	100
	+120	139.5	100
C	0	27.5	21
	+32	90.5	69
	+32	40.0	50
	+60	66.0	73
	+90	50.5	87
	+120	123.5	100
D	0	16.0	27
	+32	37.0	56
	+32	14.5	32
	+60	27.0	33
	+90	45.0	50
	+120	33.5	60
	Base-Metal Specimens		
A	-30	27.5	29
	-30	26.5	29
	0	41.5	43
	0	40.5	37
	+32	58.0	49
	+32	42.5	33
	+32	57.0	52
	+60	71.5	76
	+60	58.5	56
	+90	89.0	92
	+90	83.0	87

TABLE 6. (Continued)

Specimen	Test Temperature	Energy, ft-lb	Shear Area, percent
	Base-Metal Specimens (Continued)		
B	-60	95.0	53
	-60	34.5	14
	-30	107.0	61
	-30	44.0	25
	0	132.0	100
	0	95.0	66
	+32	101.0	70
	+32	138.0	100
	+32	126.5	100
	+60	115.5	100
	+60	111.5	100
C	-60	26.0	9
	-60	20.5	9
	-30	36.0	29
	-30	32.5	29
	0	90.0	60
	0	67.5	50
	+32	123.0	100
	+32	88.5	69
	+32	110.0	73
	+60	120.0	100
	+60	119.5	100
D	-60	87.5	52
	-60	85.0	46
	-30	41.0	29
	-30	23.0	25
	0	114.0	74
	0	99.0	61
	+32	137.0	100
	+32	128.0	100
	+32	116.0	82
	+60	133.5	100
	+60	124.5	100

TABLE 7. DYNAMIC TEAR TEST DATA

Sample	Test Temperature, F	Angle, deg		Energy	Shear Area	
		Release	Final		℄	Average
		Flash-Weld Specimens				
A	+32	140	137.2	275	25	27
	+60	"	137.0	295	50	51
	+90	"	134.0	607	100	65
	+120	"	132.2	802	100	90
B	+32	140	138.8	116	22	27
	+60	"	137.2	275	47	45
	+90	"	135.0	501	50	61
	+120	"	134.0	606	52	70
C	+32	140	137.0	294	12	15
	+60	"	132.0	824	25	37
	+90	"	136.1	387	35	59
	+120	"	134.0	606	100	100
D	+32	140	139.0	96	12	15
	+60	"	139.2	77	10	12
	+90	"	139.8	19	15	17
	+120	"	135.0	501	100	69
		Base-Metal Specimens				
A	0	140	139.2	77	15	15
	+32	"	138.5	145	15	17
	+60	"	135.0	501	50	57
	+60	"	137.0	295	32	37
	+90	"	131.6	868	100	70
	+90	"	132.5	769	100	69
	+120	"	130.0	1047	100	100
	+120	"	130.0	1047	100	100
B	0	140	138.9	106	17	17
	+32	"	135.0	501	37	57
	+32	"	136.5	345	40	47
	+60	"	133.2	693	50	62
	+60	"	135.5	449	25	47
	+90	"	119.0	2390	100	100
	+90	"	125.6	1563	100	77
	+120	"	121.5	2070	100	100

TABLE 7. DYNAMIC TEAR TEST DATA (Continued)

Sample	Test Temperature, F	Angle, deg Release	Angle, deg Final	Energy	Shear Area ℄	Shear Area Average
			Base-Metal Specimens (Continued)			
C	0	140	139.0	96	10	12
	+32	"	137.8	215	32	32
	+60	"	130.0	1048	18	47
	+60	"	131.1	924	18	45
	+90	"	121.8	2032	100	100
	+90	"	129.5	1105	35	62
	+120	"	124.5	1697	100	100
	-30	"	139.6	38	10	10
D	0	140	133.0	194	35	37
	+32	"	137.5	244	31	33
	+60	"	137.5	245	33	35
	+60	"	137.8	215	37	33
	+90	"	133.0	714	50	62
	+90	"	137.5	245	35	27
	+120	"	127.0	1396	100	100
	-30	"	138.5	145	17	17

Figures 11 through 14 and 15 through 18 for the flash-welded and base-metal specimens, respectively. Figures 19 and 20 show dynamic tear fracture surfaces for the flash-welded and base-metal specimens, respectively. It can be noted in Figure 20 that several of the base-metal specimens from Samples B and C did not fracture completely at the higher temperatures in the dynamic tear test. This is an indication of the relatively high toughness of the material and is also an indication of the tendency of the material to split in the axial direction of the chain link. (This latter indication is not believed to be of any significance in terms of the performance of the chain link.)

Based on the point where the energy curve first starts to increase, or the lower knee of the energy curve from the dynamic tear test, it is estimated that the nil ductility transition (NDT) temperature of the flash weld is +60 F for Samples C and D and +32 F for Samples A and B. The transition curves for the dynamic tear tests indicate that the base metal has a lower transition temperature than the weld metal. The NDT temperatures estimated from the base-metal dynamic tear tests are 0 F for Samples B and C, +60 F for Sample D, and +32 F for Sample A.

The significance of the results can be assessed using Figure 21. The diagram indicates the flaw-size tolerance of a structure as a function of the applied stress and temperature relative to the NDT temperature. At temperatures below the NDT, the flaw-size tolerance is constant and at its minimum value for a given applied stress level. The higher the applied stress, the smaller the flaw that can be tolerated by the material. At temperatures above the NDT, the flaw sizes increase until at temperatures of NDT +60 F the material can tolerate yield-level stresses even in the presence of large flaws.

The critical region of the link in terms of the fracture assessment is the flash-weld region. This region has an NDT temperature that is equal to or higher than that of the base metal of the link and, also, there is a possibility that the weld contains flaws that are in a plane perpendicular to the stress field which is the most critical orientation. Based on the estimated weld NDT, the temperature above which yield level stresses can be tolerated with reasonable certainty is 120 F for Samples C and D. Similarly, for Links A and B this temperature is 90 F. At temperatures down to 60 F below these temperatures the flaw tolerance of the links will gradually decrease. At temperatures below the NDT, the diagram indicates that there is no further decrease in the flaw size tolerance. Since the diagram is basically for dynamic load application (which shifts the flaw-size curves to a higher temperature by 30 to 60 F) it is highly probable that the chain will give adequate service performance down to the NDT temperatures since it is unlikely that the loading rate in service will approach a dynamic rate.

The information obtained during the dynamic tear tests reinforces the importance of two *Interim Specification* requirements: that all chain be proof tested at a high load and that every flash weld be inspected using conventional nondestructive techniques. These requirements insure the absence of large flaws which would reduce the chain's impact-energy absorption capabilities at low temperatures.

Chain-Link Surface Examination and Physical Measurement

One link from each sample set was used for a surface examination and physical measurements. The surface examination was made for burrs, rough edges, cracks, dents, cuts, or mill defects. No major surface defects over 1/16 inch high or deep were found. Sample A had one small dent, Sample B had one small area of rough edges appearing to be an as-rolled surface, Sample C had two small dents and several gouges, Sample D showed platen marks near the flash weld.

All physical measurements were as anticipated for the respective sizes of chain, with the exception of Sample A. The overall length of Sample A was 1/8 in. longer than required by the *Interim Specification.*

The visual examination did show one case of poor workmanship. The stud weld on Sample C had a poor stop and start pattern, weld spatter was quite evident, and the weld fillet was shallow. All of the Sample C links were similar; however, it should be noted that poor stud welds did not seem to affect the overall strength of Sample C.

Surface Inspection of Flash Welds

Two methods - dye penetrant and magnetic particle - were employed for inspecting the surface area near the flash weld of one chain link from each sample.

In the dye-penetrant inspection, the fluorescent post-emulsification method was used. The procedure was as follows: The surface of each chain link was cleaned with SKC-NF cleaner/remover and Z-L-32 penetrant was applied. After a penetration time of 10 minutes, the links were post-emulsified and water washed. The penetrant was held by surface roughness and produced a very high background level on all links. In some areas, the background level was so high that possible crack indications could have not been distinguished. This inspection method would produce much better results if the tested surface area were smoother. None of the chain samples that were received had surfaces smooth enough to allow proper evaluation using this technique.

The magnetic-particle inspection was not affected as much by the relatively rough chain surface. Testing was performed using an ARQ-966 Magnaflux unit with a five-turn coil at 3100 amp (15,500-amp turns). The wet continuous method was employed using fluorescent particles. Samples A, B, and C showed minute signs of machining cracks, but otherwise no defects. Sample D showed no defects, however, when the stud was cut from the link a deep corrosion pit was found under the stud location approximately 3/8 in. deep by 3/4 in. long. It should also be noted that the Sample D stud had four protuberances at each end. These protuberances are intended to prevent the studs from moving or falling out, however, it appeared in this link that the protuberances might have caused fractural impressions resulting in crevice corrosion.

Ultrasonic Inspection of Flash Welds

To conduct the ultrasonic inspection a 10-in.-long bar was cut from one link of each sample at the flash weld. The flash weld was located 5 in. from either end of the bar and was perpendicular to the longitudinal axis.

Each specimen was inspected using an ultrasonic longitudinal-wave technique with the beam directed into the end of the specimen. Sample C was also tested using the ultrasonic shear-wave technique in which the ultrasonic beam enters the specimen from the side at a 45-degree angle, and a 45-degree transducer head is required. This technique, with some additional development, might be used in actual production testing since it does not require the flash weld to be cut from the link. The results of the longitudinal-wave and the shear-wave tests on Sample C correlated.

In all of the tests, there were ultrasonic indications at the flash-weld area. In fact, flash-welded chain will almost always show ultrasonic indications in the flash-weld area. Experienced chain metallurgists have cut apart numerous links which showed ultrasonic indications in an attempt to find their cause. Usually none has been found. Since ultrasonic inspection techniques using present-state-of-the-art technology give false indications of flaws, and could result in the rejection of satisfactory chain, it is recommended that this technique not be an *Interim Specification* requirement. The results of the ultrasonic inspection of each sample are given below.

Sample A

A sketch of the inspected area is shown in Figure 22. At Location 1 there were a large number of indications of various amplitudes. Figure 23 shows the ultrasonic indication obtained at Location 1. Location 2 gave no signals of over 5 percent amplitude. The size of the area at Location 1 was estimated to be 1 by 1 in., which was the largest area giving an ultrasonic indication of any of the chain samples. The inspected piece was later cut up and subjected to dynamic tear testing. No defects were found and high impact energies were obtained.

Sample B

The strongest amplitude, about 29 percent of maximum over an area of approximately 3/8 by 1/2 in., was recorded at Location 1 (see Figures 24 and 25). Locations 2, 3, and 4 gave indications of approximately 5 percent. The estimated size of the Location 2 indication was 1/8 by 1/8 in. and the indications at Locations 3 and 4 were about 1/16 by 1/16 in.

Sample C

Location 1 (Figure 26) showed a large number of indications. Position A in Location 1 (estimated size about 1/2 by 1/2 in.) was the largest. Figure 27 shows the oscilloscope indication. Location 2 showed indications of 5 to 8 percent or less.

This specimen was also examined using the ultrasonic shear-wave technique in which the ultrasonic transducer (search unit) is placed on the chain link surface at a distance from the weld region. The ultrasonic beam enters the steel at 45 degrees to the surface, thus permitting examination of the welded region.

To perform the shear-wave test, a reference flaw was made on the surface. A sawcut 1/8 in. deep was made across the link sample. The ultrasonic indication from the sawcut is shown in Figure 28. The ultrasonic indication of the suspected flaw found at Location 1 is shown in Figure 29.

Sample D

Figure 30 shows a sketch of the inspected area. The strongest indication was obtained at Position A of Location 1 (estimated size 3/4 by 1/2 in.). No other indications of over 5 percent amplitude were recorded. Figure 31 shows the oscilloscope indication.

Metallographic Examination

Four chain links, one each from Samples A, B, C, and D were subjected to metallographic examination as specified in Paragraphs 4.5.5 and 4.5.6 of the *Interim Specification*. In addition, the microstructural variations from the outside surface to the center in each link were evaluated to aid in selecting the location from which to obtain dynamic-tear-test specimens. The results of these examinations are described below.

Examination of Link Interior

The *Interim Specification* requirements for this examination are:

4.5.5 Interior Examination of Link. A single link shall be cut in half on a plane parallel with both the long and short axes, etched, and examined.

3.7 Link Interior. Links shall be free from harmful defects such as laps, seams, pipes, cracks, scale, fins, porosity, hard spots, nonmetallic inclusions, and segregations when examined in accordance with 4.5.5

Partial sections were taken from a link of each chain sample in accordance with Paragraph 4.5.5. Those were ground, etched in a solution of

50 percent hydrochloric acid (HCl) in water at 150 F, and then examined. Photomacrographs of the four sections, from Samples A, B, C, and D, are shown in Figures 32 through 35, respectively.

Visual examination of the macroetched sections revealed that those from links of Samples A, B, and C contained no harmful defects such as those cited in Paragraph 3.7 on the previous page. Neither were there any nonmetallic inclusions, and the segregation observed was limited to the microstructural banding normally associated with wrought bar stock. The section from the Sample D link contained small cracks near the inner end of the flash-weld fusion zone, that is, adjacent to the pressed-in stud. Those cracks are visible in Figure 33 and are shown actual size in Figure 36.

All of the links showed variations in structure across the macroetched sections examined; the section from Sample B showed the least variation. The banding present in the structure of the links results from segregation of alloying elements during freezing of the steel ingot. After hot working to bar or plate, that segregation shows up as bands parallel with the primary work direction. The degree of banding observed in the sections from the links examined was not considered to be detrimental to their performance.

Examination of the Sample C section revealed that the fillet weld between the stud and the link was of poor quality. As is shown in Figure 37, the weld beads contained cracks, and regions of lack of fusion. Also, the contour of the weld bead did not conform to the requirements shown in Figure 1 of the *Interim Specification*.

Microstructural Examination of Fusion Zone

The *Interim Specification* requirements for the examination of the fusion-zone microstructure are:

> 4.5.6 Examination of Fusion Zone Microstructure. A sample of material shall be taken from or near the center of the flash-weld zone and sawed in two at the weld. A half-inch cube is considered the minimum size for a microstructure inspection. The fusion zone shall be located by acid etching and a microstructural inspection shall be performed.

3.8 Fusion Zone Microstructure. The fusion zone of the flash weld area shall have fine grain structure and be free from Widmanstätten structure of any form when examined in accordance with 4.5.6.

The statement in Paragraph 4.5.6 regarding the location of the section to be examined is not clear. It could be interpreted that the section should be cut in two along the weld line. This paragraph will be revised and clarified. (See Recommendation No. 2 at end of report for suggested revision.)

Sections parallel with the length of the links traversing the flash-weld fusion zones and extending inward from the outside surface to the center of the links were taken and prepared for examination.

The fusion zones in links from Samples A and B were judged to be acceptable based upon the criteria given in Paragraph 3.8 of the *Interim Specification*. However, the fusion zone in the link from Sample C contained a significant amount of Widmanstätten structure, as is shown in Figure 38, and the structure was relatively coarse. The fusion zone in the link from Sample D had the desired fine ferrite grain size and contained no Widmanstätten structure. However, the heat-affected zone adjacent to the weld line had the remnants of a coarse prior austenitic structure outlined by a dark etching (higher carbon) phase as is shown in Figure 39. These dark etching regions generally contained clusters of sulfide inclusions. The sulfides were agglomerated and in some areas appeared to outline the coarse prior austenite grain boundaries. The appearance of the microstructure and the agglomerated sulfide inclusions in the heat-affected zone suggests that this material was overheated during welding which resulted in incipient melting. Subsequent heat treating of the links resulted in the relatively fine ferrite grain size present in that region. The weld line in the section from this link also contained some microporosity. The pores, or voids, were small and isolated.

Microstructural Variations in the Base Steels

The microstructural variations from the outside surface to the center of links from each sample were evaluated. The sections examined were about 1 in. away from the weld fusion zone. The microstructures observed in each lot of steel are described on the following page.

Link from Sample A. The microstructural variations from the outside surface to the center of the link from Sample A are illustrated in Figure 40. Near the outside surface, the microstructure consisted of a mixture of black ferrite and pearlite with little banding. As the distance from the outside surface increase, the banding of the microstructure became more apparent.

Link from Sample B. The variation in microstructure from the outside surface to the center of the link from Sample B is illustrated in Figure 41. Near the outside surface, the microstructure consisted of a mixture of ferrite and pearlite with little evidence of banding. As the distance from the outside surface increased, the degree of banding increased. In addition, at about the midradius position and toward the center of the link, there were bands with a bainitic structure. The presence of the bainitic structure indicates that the steel in those bands had higher hardenability, presumably because of higher carbon and manganese contents, than that of the adjacent material.

Link from Sample C. The variation in microstructure from the outside surface to the center of this link is illustrated in Figure 42. Near the outside surface, the microstructure consisted of tempered martensite. As the distance from the surface increased, the amounts of higher temperature transformation products (ferrite and pearlite) increased because of the lower cooling rates at those locations. Near the center of the link, the microstructure was banded and consisted of a mixture of ferrite and pearlite.

Since the hardenability of the steel is such that it would not be expected to air harden in these large sections at the cooling rates normally expected from a normalizing treatment, the martensitic structure observed in the link from the chain sample indicates that the steel was austenitized, quenched, and tempered after welding. Thus, it would not meet the requirement of the *Interim Specification* for the steel to be normalized after welding (Paragraph 3.13.5).

Link from Sample D. The microstructural variations from the outside surface to the center of the link from Sample D are illustrated in Figure 43. The microstructure near the outside surface was fine grained and consisted of a mixture of ferrite and pearlite; there was little banding evident in that region.

As the distance from the outside surface increased, the amount of microstructural banding increased. The carbides in the microstructure of this steel were partially spheroidized, a condition that indicates that the steel had been tempered after normalizing.

CONCLUSIONS

On the basis of this investigation, the follow conclusions have been drawn:

(1) The developed guidelines and procedures for manufacturing 4-3/4-inch flash-welded anchor chain, as outlined in the *Interim Specification* (see Appendix A), are an accurate representation of the present state of the art in this technical area.

(2) Flash-welded 4-3/4-in. anchor chain can be manufactured by existing commercial interests in accordance with the *Interim Specification*, although certain changes (indicated in the "Recommendations" section which follows) should be made in the *Interim Specification*.

(3) At present shear-wave ultrasonic testing techniques are not an effective quality-assurance tool for use in testing chain flash welds, since ultrasonic indications are often experienced when, in fact, no defects are actually present.

(4) It would appear that flash-welded chains manufactured with studs having end protuberances designed to grip the chain link are more susceptible to corrosion and cracking in the link beneath the stud.

RECOMMENDATIONS

The following recommendations are made on the basis of the above conclusions:

(1) It is recommended that the *Interim Specification* be modified to delete the requirements in Paragraphs 3.6, 4.5.4, and 4.5.4.1 concerning ultrasonic testing of the flash-weld area.

(2) It is recommended that Paragraph 4.5.6 of the *Interim Specification* concerning taking the fusion-zone microstructure specimen be clarified to indicate more clearly the area from which the specimen should be taken. The first two sentences of Paragraph 4.5.6 should be changed to read:

"A sample of material shall be taken parallel with the length of the link, traversing the flash-weld fusion zone, and extending inward from the outside surface to the center of the link."

(3) Since the impact-energy testing conducted during this program indicated a relatively high nil ductility transformation (NDT) temperature for the flash-welded portion of the chain, it is recommended that tests be conducted to determine the actual degradation in performance of flash-welded chain at lower temperatures.

(4) Although both longitudinal- and shear-wave ultrasonic testing techniques resulted in false indications of defects, the latter technique might be developed to provide effective quality-assurance information during the manufacture of flash-welded chain. It is recommended that calibration specimens, threshold adjustment, and inspection procedures be investigated for making the shear-wave ultrasonic technique applicable to flash-welded chain.

(5) Use of 4-3/4-in. flash-welded anchor chain will result in considerable cost savings to the U. S. Navy. It is recommended that manufacturing procedures and guidelines be developed to aid the Navy in the selection and procurement of all sizes and grades of flash-welded anchor chain. In addition, it is recommended that an evaluation program, similar to that for the 4-3/4-inch chain, be conducted for all sizes and grades of flash-welded anchor chain in order to assure that the cost-saving results in chain of satisfactory quality for naval applications.

APPENDIX A

INTERIM SPECIFICATION: CHAIN, 4-3/4-INCH (120.5 MM) STUD LINK, ANCHOR, STEEL, FLASH-BUTT-WELDED

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INTERIM SPECIFICATION: CHAIN, 4-3/4-INCH (120.5 MM) STUD LINK, ANCHOR, STEEL, FLASH-BUTT-WELDED

1. SCOPE

1.1 Scope. This specification covers 4-3/4 in. (120.5 mm) alloy steel, flash butt welded, stud link anchor chain for use on ships.

1.2 Classification. Chain shall be of the standard classification.

2. APPLICABLE DOCUMENTS

2.1 Government Documents. The following documents form a part of this specification. Unless otherwise indicated, the issue in effect on date of invitation for bids shall apply.

SPECIFICATIONS

MIL-I-45208 - General Specification for Inspection Requirements
MIL-P-24380 - Paint, Anchor Chain, Solvent Type, Gloss Black

STANDARDS

MIL-STD-129 - Marking for Shipment and Storage
MIL-STD-248 - Qualification Tests for Welders
MIL-STD-271 - Non-Destructive Testing Requirements for Metals

(Copies of specifications, standards, drawings, and publications required by contractors in connection with specific procurement functions should be obtained from the procuring agency or as directed by the contracting officer.)

2.2 Non-Government Documents. The following documents form a part of this specification. Unless otherwise indicated, the issue in effect on date of invitation for bids shall apply.

STANDARDS

Annual Book of ASTM Standards
Part 1, Steel Piping, Tubing, and Fittings

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.)

OTHER PUBLICATIONS

Official Classification Committee
Uniform Freight Classification Rules

(Application for copies should be addressed to the Official Classification Committee, One Park Avenue at 33rd Street, New York 16, New York.)

3. REQUIREMENTS

3.1 First Article Inspection. Before actual production work is undertaken, the contractor shall demonstrate that a uniform and acceptable product can be produced by the manufacturing procedure proposed for use by (1) conducting and submitting to the agency involved the results of the First Article Examinations and Tests, as per 4.3 and (2) submitting to the agency involved a First Article Engineering Report as per 4.3.1.

3.2 Material. All steel used in the manufacture of the chain shall have fine-grain structure and be special quality grade made by either the open hearth, basic oxygen, or electric furnace process. The same material shall be used in making the links and the studs . Studs shall be either drop or press forged. Bar stock used in the manufacture of links shall be 4-3/4 in. (120.5 mm) diameter with a diametral tolerance of 0 to plus 3/32 inch (0 to plus 2.4 mm).

3.2.1 Material Chemical Composition. The chemical composition of the steel shall be determined at the steel mill for each heat of steel. A certified copy of the mill sheet listing the chemical composition for each heat shall be provided as per 4.1.2(b). The chemical composition of the steel used in the manufacture of links for First Article testing shall be verified by a chemical or spectrographic analysis conducted by the chain manufacturer. A certified copy of the results of the analysis listing the chemical composition shall be provided in the First Article Engineering Report 4.3.1.

3.2.2 Material Mechanical Properties. The 4-3/4 in. (120.5 mm) bar stock used in manufacture of the chain, after receiving identical heat treatment as the chain, as per 3.13.5, shall possess the mechanical properties specified in Table I, when tested as per 4.6.5 and 4.6.6.

TABLE I. BAR STOCK MECHANICAL PROPERTIES

Property	Value
Ultimate strength minimum	99,600 psi (7000 kg/cm^2)
Elongation minimum, specimen gage length = 4 x specimen diameter	15.5 percent
Reduction in area minimum	40 percent
Impact, average for three specimens at 32 F (0 C), minimum	43 ft lb (6 mkg)

3.2.3 Material Certification. The chemical composition shall be determined at the steel mill on samples taken from each ladle of each heat. A certified copy of the mill sheet listing the chemical composition of each heat shall be provided to the government inspector.

3.3 Link Dimensions. Link dimensions and tolerances are shown in Figure 1. Dimensions in Figure 1 shall be checked when obvious dimensional discrepancies occur.

3.4 Link Surface. Burrs and rough edges shall be ground flat. Links shall be free from mill defects, surface cracks, dents, or cuts when examined in accordance with 4.5.2.

3.5 Flash Weld Surface. Link surface at the flash weld shall be free of cracks or poor welding when examined in accordance with 4.5.3. A maximum diameter overage of 3/32 inch (2.4 mm) is permitted after the flash weld is deburred.

3.6 Flash Weld Interior. The flash weld shall be free of defects causing ultrasonic back reflections equal to or greater than the calibration standard, as per 4.5.4, when tested in accordance with 4.5.4.

3.7 Link Interior. Links shall be free from harmful defects such as laps, seams, pipes, cracks, scale, fins, porosity, hard spots, non-metallic inclusions, and segregations when examined in accordance with 4.5.5.

3.8 Fusion Zone Microstructure. The fusion zone of the flash weld area shall have fine grain structure and be free from Widmanstatten structure of any form when examined in accordance with 4.5.6.

3.9 Chain Length and Weight. Unless otherwise specified in the contract or order, the chain submitted to the government shall be in 90 foot (27.4 m) shots, weighing 20,500 pounds (9300 kg) plus or minus 5 percent. The overall length of any six consecutive links, measured from every third link shall be within the limits specified in Table II. Measurements shall be made after proof testing and while 10 percent of the proof load remains. Alternate measuring methods may be approved by the agency concerned.

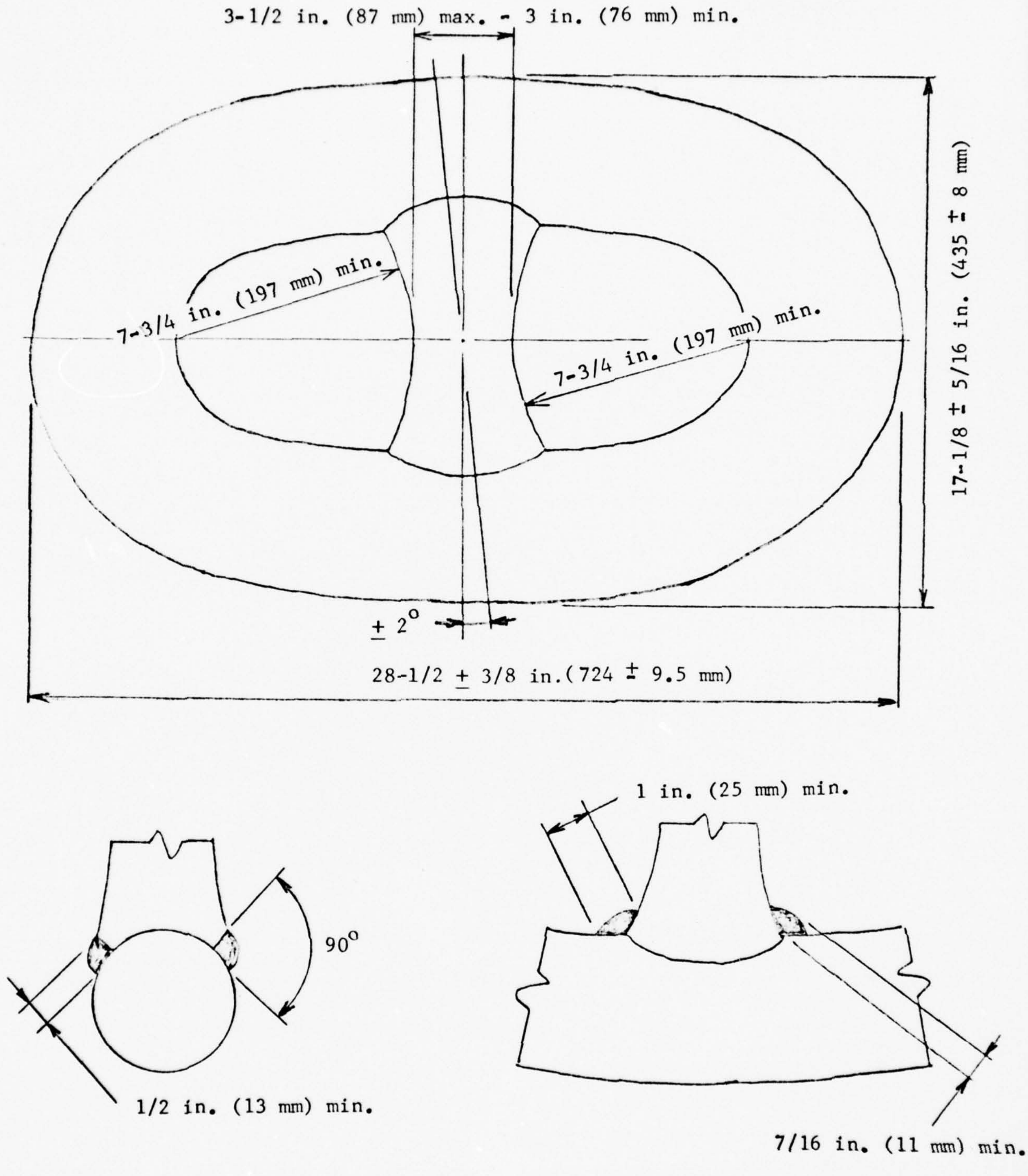


FIGURE 1. BASIC LINK AND STUD WELDMENT DIMENSIONS

TABLE II. CHAIN LENGTH AND WEIGHT

Number of Links per 90-Foot (27.4-m) Shot	Weight Plus or Minus 5 Percent	Length of Six Consecutive Links		
		Minimum	Nominal	Maximum
57	20,500 lb	121 29/32 in.	122 1/2 in.	124 9/32 in.
	9300 kg	3096 mm	3111 mm	3157 mm

3.9.1 Approval of alternate measuring methods, as per 3.9, shall be by the Naval Ship Engineering Center for chain intended for use aboard U.S. Navy ships.

3.10 Chain Breaking Load. When tested as per 4.6.3 the chain shall be capable of withstanding the breaking load specified in Table III and not break in the flash weld or flash weld heat affected zone. When tested as per 4.6.2, the chain shall not break in the flash weld area or flash weld heat affected zone.

3.11 Chain Proof Load. When tested as per 4.6.4 at the load designated in Table III, the chain shall withstand the proof load without fracture, tendency to open at the weld, or stretching beyond the tolerance shown in Table II.

3.12 Chain Mechanical Properties. One tensile specimen taken from heat-treated chain and tested as per 4.6.5, and six impact specimens taken from heat-treated chain and tested as per 4.6.6 shall possess the mechanical properties shown in Table III. In addition, the angle of bend shall be not less than 120 degrees before fracture for one bend test specimen taken from heat-treated chain and tested as per 4.6.7.

TABLE III. CHAIN PERFORMANCE

Test	Value
Chain breaking load	2,550,000 lb (1,156,680 kg) min.
Chain proof load	1,700,000 lb (771,120 kg) min.
Specimen ultimate strength	99,600 psi (7000 kg/cm^2) min.
Specimen reduction in area	40 percent min.
Specimen impact, unwelded portion of link, average for three specimens at 32 F (0 C) minimum	43 ft lb (6 mkg) min.
Specimen impact, flash welded zone of link, average for three specimens at 32 F (0 C) minimum	36 ft lb (5 mkg) min.

3.13 Standards of Manufacture. Manufacture of chain shall include the following processes and equipments:

3.13.1 Heating and Bending. Bars shall be electrically heated. Batch-type furnace heating is not permitted. In order to prevent undue scaling or flaking due to excessive heating, the preheating phase for bending bar stock shall be controlled. The controller shall be checked for accuracy and functional operation at least once every 24 hours.

3.13.2 Flash Butt Welding. The bent bar shall be electrically flash welded with a maximum longitudinal bar end misalignment of 3/32 in. (2.4 mm). Bar end misalignment shall be frequently (no less than once in every 10 links) and systematically checked.

3.13.2.1 The following welding parameters shall be controlled during welding of each link within the limits established in the First Article Engineering Report (4.3.1):

(a) Platen motion
(b) Current as a function of time
(c) Hydraulic pressure.

All excessive flash weld material shall be removed to a uniform surface consistency over the entire link.

3.13.3 Stud Placement. After the stud is inserted into the oval link and pressed, the stud ends shall match the link surface such that there is an even and minimal gap between the stud and the link. The stud shall be positioned as shown in Figure 1.

3.13.4 Stud Welding. The stud shall be completely welded circumferentially on the end opposite the flash weld using hydrogen controlled electrodes (xx18) or GMA filler metals. The weld shall be of the size shown in Figure 1 and have full penetration with no undercutting when examined in accordance with 4.5.5. Welders shall be qualified in accordance with MIL-STD-248.

3.13.5 Heat Treating. Chain shall be normalized above the transformation temperature at a combination of temperature and time to produce a fine grain structure throughout the link. Heat treatment shall be performed after all welding has been completed and prior to testing and inspection. Chain shall not be run through the normalizing furnace more than twice. Temperature and chain speed shall be controlled and recorded.

3.13.6 Marking. The stud of each link shall be permanently marked, in raised or indented letters, with the letters "USN", and wire diameter of the links on one side, and with the brand name or trade name of the manufacturer on the other side. The end links of each shot shall be stamped with serial numbers assigned by the Government inspector. All markings shall be a minimum of 3/4 in. (19 mm) in height and raised or indented a minimum of 1/8 in (3 mm).

3.13.7 Finishing. After tumbling or grit blasting to remove scale, shots of chain shall be covered with one coat of gloss black anchor chain paint conforming to Specification MIL-P-24380. Preheating of the chain to not more than 250 F to accelerate drying may be used. The finish shall be applied after it has been found that the chain otherwise complies with the requirements of this specification.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection. Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract or order, the supplier may use his own or any other facilities suitable for the performance of the inspection requirements specified herein, unless disapproved by the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.1.1 Inspection System. The supplier shall provide and maintain an inspection system acceptable to the Government for supplies and services covered by this specification. The inspection system shall be in accordance with MIL-I-45208.

4.1.2 Certification. Certification documentation for each shot of chain shall be provided as follows to the consignee and the procuring activity, or as otherwise specified:

(a) Serial number assigned by the government inspector
(b) Material chemical composition
(c) Results of examinations 4.5.1, 4.5.2, 4.5.3, and 4.5.4
(d) Results of tests 4.6.2 (as applicable), 4.6.3, 4.6.4, 4.6.5 (as applicable), 4.6.6 (as applicable), 4.6.8 and 4.6.9
(e) Statement: "Records are available covering heat-treating parameters as per 3.13.5.

4.2 Classification of Inspections. The inspection requirements specified herein are classified as follows:

(a) First article inspection
(b) Quality conformance inspection.

The agenda of examinations and tests for each classification is given in Table IV.

TABLE IV. AGENDA OF EXAMINATION AND TESTS

Examination	First Article Rejection Criteria	Quality Conformance Rejection Criteria	Applicable Requirement	Applicable Method
Chain Length	4.7.1	4.7.1	3.9	4.5.1
Link Surface	4.7.2	4.7.2	3.4	4.5.2
Flash Weld Surface	4.7.3	4.7.3	3.5	4.5.3
Flash Weld Interior	4.7.4	4.7.4	3.6	4.5.4
Link Interior	4.7.2	N.R.*	3.7	4.5.5
Fusion Zone Microstructure	4.7.2	N.R.	3.8	4.5.6
Test				
Chemical Composition	4.7.5	N.R.	3.2.1	4.6.1
Destructive Test	4.7.6	4.7.6	3.10	4.6.2
Chain Breaking Load	4.7.7	4.7.7	3.10	4.6.3
Chain Proof Load	4.7.8	4.7.8	3.11	4.6.4
Chain Specimen Tensile	4.7.9	4.7.9	3.12	4.6.5
Chain Specimen Impact	4.7.10	4.7.10	3.12	4.6.6
Chain Specimen Bend	4.7.11	N.R.	3.12	4.6.7
Bar Stock Tensile	4.7.9	4.7.9	3.2.2	4.6.8
Bar Stock Impact	4.7.10	4.7.10	3.2.2	4.6.9

* Not required for Quality Conformance Inspection.

4.3 First Article Inspection. The contractor shall submit to the agency involved results of the First Article Inspection Examinations and Tests listed in Table IV. These examinations and tests shall be conducted using the First Article Inspection Samples listed in 4.3.2. In addition, the manufacturer shall submit to the agency involved a First Article Engineering Report, as per 4.3.1, detailing information concerning manufacturing capability. In the event that all First Article Inspection Samples meet the requirements heretofore specified and the First Article Engineering Report demonstrates to the satisfaction of the agency concerned that uniform and acceptable chain can be manufactured, permission to commence actual production work may be granted by the agency concerned.

4.3.1 First Article Engineering Report. Prior to manufacture of the First Article Inspection Samples the manufacturer shall submit to the agency concerned an engineering report containing the following information. It is understood that the information contained in this report may be considered proprietary to the manufacturer and will be treated as such by the agency concerned.

(a) Name and address of the manufacturing plant and head office
(b) A brief statement of background indicating whether the manufacturing plant is new or long established with particular reference to the relevant manufacturing processes
(c) Total production capacity and chain-size capability of the manufacturing plant
(d) A complete description of all relevant manufacturing procedures and facilities, including each fabrication and inspection operation.

4.3.1.1 The report shall demonstrate to the agency involved that the manufacturer is capable of producing uniform and acceptable chain. If in the opinion of the agency concerned the facility is not capable of making uniform and acceptable chain, the contract or order may be cancelled without penalty to the Government.

4.3.1.2 Permission to commence actual production work, as per 4.3, and review and approval of the First Article Engineering Report, as per 4.3.1 and 4.3.1.1, shall be by the Naval Ship Engineering Center for all chain intended for use aboard U.S. Navy ships.

4.3.2 First Article Inspection Samples. In accordance with the proposed manufacturing process the following set of samples shall be prepared for the First Article Inspection Examinations and Tests listed in Table IV. Chain links shall be tumbled or grit blasted.

4.3.2.1 One seven-link section for examination of chain length 4.5.1, link surface examination 4.5.2, surface examination of flash weld 4.5.3, interior examination of flash weld 4.5.4, and chain proof load test 4.6.4.

4.3.2.2 One single link, or two links if required, for verification of chemical composition 4.6.1, chain specimen tensile test 4.6.5, chain specimen impact test 4.6.6, chain specimen bend test 4.6.7, link interior examination 4.5.5, and microstructure examination 4.5.6.

4.3.2.3 One triplet for breaking load test 4.6.3, and destructive test 4.6.2.

4.3.2.4 One 8 to 12 inch (200 to 300 mm) long section of bar stock. The material shall be selected from bar stock of the same melt of steel as the chain links used for First Article Inspection. The section of bar stock shall be used for bar stock mechanical properties tests 4.6.8 and 4.6.9.

4.4 Quality Conformance Inspection. After actual production work has started, bar stock and chain shall be selected, as per 4.4.1, and inspected in accordance with Table IV. In addition, a detailed inspection of the chain by the Government inspector shall be performed, following grit blasting and proof testing. The chain shall be suspended 3 to 4 feet (0.9 to 1.2 m) above the floor to permit careful inspection from all sides. The chain shall be free of paint or other coating which would tend to conceal defects during the testing and inspection.

4.4.1 Sampling for Quality Conformance.

4.4.1.1 Sampling Bar Stock Material. For the purpose of sampling bar stock material, one 8 to 12 in. (200 to 300 mm) long section shall be selected from each melt of steel. The section shall be removed from either end of any bar in the melt. Bar stock mechanical properties tests 4.6.8 and 4.6.9 shall be conducted for each melt of steel.

4.4.1.2 Sampling Finished Chain. For the purpose of sampling finished chain each shot shall be manufactured with four extra links, or 61 links long. A triplet shall then be removed from each shot for the chain breaking load test 4.6.3. The chain breaking load test 4.6.3 shall be conducted for each shot of chain. The destructive test 4.6.2 shall then be conducted on one in every four triplets used for the chain breaking load test. The fourth link that is burned to release the triplets shall be removed in such a manner as to allow specimens to be taken for chain specimen tensile test 4.6.5, and chain specimen impact test 4.6.6. Tests 4.6.5 and 4.6.6 shall be conducted on one in every four shots from each melt of steel. Examination of chain length 4.5.1 and the chain proof load test 4.6.4 shall be conducted on each shot of chain. The surface examination 4.5.2, surface examination of flash weld 4.5.3, and interior examination of flash weld 4.5.4 shall be conducted on each link of each shot.

4.5 Examination Methods.

4.5.1 Chain Length. Chain length measurements shall be made after proof testing and while 10 percent of the proof load remains. The overall length of six lengths shall be measured from every third link of each shot for compliance with Table II.

4.5.2 Surface Examination of Link. After grit blasting and before painting, the link shall be visually examined for burrs, rough edges, cracks, dents, and cuts.

4.5.3 Surface Examination of Flash Weld. Magnetic particle or liquid penetrant inspection means shall be employed to examine the flash-welded area of each link. Procedures and equipment in compliance with MIL-STD-271 shall be used. This examination shall be done after grit blasting and proof testing.

4.5.4 Interior Examination of Flash Weld. Ultrasonic means shall be employed to examine the flash-welded area of each link. Procedures and equipment in compliance with MIL-STD-271 shall be used. On-site calibration standards for chain configurations shall be approved by the agency involved.

4.5.4.1 Approval of calibration standards as per 4.5.4 shall be by the Naval Ship Engineering Center for chain intended for use aboard U.S. Navy ships.

4.5.5 Interior Examination of Link. A single link shall be cut in half on a plane parallel with both the long and short axes, etched, and examined.

4.5.6 Examination of Fusion Zone Microstructure. A sample of material shall be taken from or near the center of the flash-weld zone and sawed in two at the weld. A half-inch cube is considered the minimum size for a microstructure inspection. The fusion zone shall be located by acid etching and a microstructural inspection shall be performed.

4.6 Testing Methods.

4.6.1 Chemical Composition. The material sample shall be selected as per 4.3.2.2 and be analyzed to determine chemical composition. The method of analysis shall be noted in the certification documents as per 3.2.1.

4.6.2. Destructive Test. Samples for destructive tests shall be tested by suitably securing them in a testing machine in such a manner that the chain shall be free from twist, and the holding arrangement shall be such that all stresses bearing on the end links of the section under test are the same as those applied to every link tested. The chain shall be pulled to break and the fracture shall be inspected.

4.6.3 Chain Breaking Load Test. Samples for break tests shall be tested by suitably securing them in a testing machine in such a manner that the chain shall be free from twist, and the holding arrangement shall be such that all stresses bearing on the end links of the section under test are the same as those applied to every link tested. Whenever it is considered that the test equipment would be endangered by a sudden break, it will be considered acceptable if the triplet is loaded to the required breaking strength and maintained at that load for 15 seconds. In any event the test triplet shall be discarded and not used.

4.6.3.1 The break testing machine shall be calibrated within the past 12 months previous to the chain breaking load test.

4.6.4 Chain Proof Load Test. Shots shall be tested by suitably securing them in a testing machine in such a manner that the chain shall be free from twist, and the holding arrangement shall be such that all stresses bearing on the end links of the section under test are the same as those applied to every link tested.

4.6.4.1 The proof load testing machine shall be calibrated within the past 12 months previous to the chain proof load test.

4.6.5 Chain Specimen Tensile Test. The tensile specimen shall be taken from the link in the side opposite the flash weld. Orientation of the specimen shall be shown in Figure 2. Tensile tests shall be conducted in accordance with ASTM A370 (Tension Test) procedures using Standard Specimens machined in accordance with ASTM A370 (Figure 5).

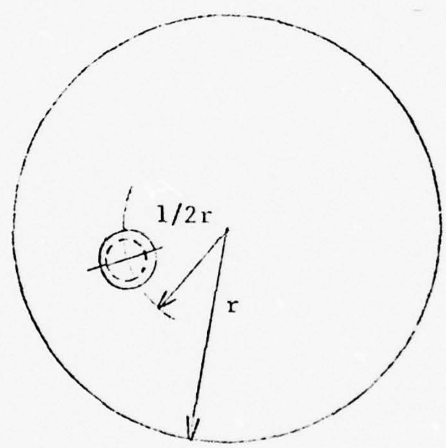


FIGURE 2. ORIENTATION OF TENSILE TEST SPECIMEN

4.6.6 Chain Specimen Impact Test. Six impact test specimens shall be taken from the link. Three impact test specimens shall be taken across the weld and three impact test specimens shall be taken across the unwelded side of the link. Orientation of the specimens shall be as shown in Figure 3. The notch must be precisely bottomed in the flash weld line for the three specimens taken from that side of the link. Impact tests shall be in accordance with ASTM A370 (Charpy Impact Testing) using Charpy V-notch Type A specimens in accordance with ASTM A370 (Figure 11).

4.6.4 Chain Proof Load Test. Shots shall be tested by suitably securing them in a testing machine in such a manner that the chain shall be free from twist, and the holding arrangement shall be such that all stresses bearing on the end links of the section under test are the same as those applied to every link tested.

4.6.4.1 The proof load testing machine shall be calibrated within the past 12 months previous to the chain proof load test.

4.6.5 Chain Specimen Tensile Test. The tensile specimen shall be taken from the link in the side opposite the flash weld. Orientation of the specimen shall be shown in Figure 2. Tensile tests shall be conducted in accordance with ASTM A370 (Tension Test) procedures using Standard Specimens machined in accordance with ASTM A370 (Figure 5).

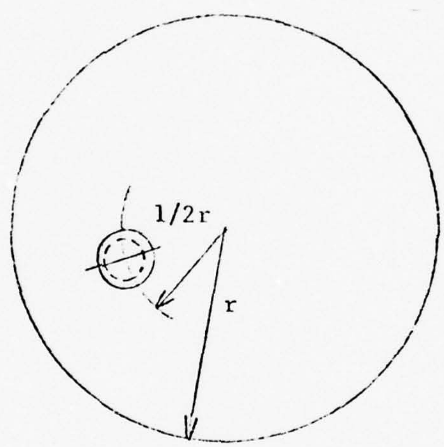


FIGURE 2. ORIENTATION OF TENSILE TEST SPECIMEN

4.6.6 Chain Specimen Impact Test. Six impact test specimens shall be taken from the link. Three impact test specimens shall be taken across the weld and three impact test specimens shall be taken across the unwelded side of the link. Orientation of the specimens shall be as shown in Figure 3. The notch must be precisely bottomed in the flash weld line for the three specimens taken from that side of the link. Impact tests shall be in accordance with ASTM A370 (Charpy Impact Testing) using Charpy V-notch Type A specimens in accordance with ASTM A370 (Figure 11).

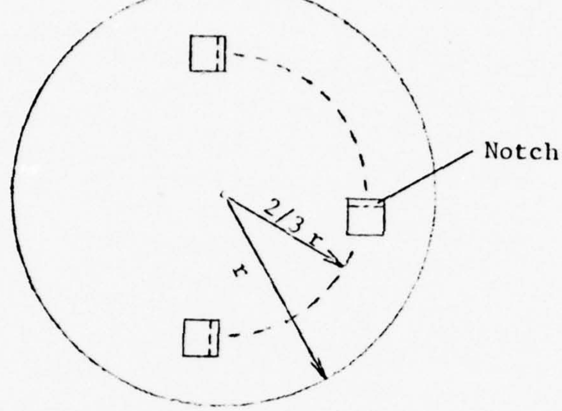


FIGURE 3. ORIENTATION OF CHARPY V-NOTCH IMPACT TEST SPECIMENS

4.6.7 Chain Specimen Bend Test. Orientation of the bend test specimen is shown in Figure 4. The sample shall be taken from an area of the link below the stud. The test piece shall be prepared with the maximum area of original bar surface retained and with a maximum thickness of 20 mm. The test is to be conducted with the bar surface in tension round a former of 100-mm diameter. The specimen shall be precisely positioned over the former such that the weld area is parallel to and in contact with the former.

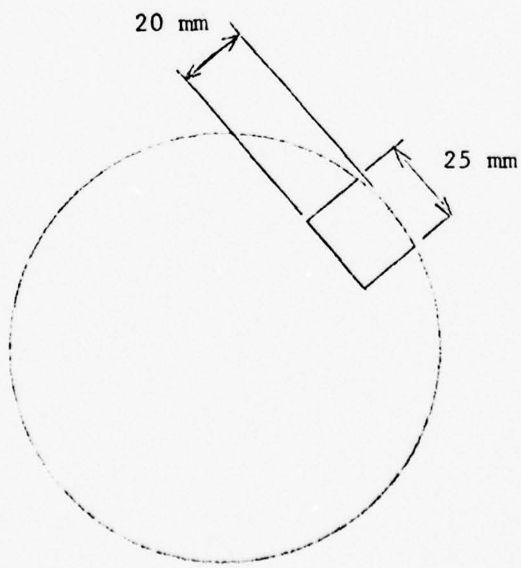


FIGURE 4. ORIENTATION OF BEND TEST SPECIMEN

4.6.8 Bar Stock Tensile Test. The specimen shall be taken from the sample and tested in the manner described in Section 4.6.5.

4,6,9 Bar Stock Impact Test. Three specimens shall be taken from the sample and tested in the manner described in Section 4.6.6.

4.7 Retest Procedure and Rejection Criteria.

4.7.1 If the length of six consecutive links is short, the chain may be stretched by loading above the proof test load in Table III, providing this load does not exceed the proofed load by 10 percent. If the chain length over six links exceeds the tolerances in Table II, the overlength chain links shall be cut out and 4.7.2 applies.

4.7.2 If the link fails to comply with the Applicable Requirement it shall be cut out and a connecting link shall be inserted in its place. After the entire shot has successfully completed all manufacturing and inspection steps, the connecting link shall be removed and the two remaining lengths may be used to start new shots of chain. No chain shall be normalized more than twice.

4.7.3 If a crack, dent, or cut is found it shall be ground down no more than 1/16 inch (1.6 mm) and streamlined to provide no reentry contours. The link shall then be rechecked for compliance with 3.4, otherwise 4.7.2 applies.

4.7.4 If a crack or poor weld is found, the area shall be ground no more than 1/32 inch (0.8 mm) and retested. If the crack is still present 4.7.2 applies.

4.7.5 If the chemical analysis shows the steel composition not to be as ordered from the steel mill, the material is rejected.

4.7.6 If fracture occurs in the flash weld or flash weld heat affected zone, the connected shot is rejected. In addition, each Chain Breaking Load Test triplet representative of the previous three shots manufactured from the same heat of steel shall be subjected to the Destructive Test. If any of these triplets fracture in the flash weld or flash weld heat affected zone, the connected shot is rejected.

4.7.7 If the chain breaks below the level specified in Table III, the connected shot is rejected.

4.7.8 If there is sign of fracture during the proof test, 4.7.2 applies.

4.7.9 If the tensile test fails to meet the requirements in Table III, but are within 2,000 psi (140 kg/cm^2) of the required tensile strength, or within 2 percent of the required elongation, a retest of another specimen selected from the same sample is permissible. If the second test fails to meet the requirements of Table III, the connected shot or material (as applicable) is rejected.

4.7.10 The average results of the three tests shall meet or exceed the minimum requirements listed in Table III. If the average fails to meet the minimum requirement by an amount not exceeding 15 percent, three additional specimens from the same sample may be tested and the results added to those previously obtained to form a new average. If the new average fails to meet the requirements of Table III, the connected shot or material (as applicable) is rejected.

4.7.11 If there is sign of fracture in the bend specimen before 120 degrees of bend is made, the material is rejected.

5. PREPARATION FOR DELIVERY

5.1 Bundling. Shots or lengths of chain shall be bundled or faked down and secured in such a manner that each unit may be lifted.

5.2 Loading. Unless otherwise specified in the contract or order, chain shall be shipped in gondola cars and so loaded as to conform to Uniform Freight Classification Rules.

5.3 Marking. See Section 3.13.6.

5.3.1 For Identification. Each shot or length of chain shall have securely wired to each end link a corrosion-resistant metal tag plainly marked with the following information.

SERIAL NUMBER ______________

SIZE ______________

LENGTH ______________

CONTRACT NUMBER ______________

CONTRACTOR ______________

5.3.2 For Shipment. Additional marking required by the contract or order shall be in accordance with Standard MIL-STD-129.

6. NOTES

6.1 Ordering Data. Procurement documents should specify the following:

(a) Title, number, and date of this specification.

Notice. When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

6.2 Minimum Order for U.S. Navy Ships. For all U.S. Navy ships the minimum ordering quantity should be eight shots. Orders for a lesser quantity require approval by the Naval Ship Engineering Center.

6.3 Contract Data Requirements. When this specification is used in a procurement invoking the data requirement clause of the Armed Services Procurement Regulations (ASPR) paragraph 7-104.9(n) and which incorporates a DD Form 1423 Contract Data Requirements List (CDRL), the data requirements identified below will be developed as specified in the cited Data Item Description (DID) and delivered in accordance with such CDRL. When the ASPR provisions are not invoked, the data specified below shall be delivered in accordance with the contract requirements.

Specification Paragraph	Requirements	Service	Applicable DID	Options
(a) 4.1.1	Inspection System Program Plan	SH	DI-R-4803	---
(b) 4.1.2	Certification Data/Report	SH	UDI-A-23264	---

(Copies of DID'S required by the supplier in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.)

6.4 Waiver of First Article Inspection. Invitations for bids should provide that the Government reserves the right to waive the requirement for samples for first article inspection as to those bidders offering a product which has been previously procured or tested by the Government, and that bidders offering such products, who wish to rely on such production or test, must furnish evidence with the bid that prior Government approval is presently appropriate for the pending procurement.

APPENDIX B

FIGURES

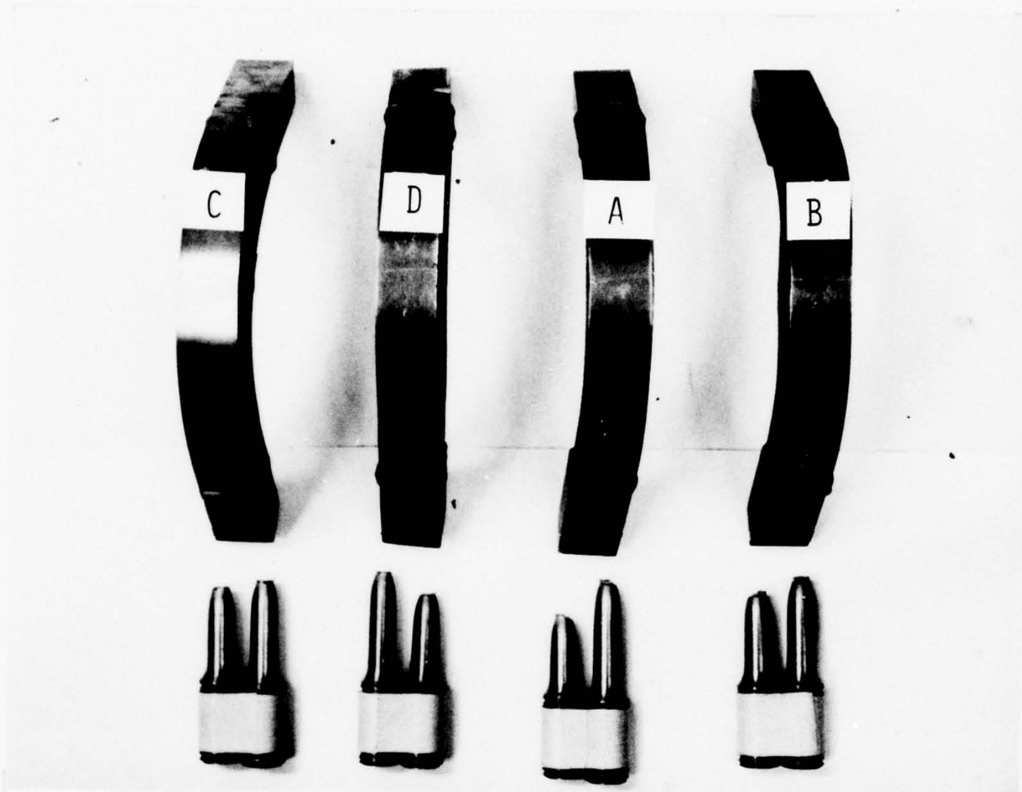


FIGURE 1. TENSILE SPECIMENS AFTER BEND TESTING

The 0.505-in. round bar specimens were cut from the unwelded portion of the chain samples in accordance with the *Interim Specification*.

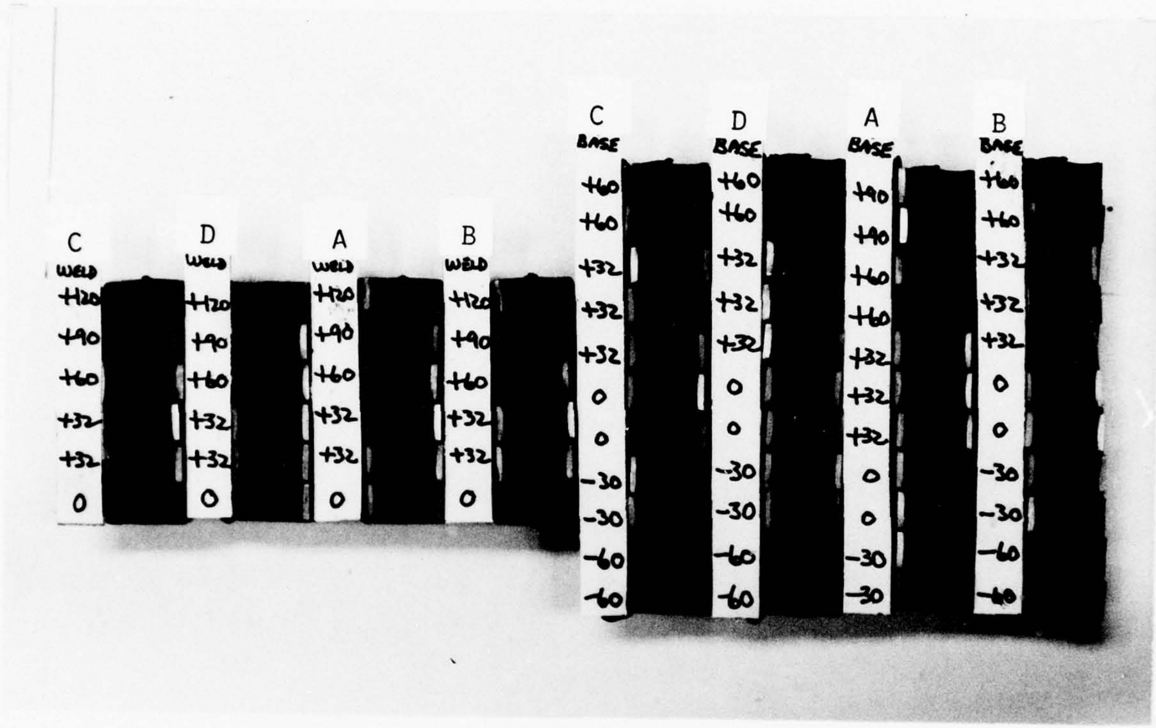


FIGURE 2. CHARPY V-NOTCH IMPACT TEST SPECIMENS

All specimens were taken at the same radial distance from the center of the chain link and machined and tested in accordance with the procedures outlined in ASTM A370; Type A V-notches were used.

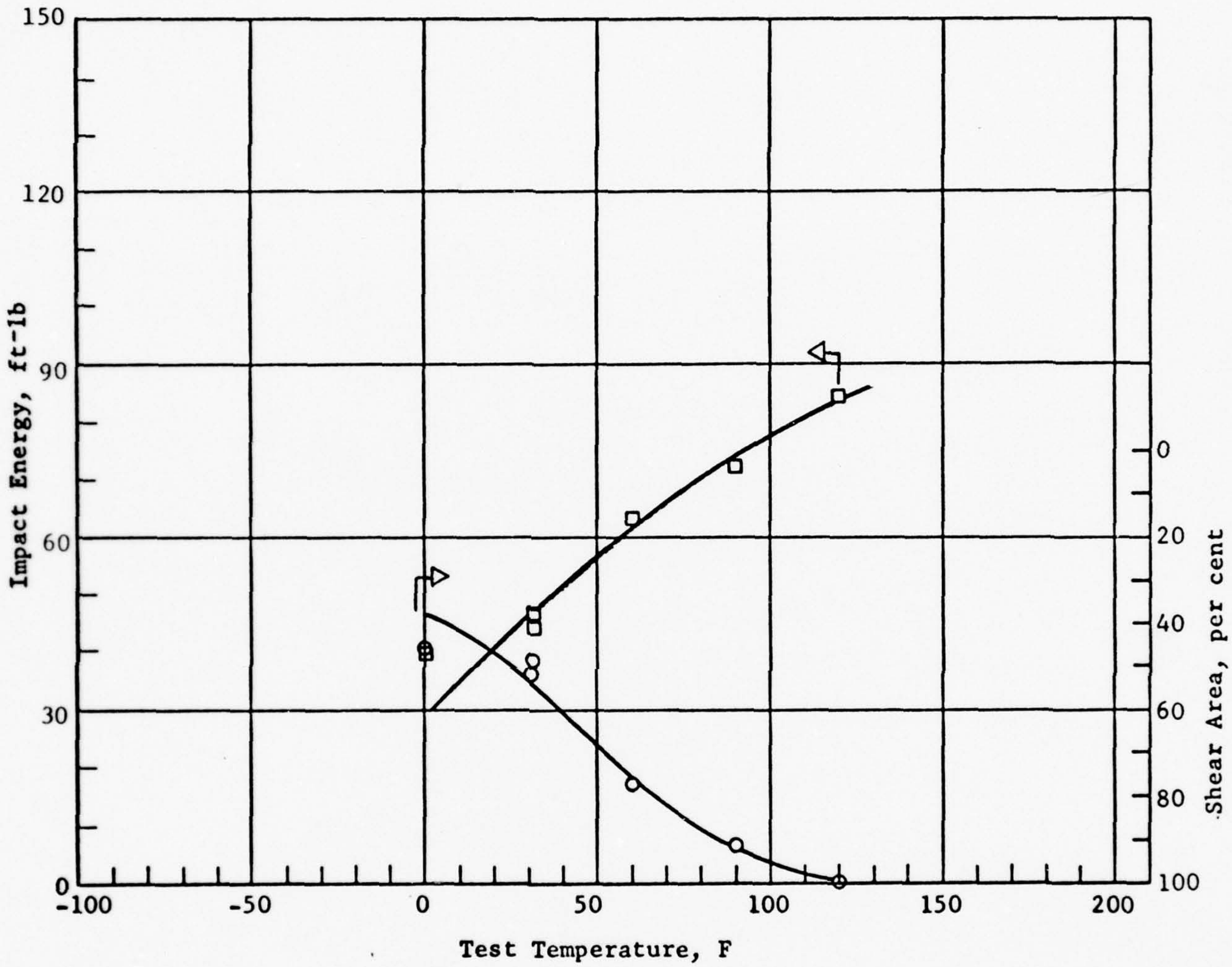


FIGURE 3. RESULTS OF CHARPY V-NOTCH IMPACT TEST
(SAMPLE A, FLASH-WELD SPECIMENS)

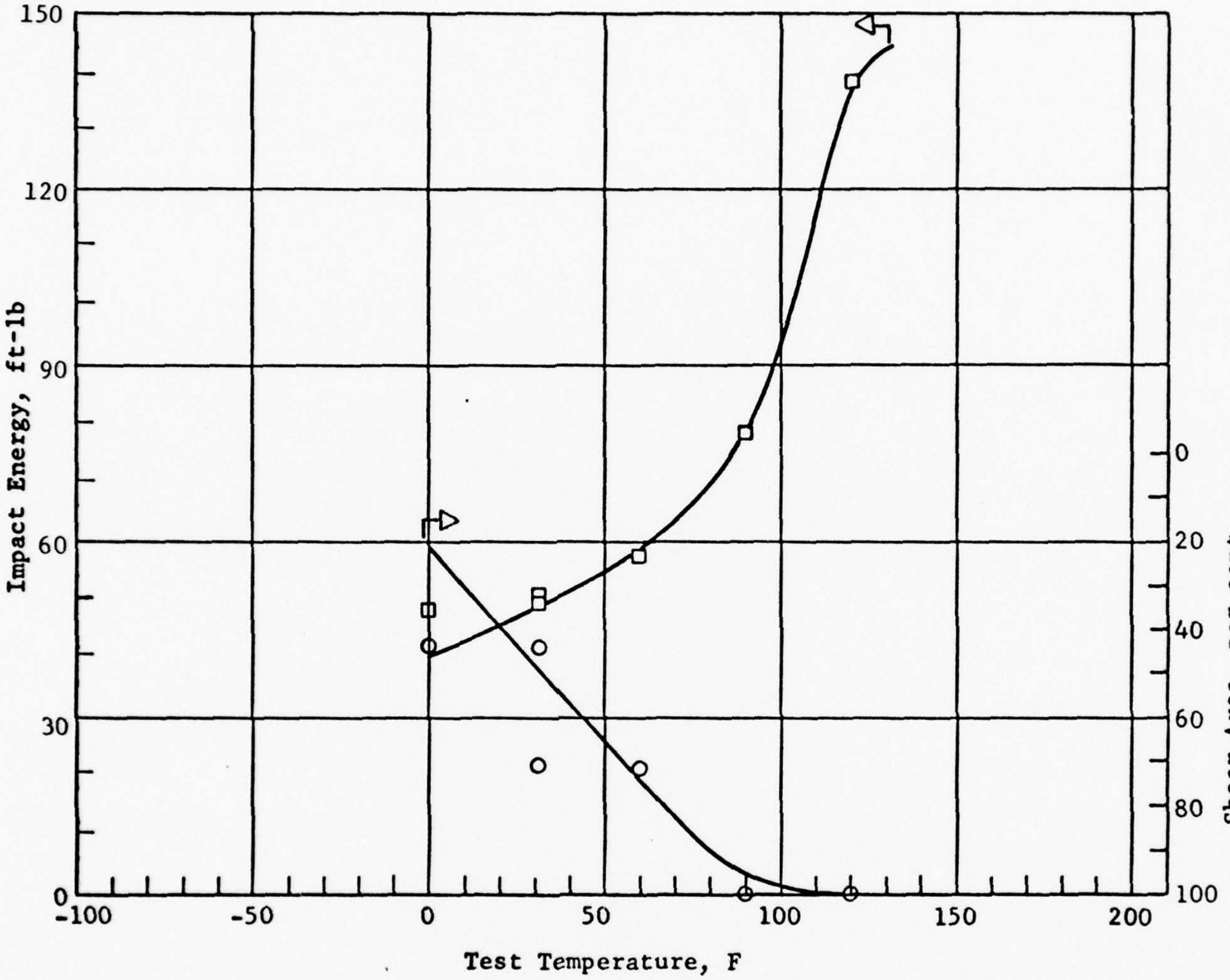


FIGURE 4. RESULTS OF CHARPY V-NOTCH IMPACT TEST
(SAMPLE B, FLASH-WELD SPECIMENS)

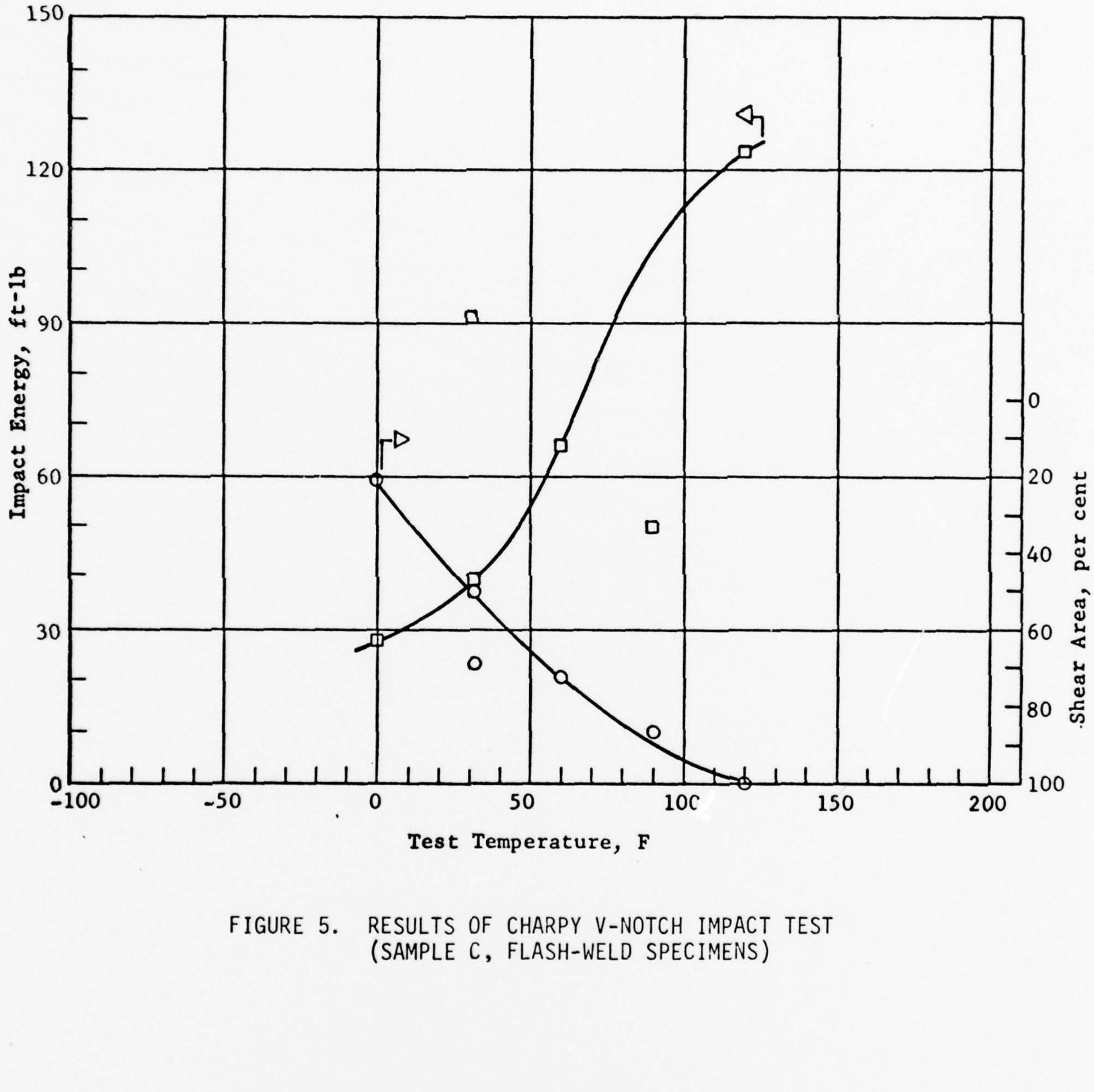


FIGURE 5. RESULTS OF CHARPY V-NOTCH IMPACT TEST
(SAMPLE C, FLASH-WELD SPECIMENS)

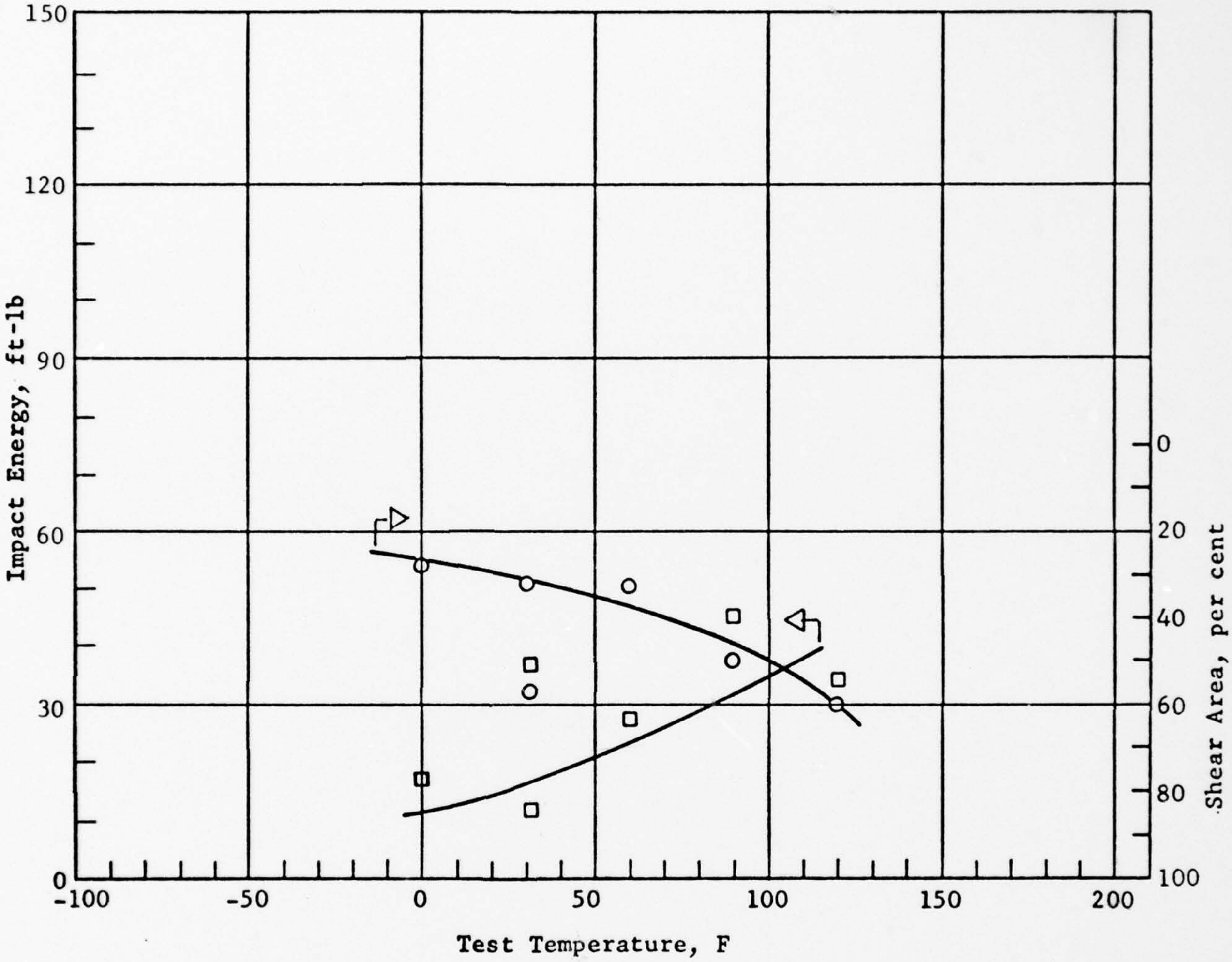


FIGURE 6. RESULTS OF CHARPY V-NOTCH IMPACT TEST (SAMPLE D, FLASH-WELD SPECIMENS)

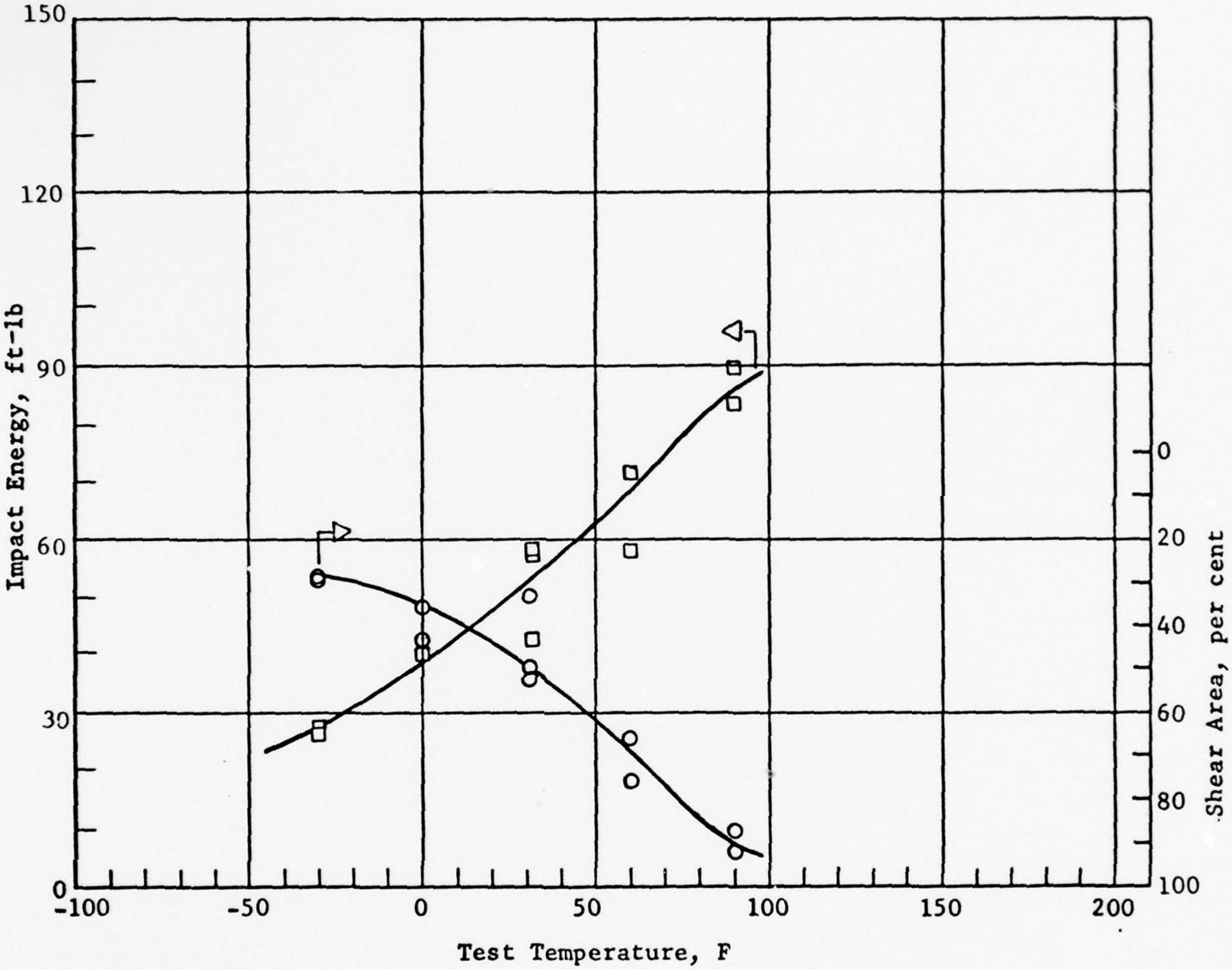


FIGURE 7. RESULTS OF CHARPY V-NOTCH IMPACT TEST
(SAMPLE A, BASE-METAL SPECIMENS)

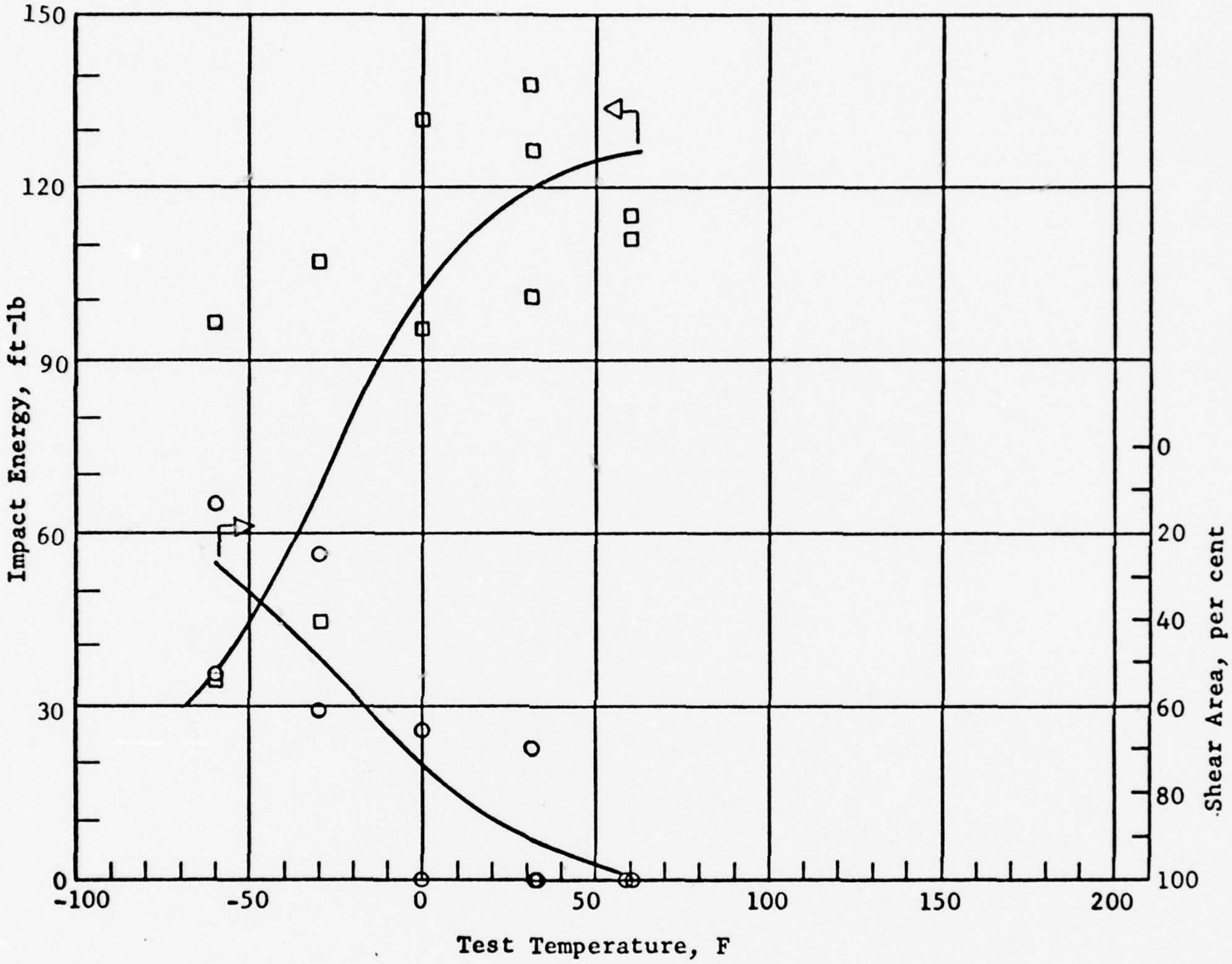


FIGURE 8. RESULTS OF CHARPY V-NOTCH IMPACT TEST (SAMPLE B, BASE-METAL SPECIMENS)

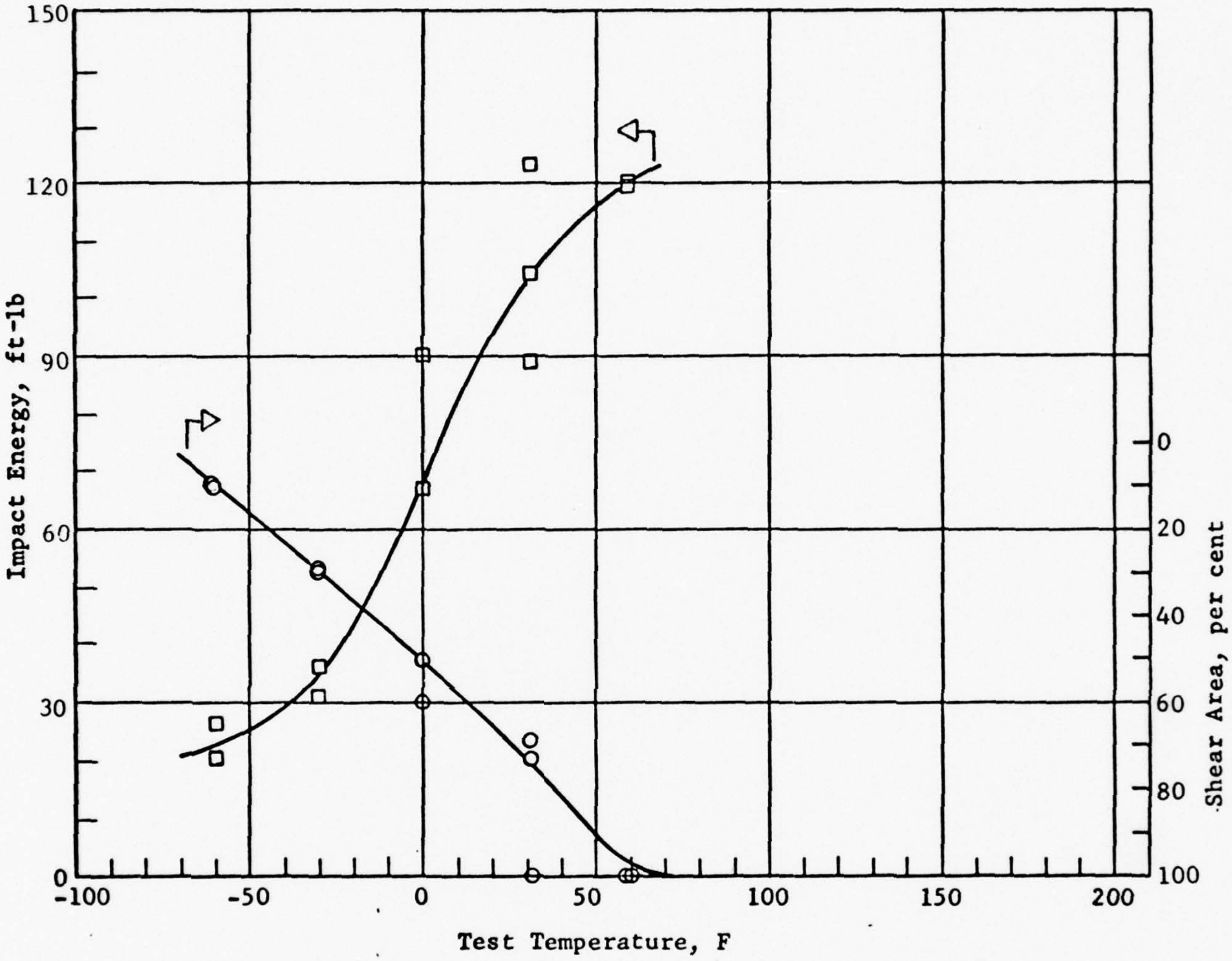


FIGURE 9. RESULTS OF CHARPY V-NOTCH IMPACT TEST (SAMPLE C, BASE-METAL SPECIMENS)

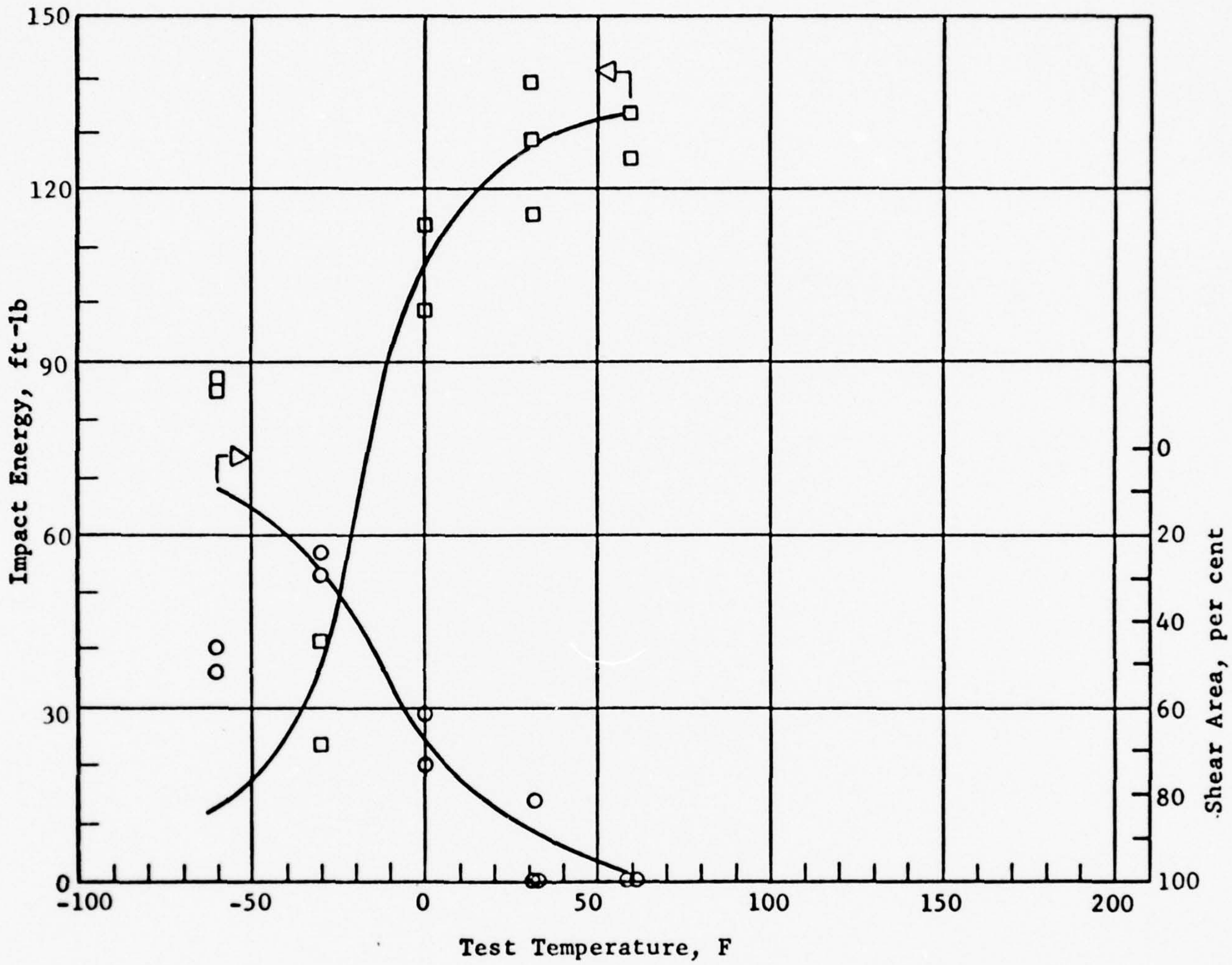


FIGURE 10. RESULTS OF CHARPY V-NOTCH IMPACT TEST
(SAMPLE D, BASE-METAL SPECIMENS)

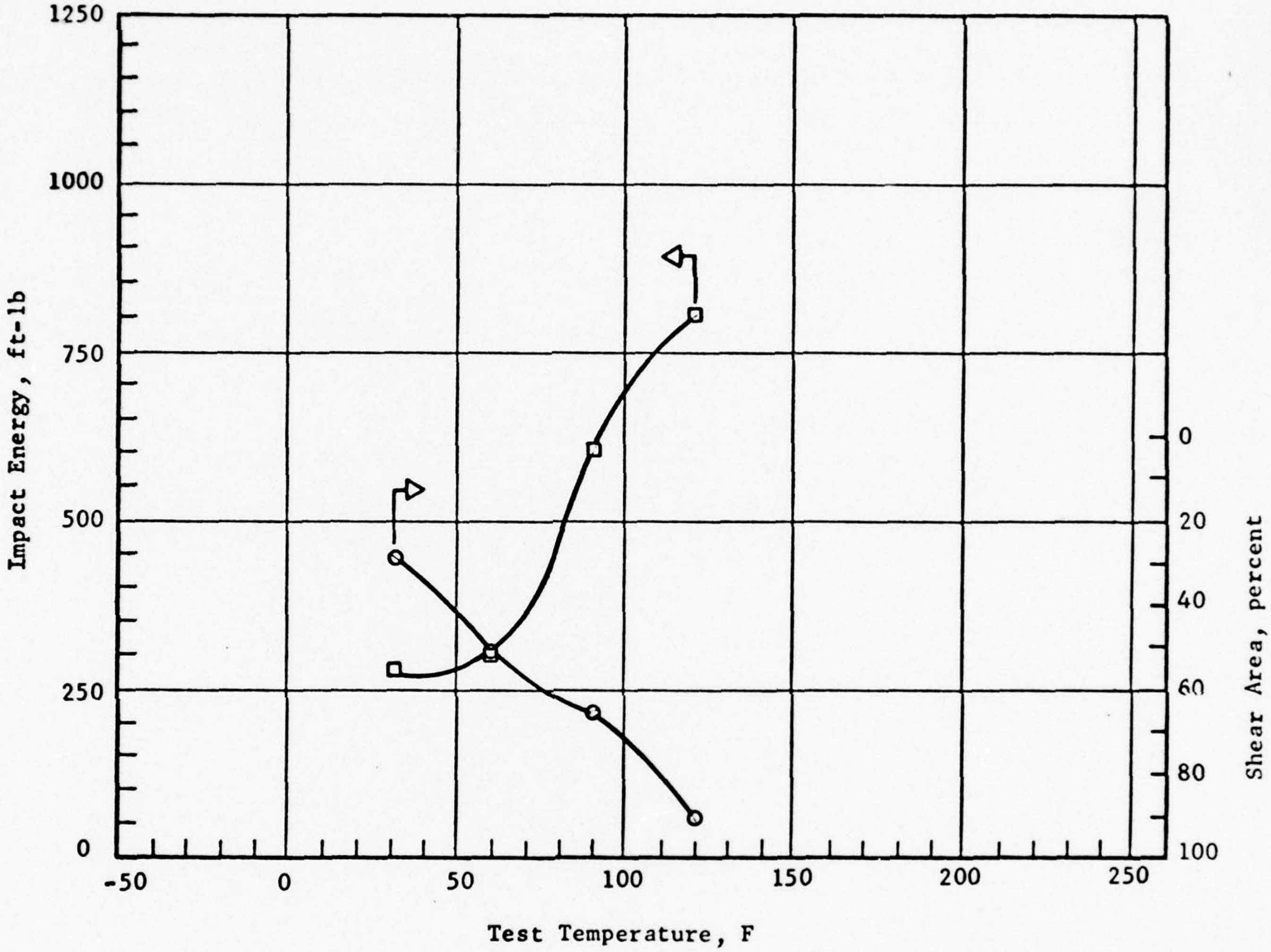


FIGURE 11. RESULTS OF DYNAMIC TEAR TEST
(SAMPLE A, FLASH-WELD SPECIMENS)

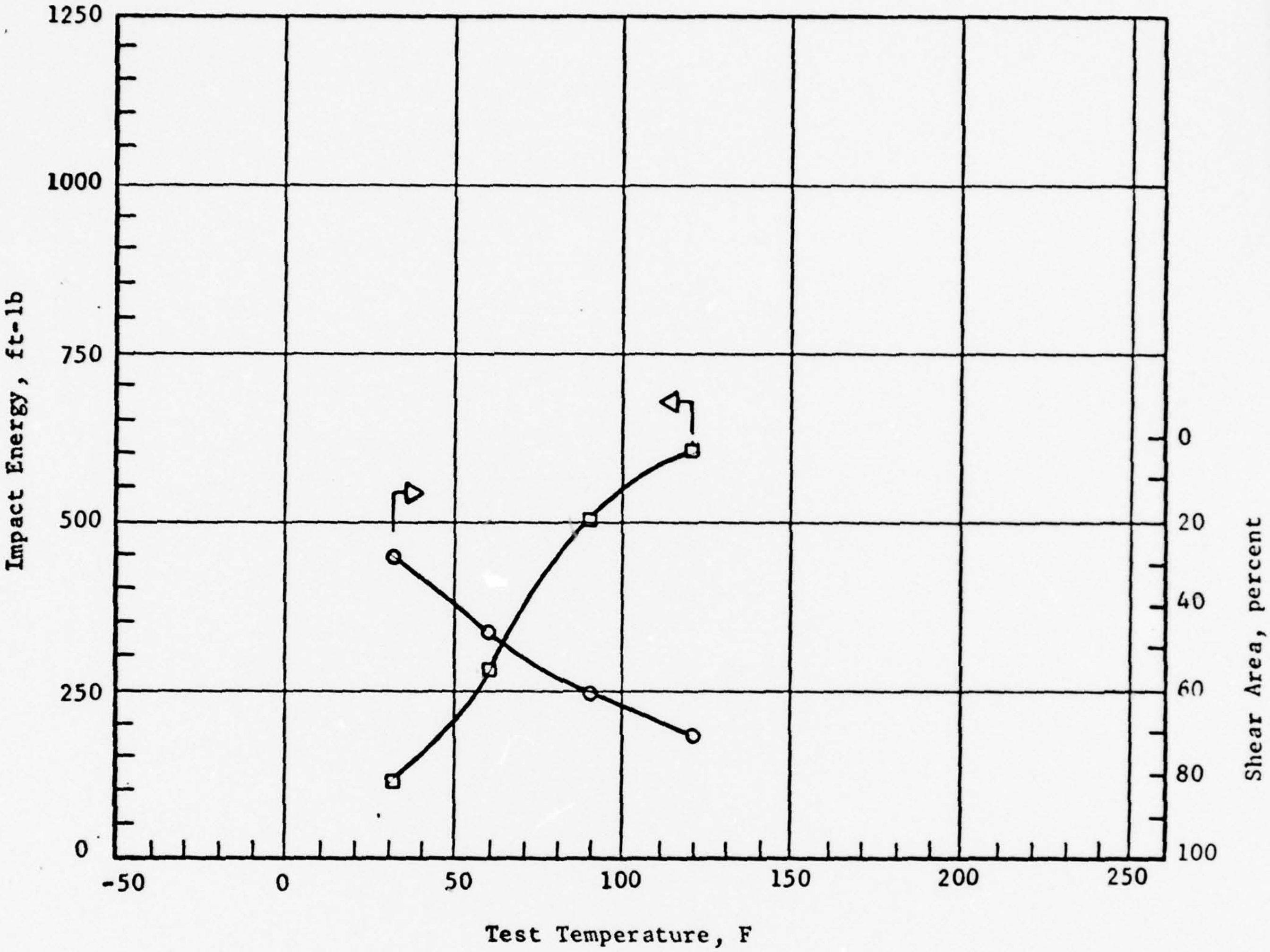


FIGURE 12. RESULTS OF DYNAMIC TEAR TEST
(SAMPLE B, FLASH-WELD SPECIMENS)

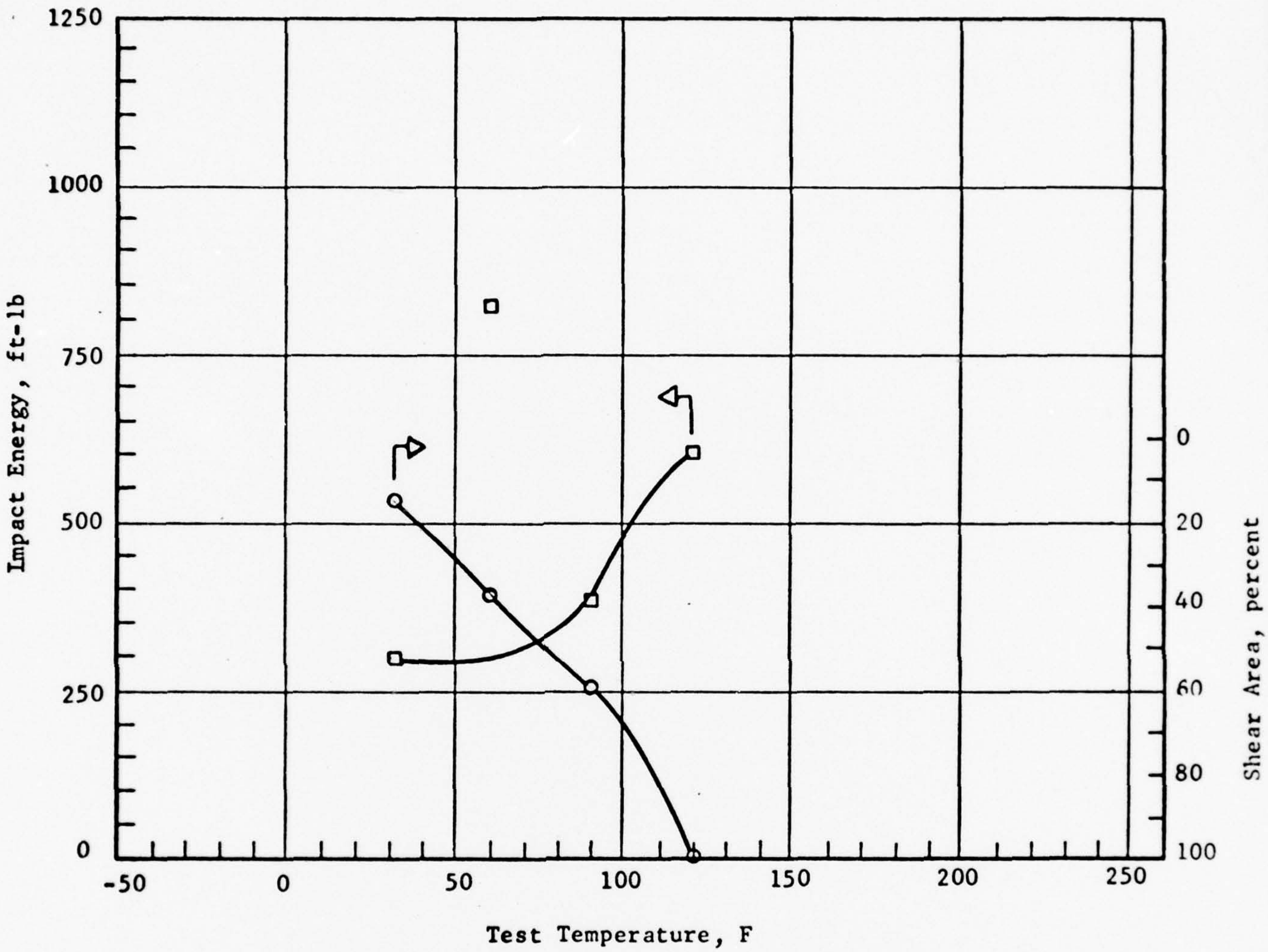


FIGURE 13. RESULTS OF DYNAMIC TEAR TEST
(SAMPLE C, FLASH-WELD SPECIMENS)

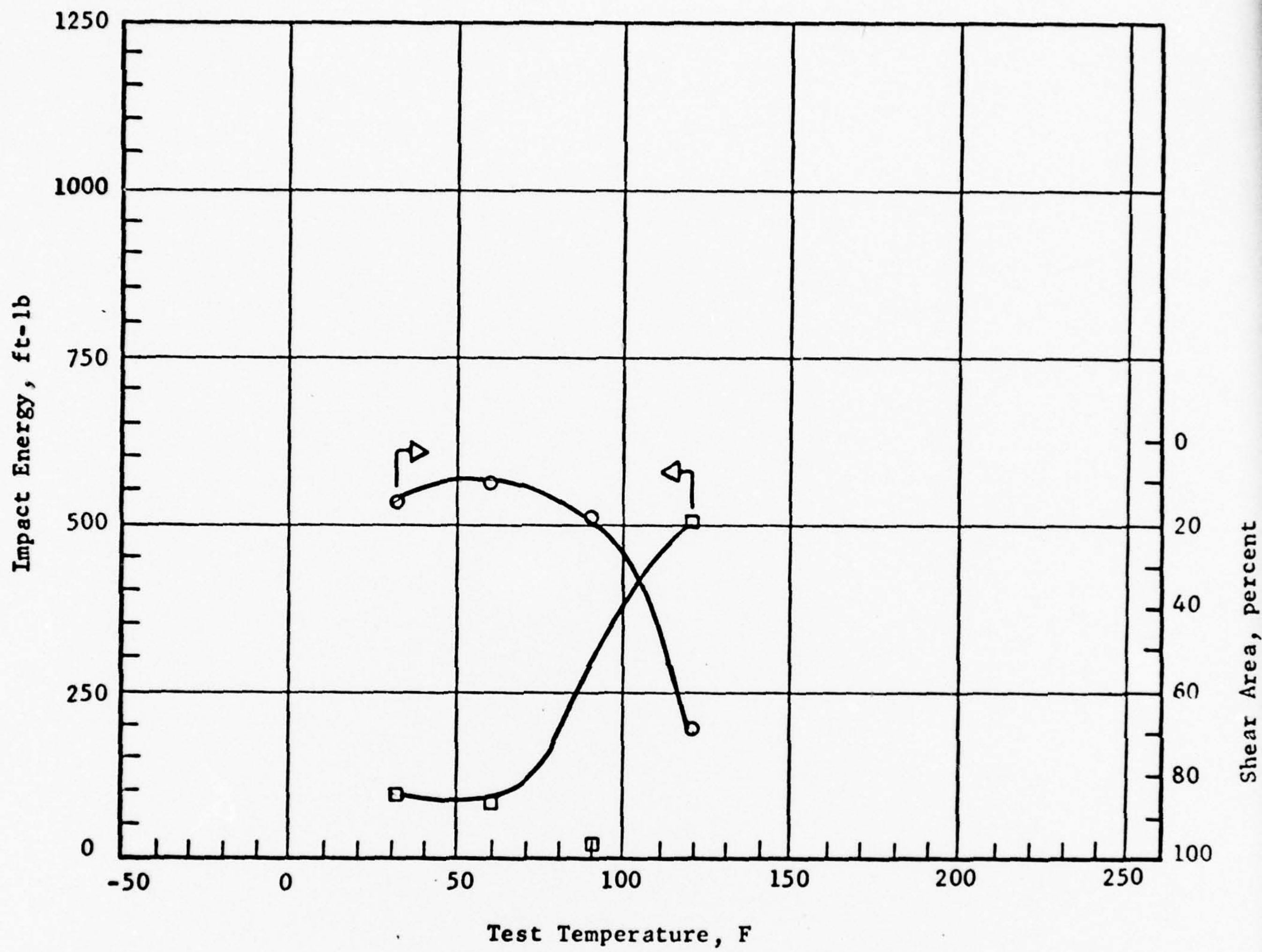


FIGURE 14. RESULTS OF DYNAMIC TEAR TEST
(SAMPLE D, FLASH-WELD SPECIMENS)

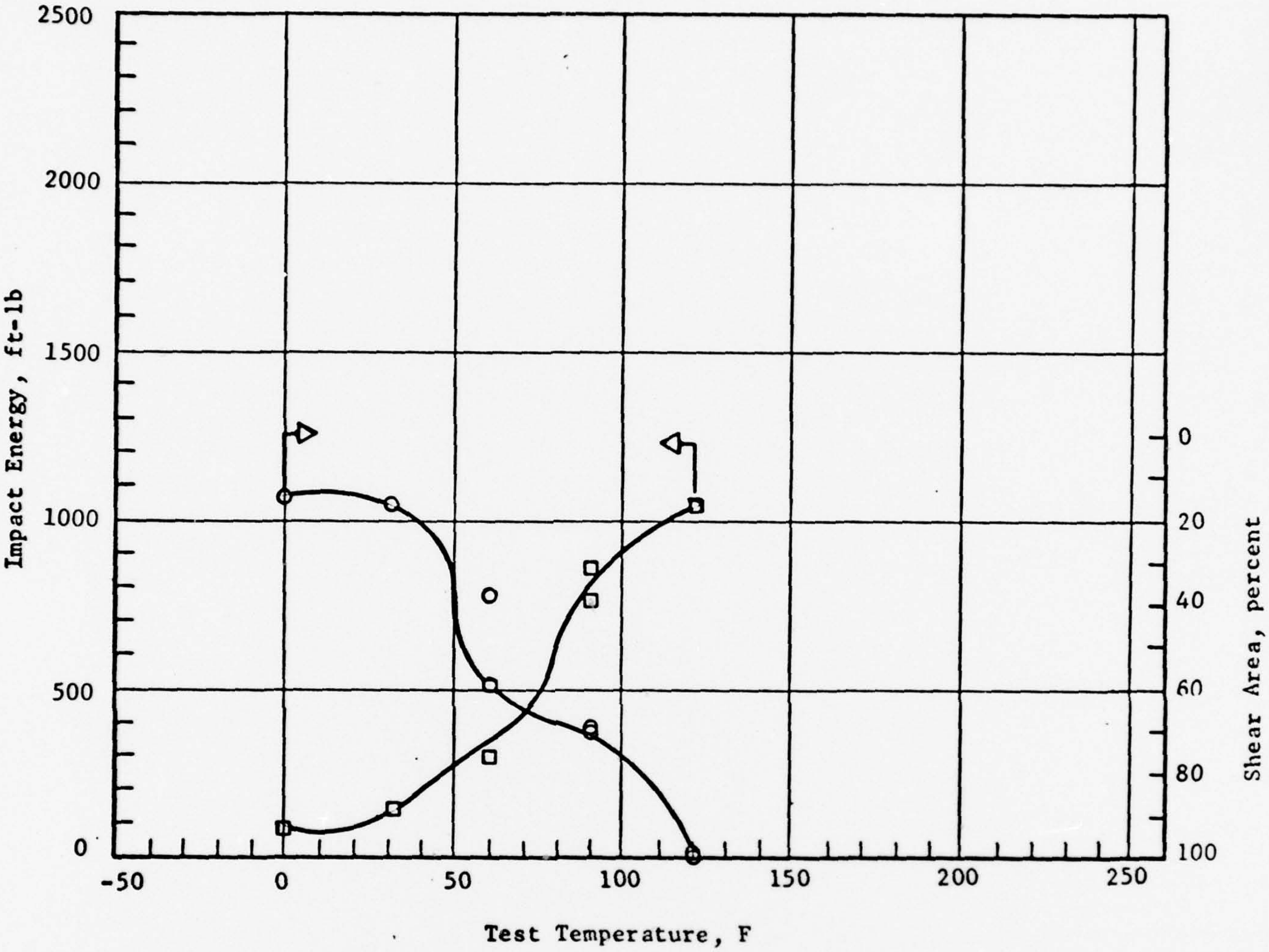


FIGURE 15. RESULTS OF DYNAMIC TEAR TEST
(SAMPLE A, BASE-METAL SPECIMENS)

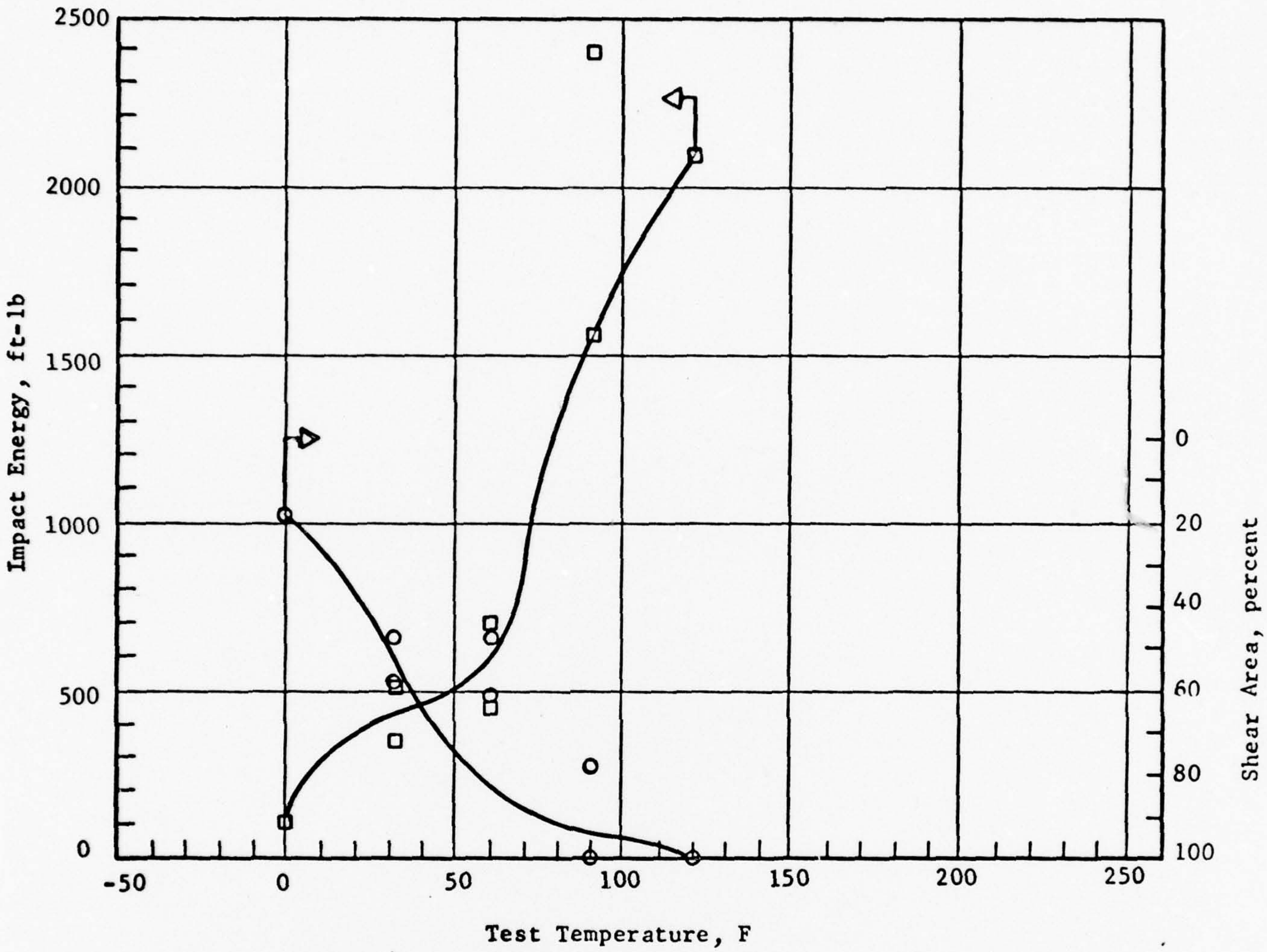


FIGURE 16. RESULTS OF DYNAMIC TEAR TEST
(SAMPLE B, BASE-METAL SPECIMENS)

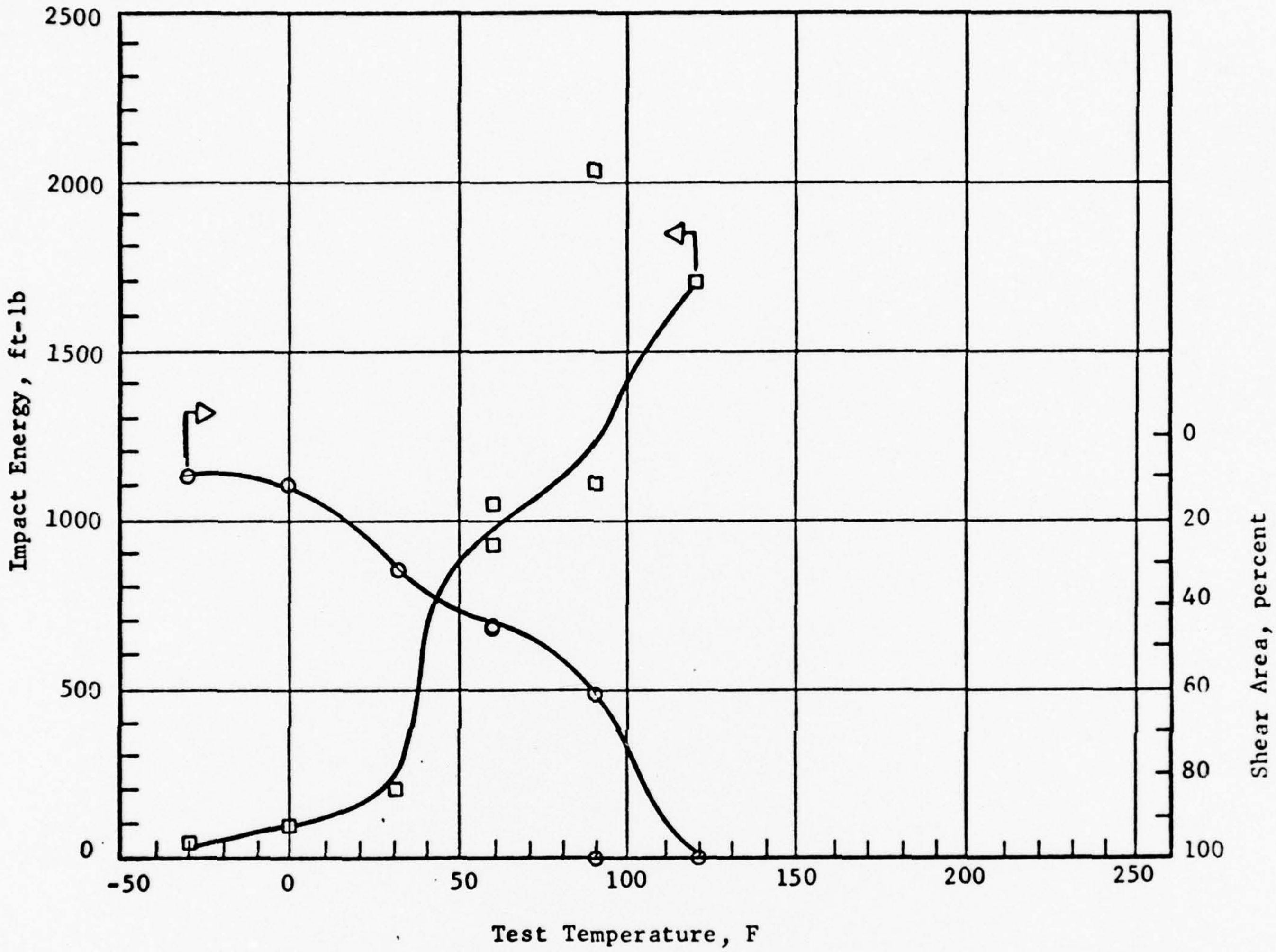


FIGURE 17. RESULTS OF DYNAMIC TEAR TEST (SAMPLE C, BASE-METAL SPECIMENS)

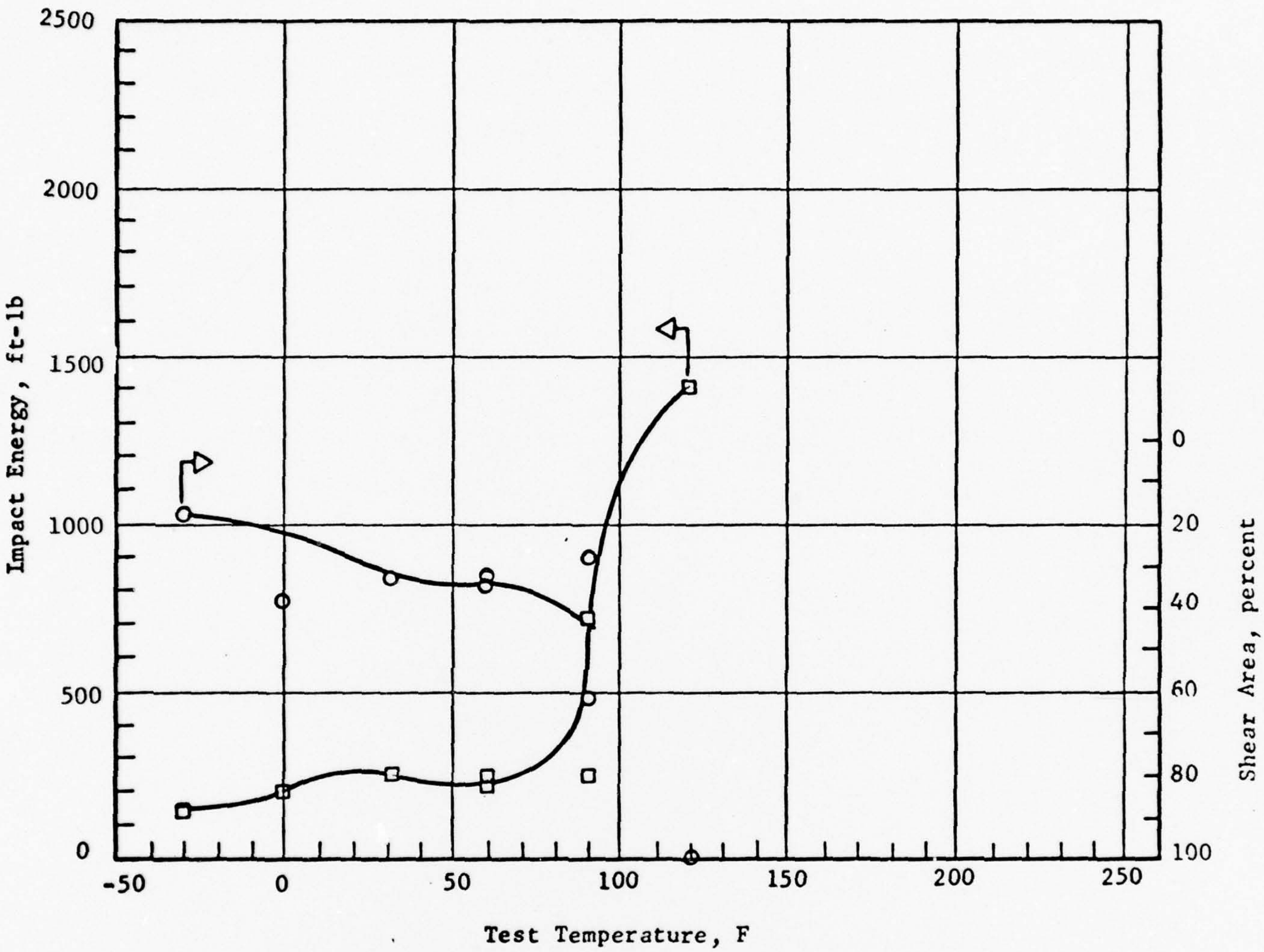


FIGURE 18. RESULTS OF DYNAMIC TEAR TEST
(SAMPLE D, BASE-METAL SPECIMENS)

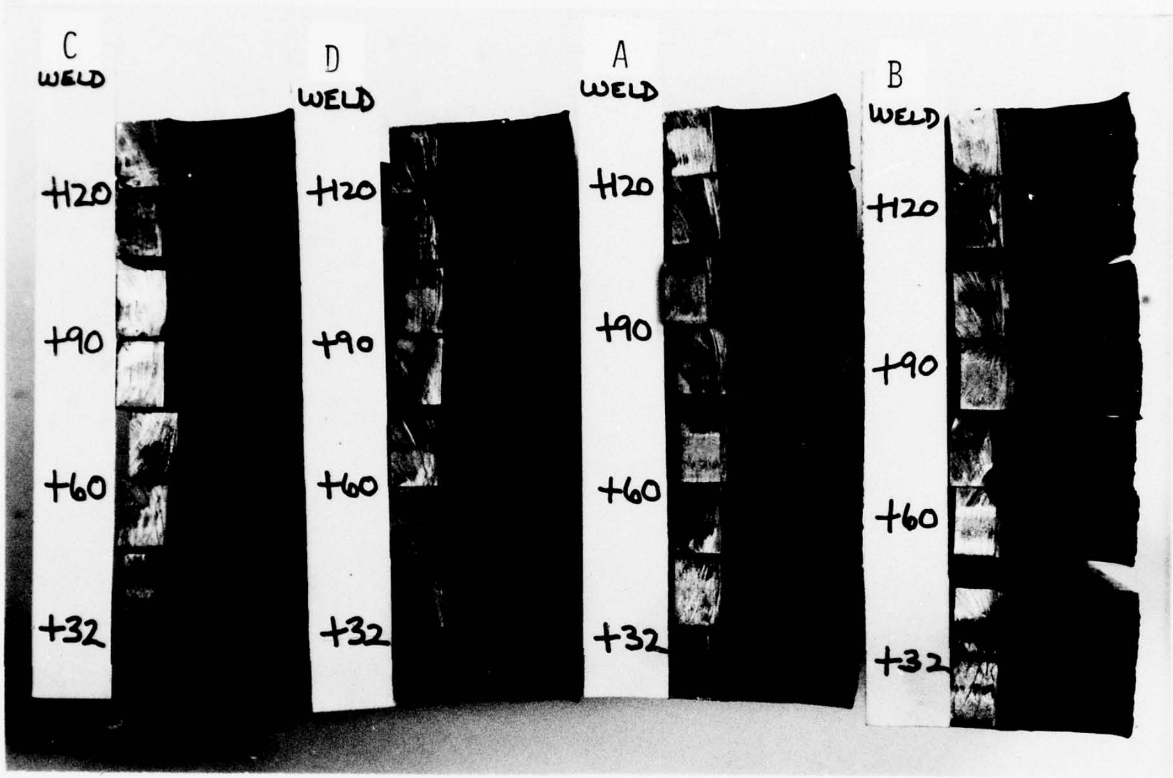


FIGURE 19. DYNAMIC TEAR FRACTURE SURFACES OF FLASH-WELDED SPECIMENS

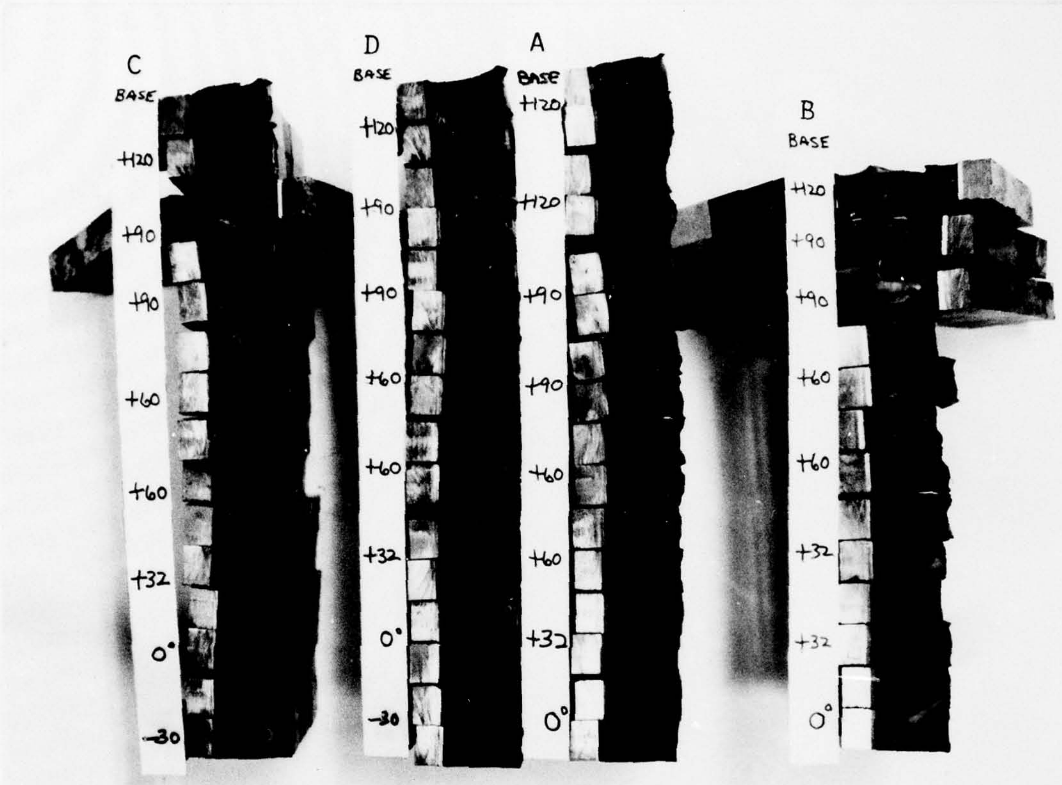


FIGURE 20. DYNAMIC TEAR FRACTURE SURFACES OF BASE-METAL SPECIMENS

Note that some specimens from Samples B and C did not fracture completely at the higher temperatures, indicating the relatively high toughness of the material and tendency to split in the axial direction of the link.

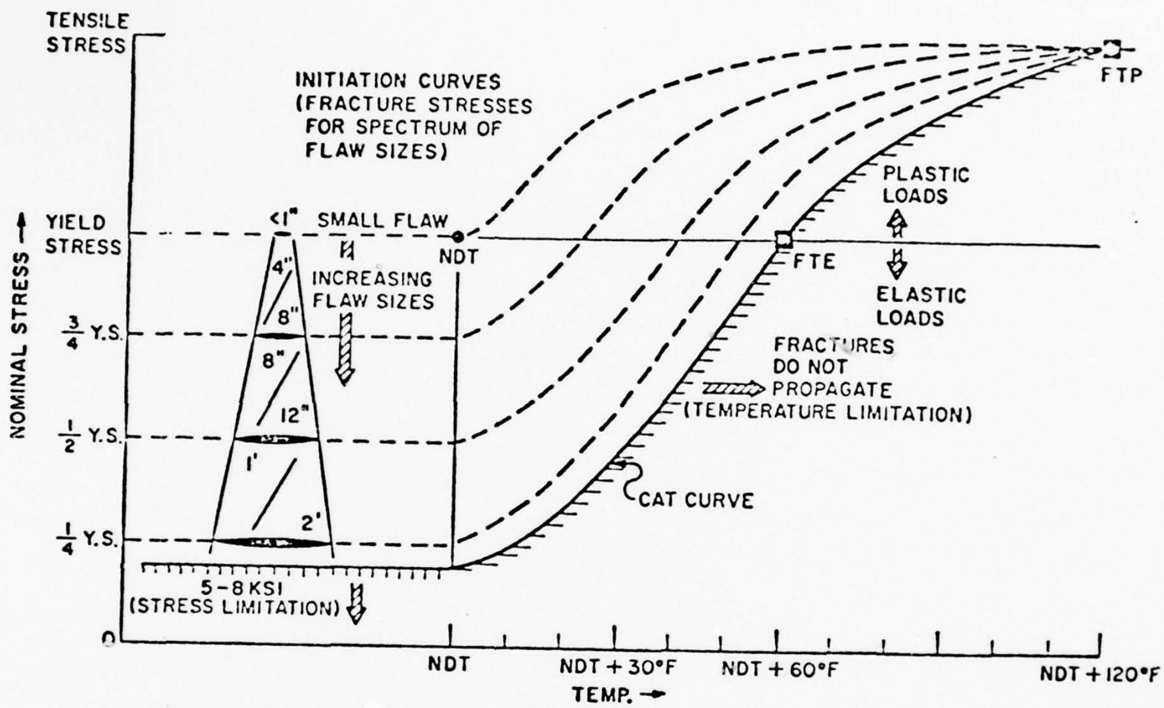


FIGURE 21. FRACTURE ANALYSIS DIAGRAM

After Puzak and Pellini, Naval Research Laboratory.

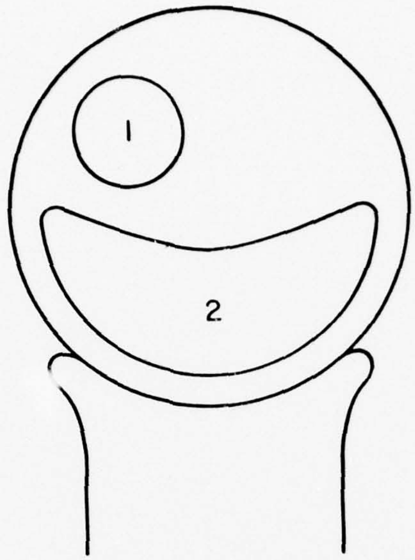


FIGURE 22. ULTRASONIC INSPECTION AREAS, SAMPLE A LINK

Location 1 was estimated to be approximately 1 by 1 in. and was the largest area giving an ultrasonic indication of any of the chain samples. Location 2 gave no signals of more than 5 percent amplitude.

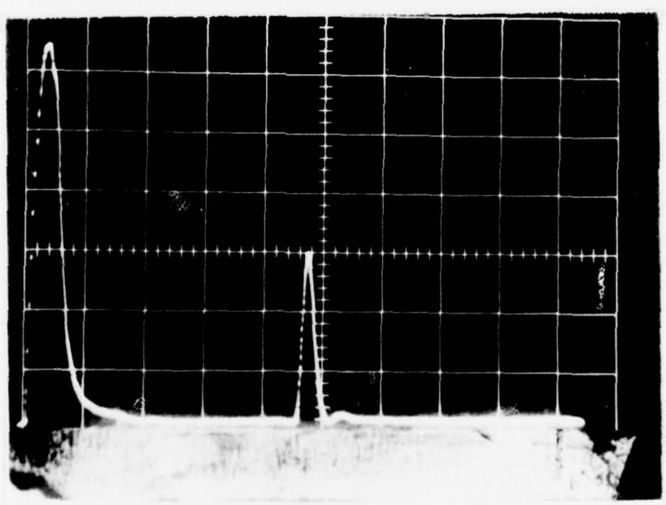


FIGURE 23. ULTRASONIC INDICATION AT LOCATION 1, SAMPLE A LINK

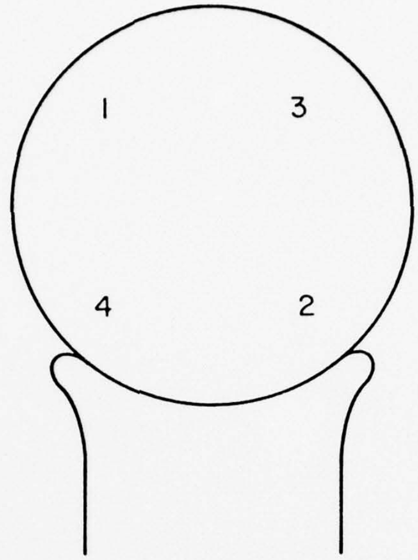


FIGURE 24. ULTRASONIC INSPECTION AREAS, SAMPLE B LINK

The strongest indication (about 29 percent of maximum) was at Location 1 (estimated area 3/8 by 1/2 in.), Location 2 (estimated area 1/8 by 1/8 in.) and Locations 3 and 4 (estimated area 1/16 by 1/16 in.) gave indications of about 5 percent of maximum.

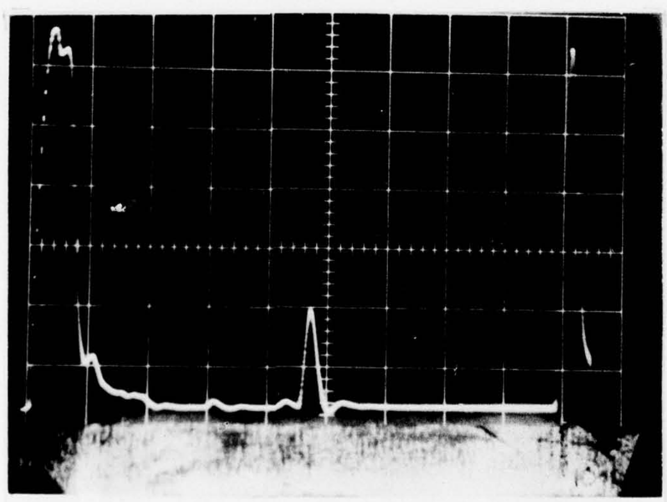


FIGURE 25. ULTRASONIC INDICATION AT LOCATION 1, SAMPLE B LINK

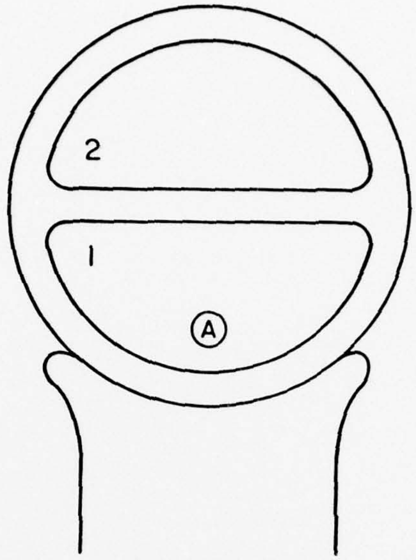


FIGURE 26. ULTRASONIC INSPECTION AREAS, SAMPLE C LINK

Location 1 showed a large number of indications. Position A (estimated size about 1/2 by 1/2 in.) was the largest. Location 2 showed indications of 5 to 8 percent of maximum or less. This link was also examined using the ultrasonic shear-wave technique (see Figures 28 and 29).

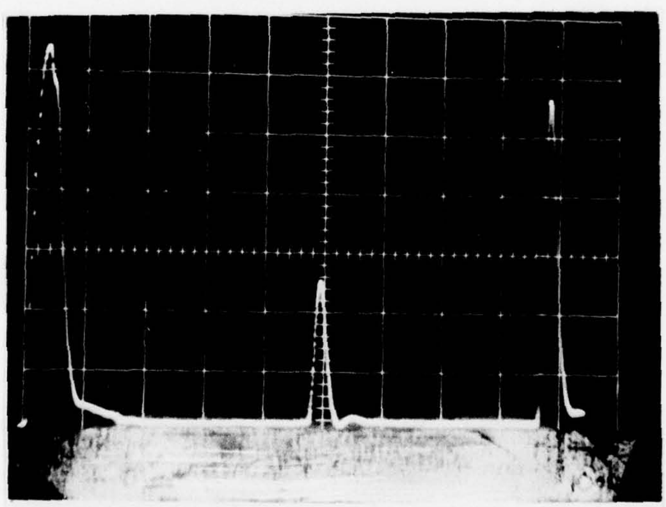


FIGURE 27. ULTRASONIC INDICATION AT LOCATION 1, POSITION A, SAMPLE C LINK

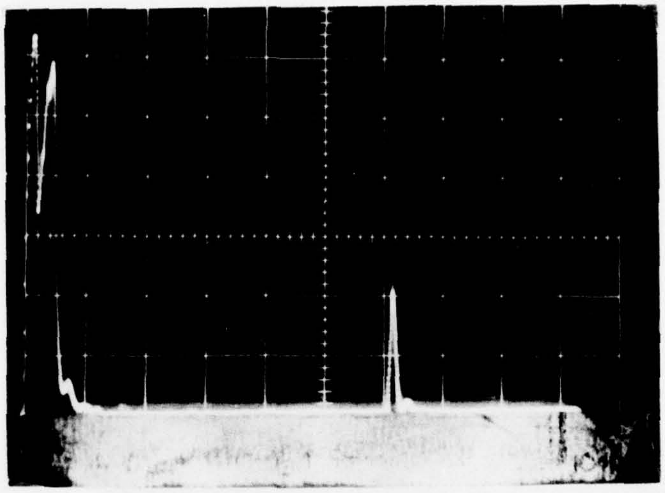


FIGURE 28. SHEAR-WAVE ULTRASONIC INDICATION OF THE 1/8-IN.-DEEP SAWCUT, SAMPLE C LINK

The sawcut was made across the surface of the link as a reference flaw.

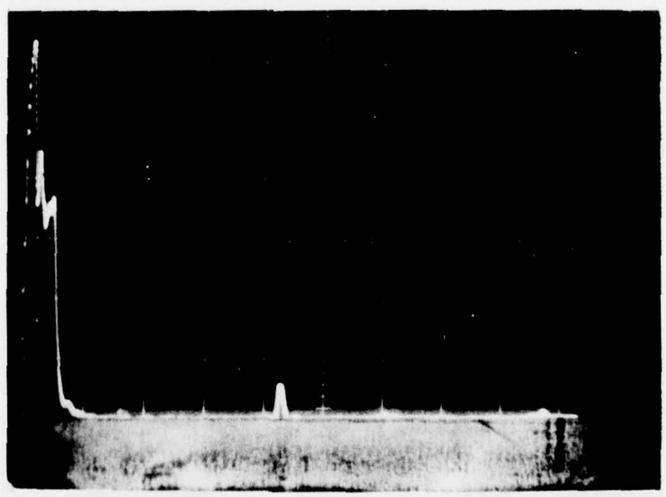


FIGURE 29. SHEAR-WAVE ULTRASONIC INDICATION OF THE SUSPECTED FLAW AT LOCATION 1, POSITION A, SAMPLE C LINK

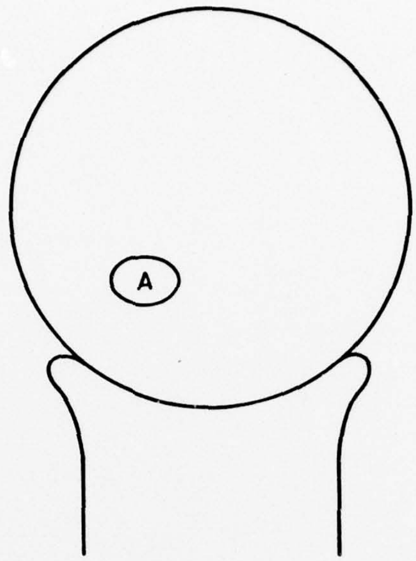


FIGURE 30. ULTRASONIC INSPECTION AREA, SAMPLE D LINK

Position A (estimated size 3/4 by 1/2 in.) gave the strongest indication. No other indications over 5 percent were recorded.

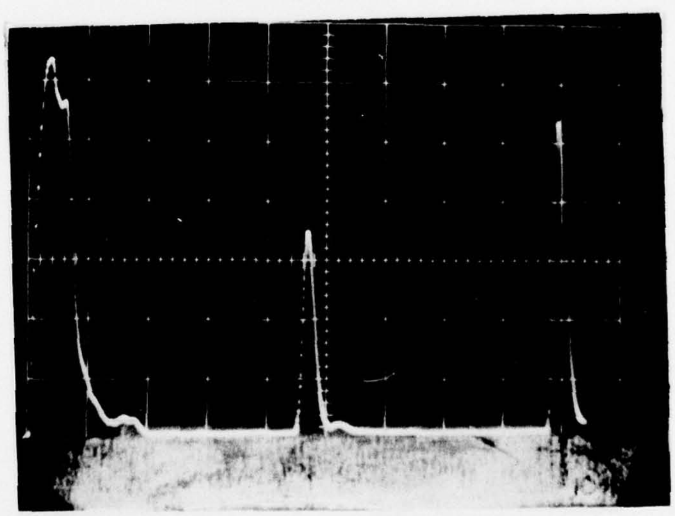
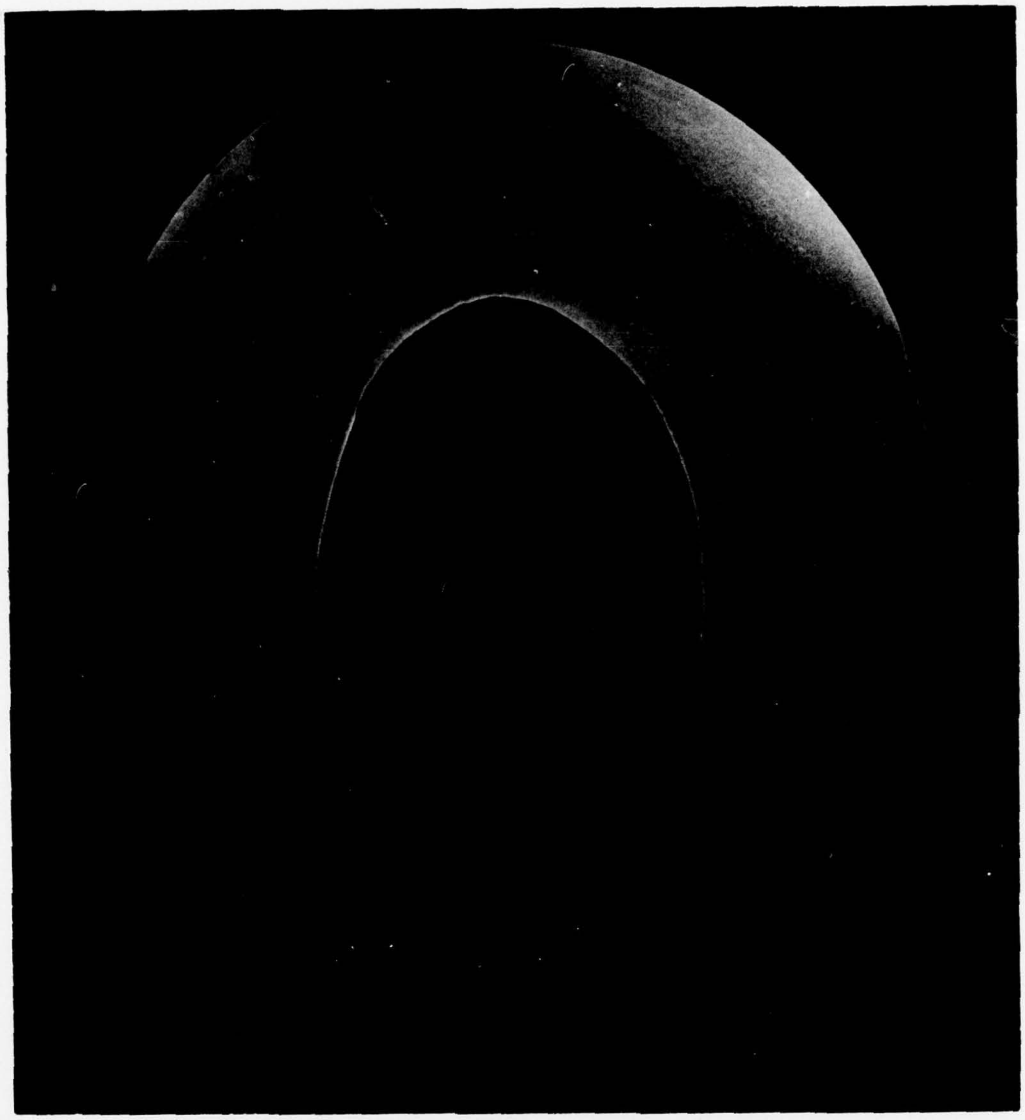


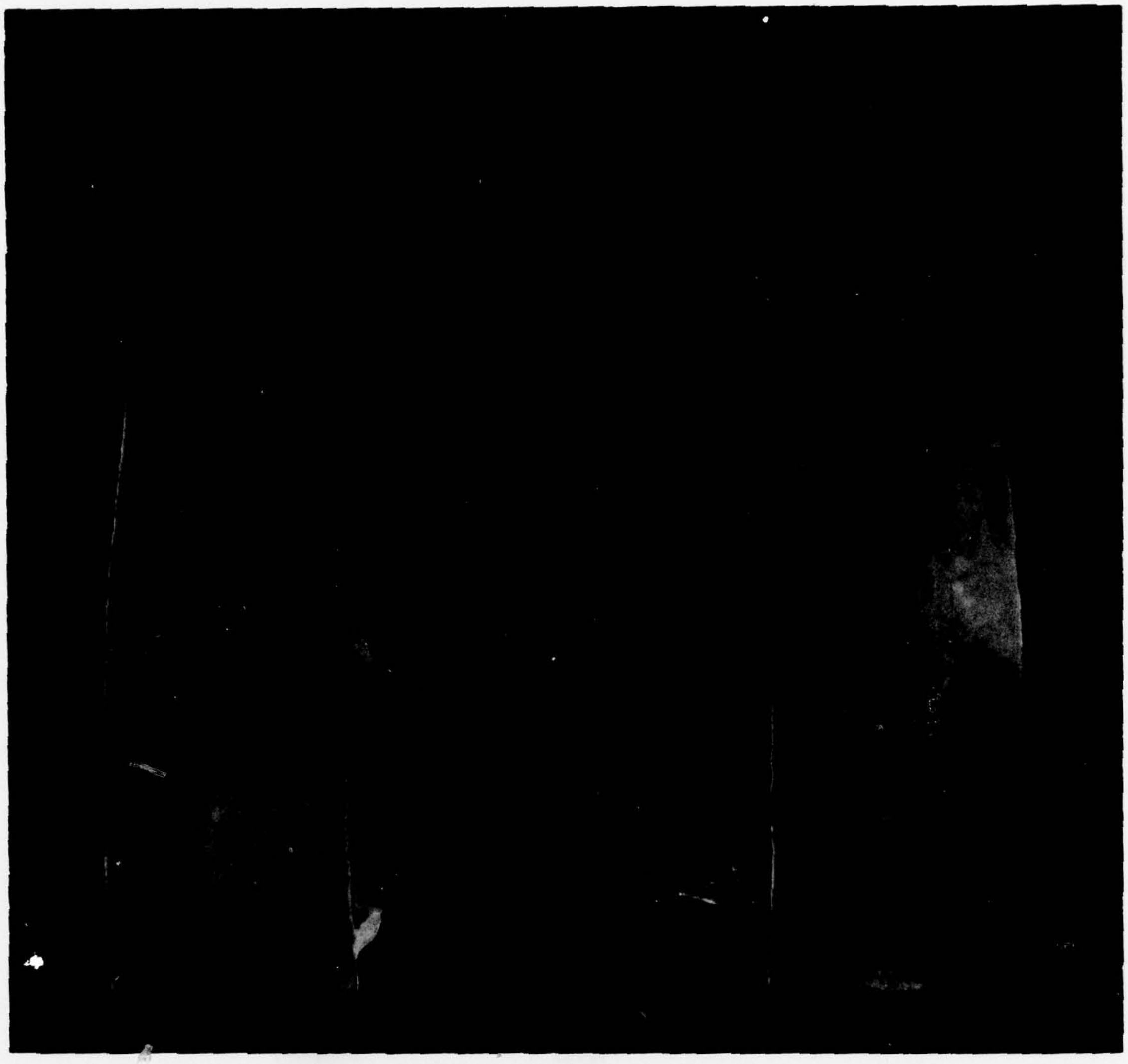
FIGURE 31. ULTRASONIC INDICATION AT POSITION A, SAMPLE D LINK



0.25X IJ914

Macroetched (50 percent HCl in H_2O at 150 F)

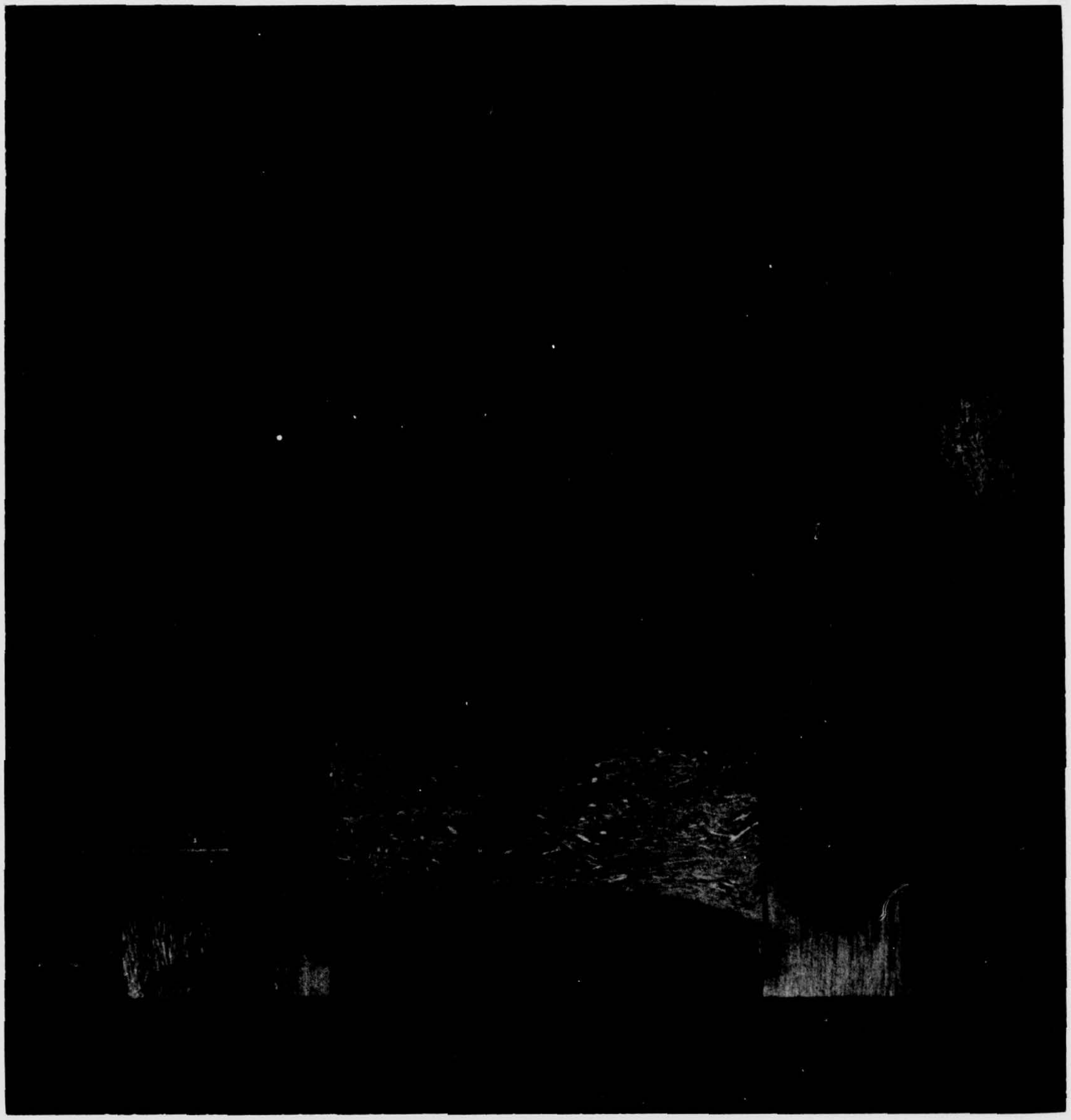
FIGURE 32. MACROETCHED SECTION OF LINK FROM SAMPLE A



0.25X IJ805

Macroetched (50 percent HCl in H_2O at 150 F)

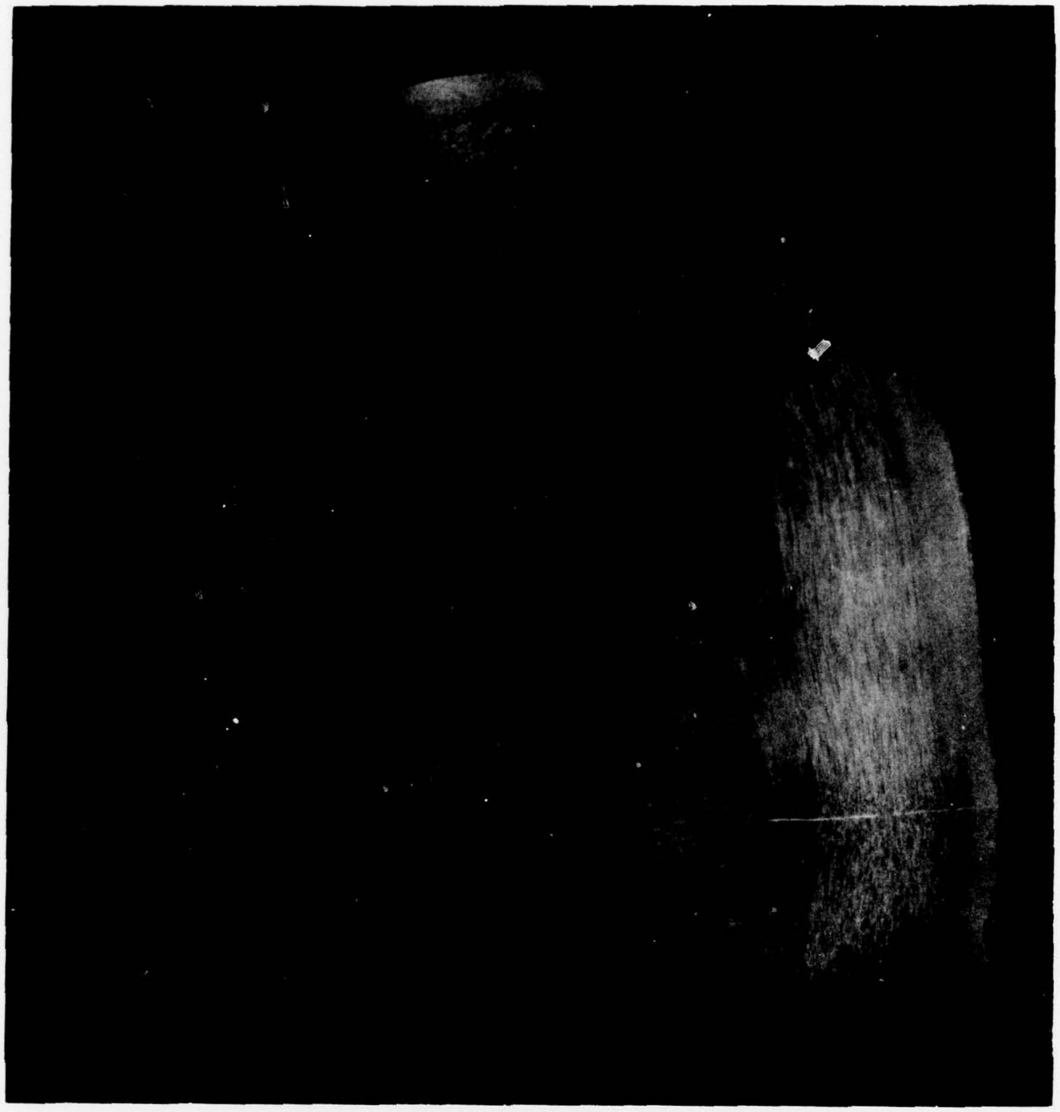
FIGURE 33. MACROETCHED SECTION OF LINK FROM SAMPLE B



0.25X IJ803

Macroetched (50 percent HCl in H_2O at 150 F)

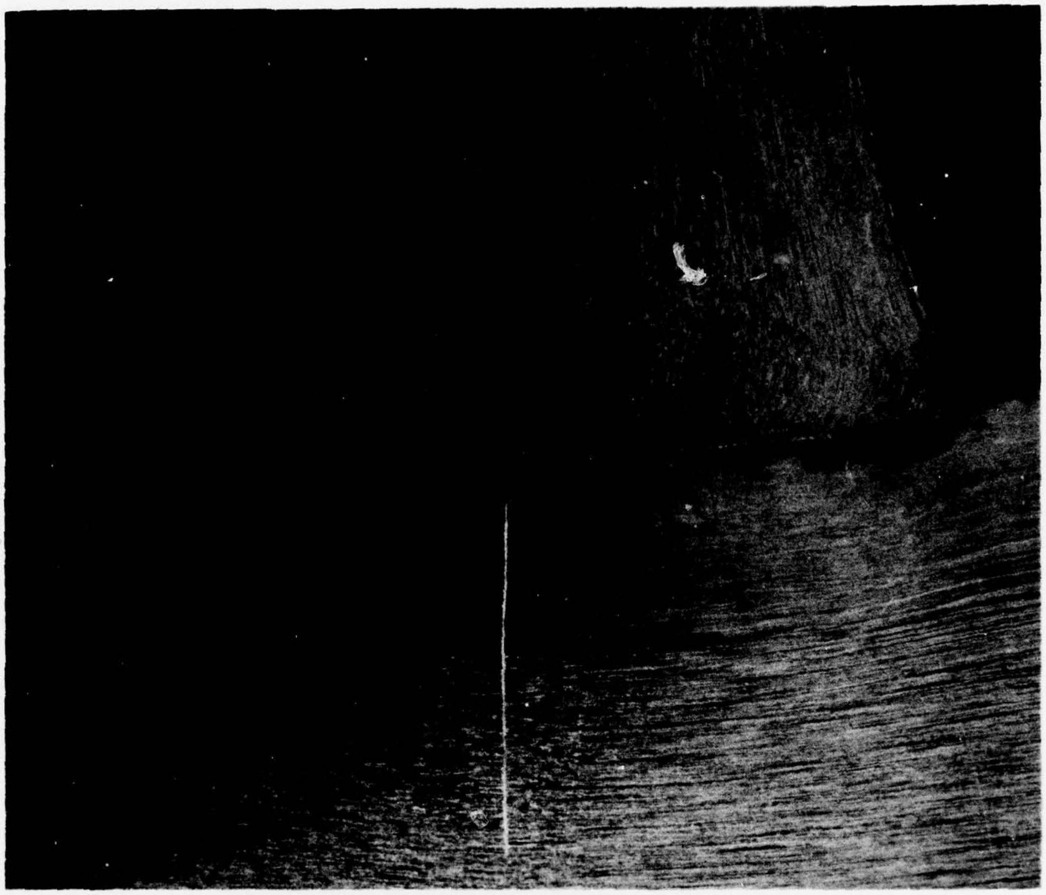
FIGURE 34. MACROETCHED SECTION OF LINK FROM SAMPLE C



0.25X IJ801

Macroetched (50 percent HCl in H_2O at 150 F)

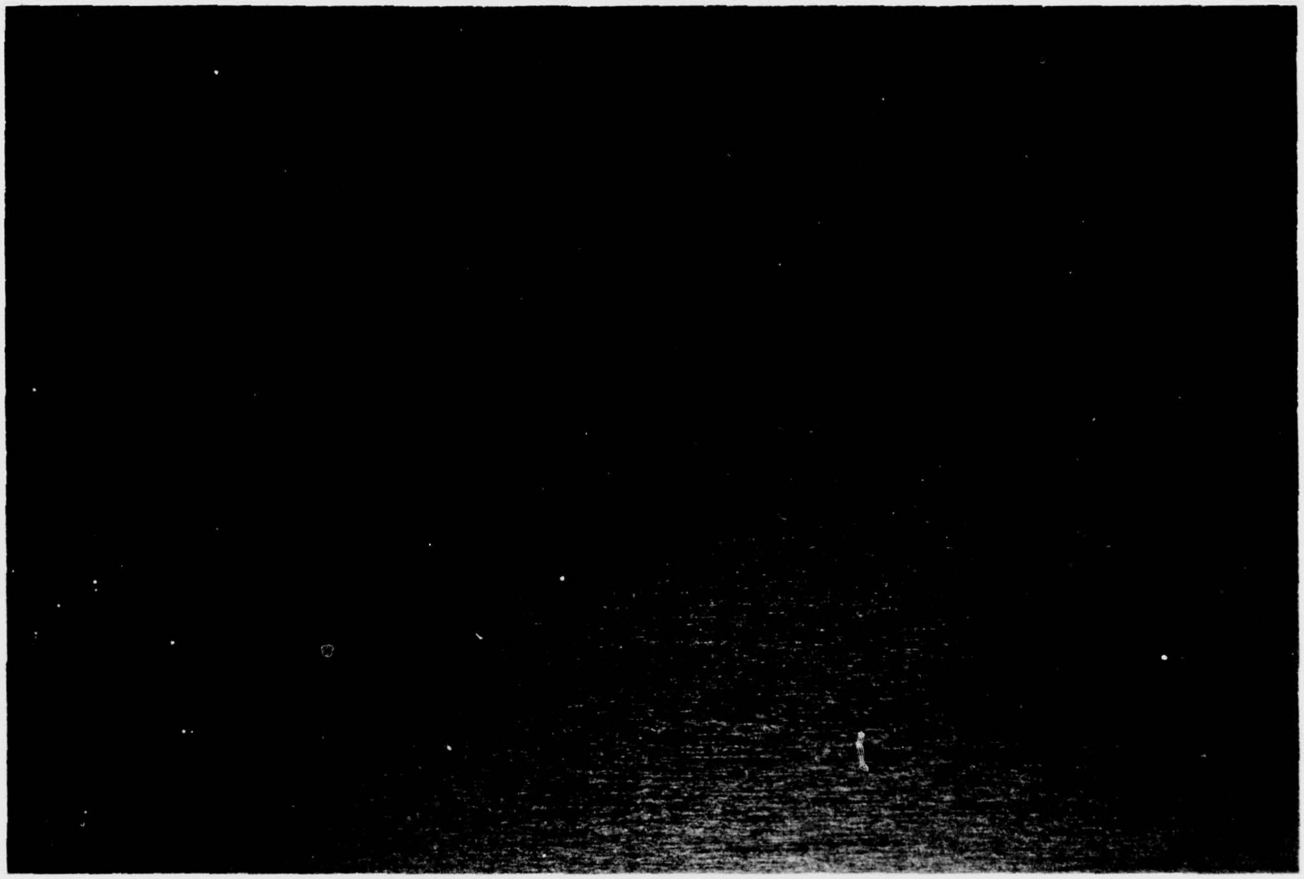
FIGURE 35. MACROETCHED SECTION OF LINK FROM SAMPLE D



1X IJ802

Macroetched (50 percent HCl in H_2O at 150 F)

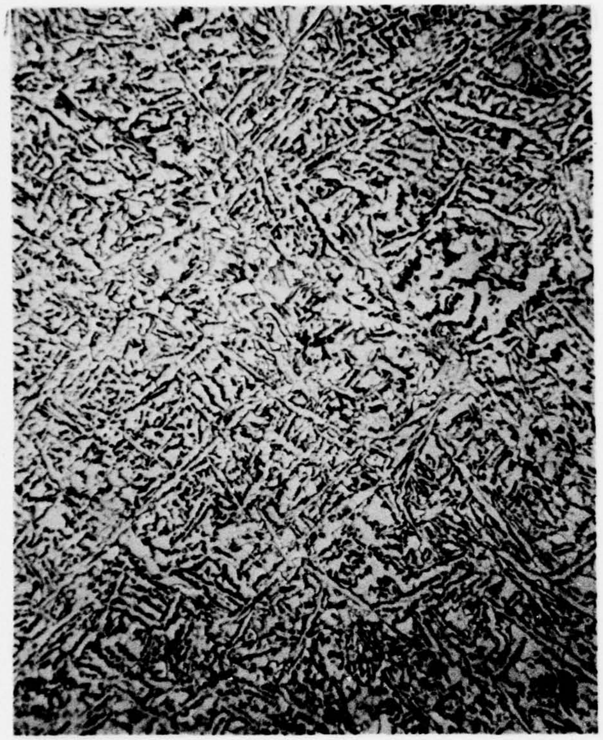
FIGURE 36. SMALL CRACKS IN FLASH-WELD TRIM REGION ADJACENT TO PRESSED-IN STUD IN LINK FROM SAMPLE D



1X IJ804

Macroetched (50 percent HCl in H_2O at 150 F)

FIGURE 37. CRACKS, LACK OF FUSION, AND POOR CONTOUR OF STUD FILLET WELD IN LINK FROM SAMPLE C



250X IJ956

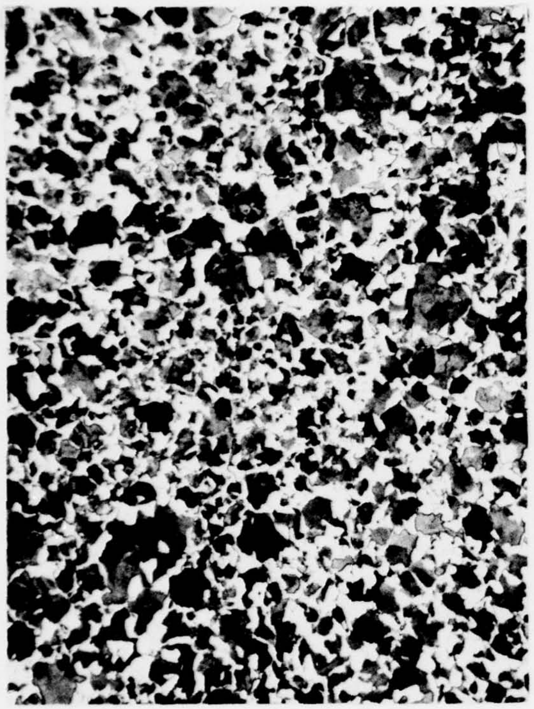
Picral Etch

FIGURE 38. COARSE WIDMANSTÄTTEN STRUCTURE IN FUSION ZONE OF LINK FROM SAMPLE C

100X 2J472

Picral Etch

FIGURE 39. COARSE PRIOR STRUCTURE OUTLINED BY DARK ETCHING MATERIAL ADJACENT TO FUSION ZONE IN LINK FROM SAMPLE D



250X IJ957

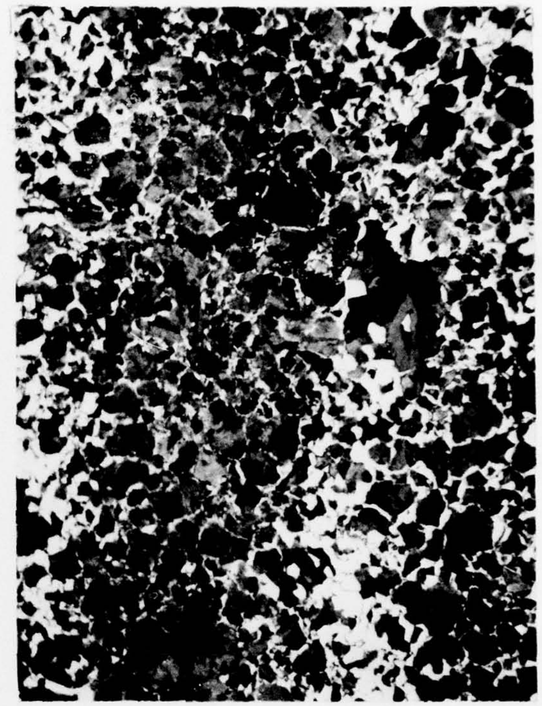
Picral Etch

a. Near Outside Surface

250X IJ958

Picral Etch

b. Half-Radius

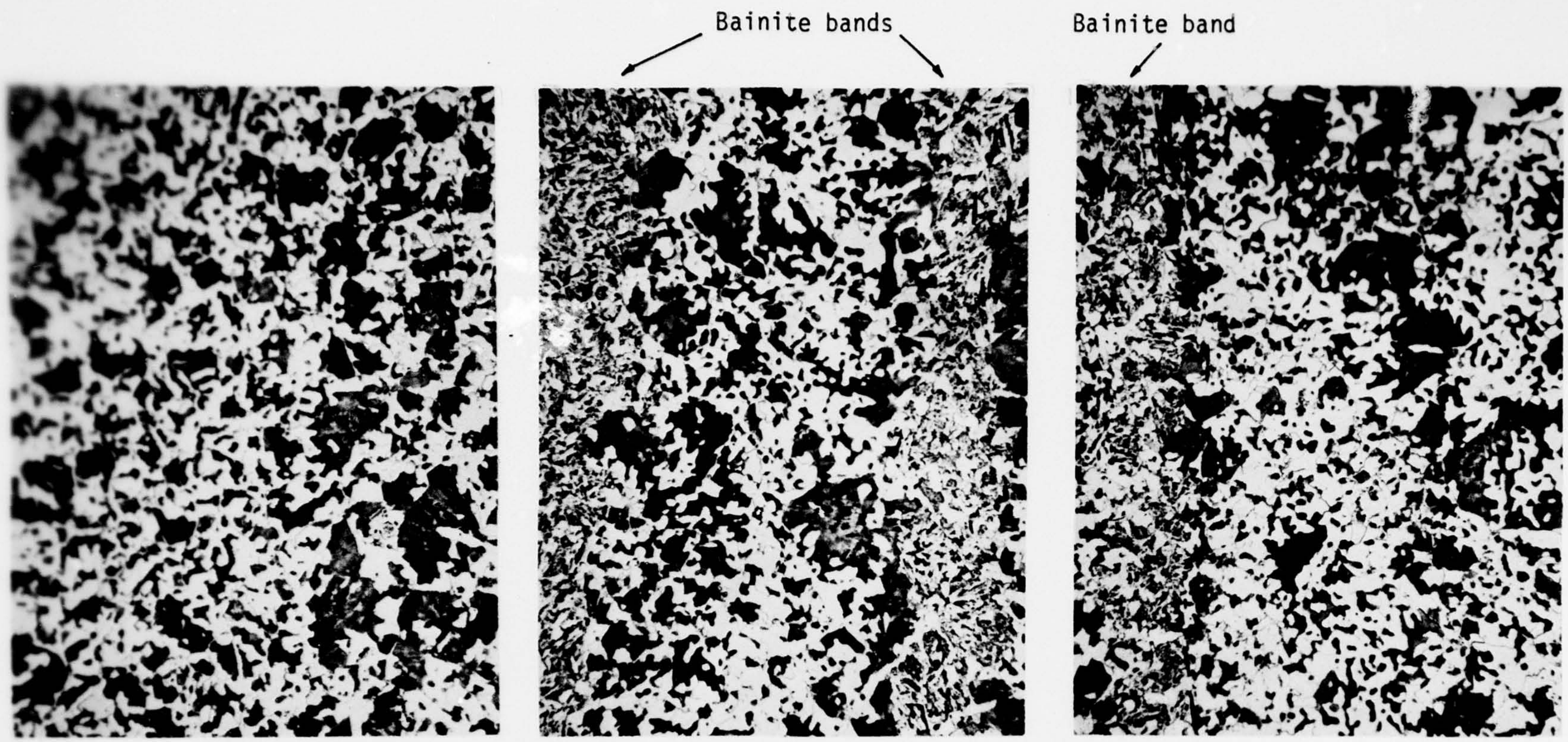


250X IJ959

Picral Etch

c. Near Center

FIGURE 40. VARIATION IN MICROSTRUCTURE FROM OUTSIDE SURFACE TO CENTER OF LINK FROM SAMPLE A



250X IJ950

Picral Etch

a. Near Outside Surface

250X IJ951

Picral Etch

b. Half-Radius

250X IJ952

Picral Etch

c. Near Center

FIGURE 41. VARIATION IN MICROSTRUCTURE FROM OUTSIDE SURFACE TO CENTER OF LINK FROM SAMPLE B

250X IJ953

Picral Etch

a. Near Outside Surface

250X IJ954

Picral Etch

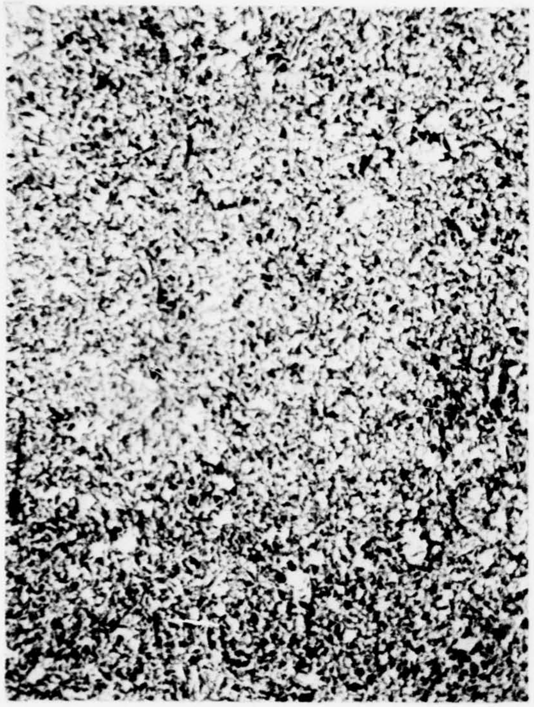
b. Half-Radius

250X IJ955

Picral Etch

c. Near Center

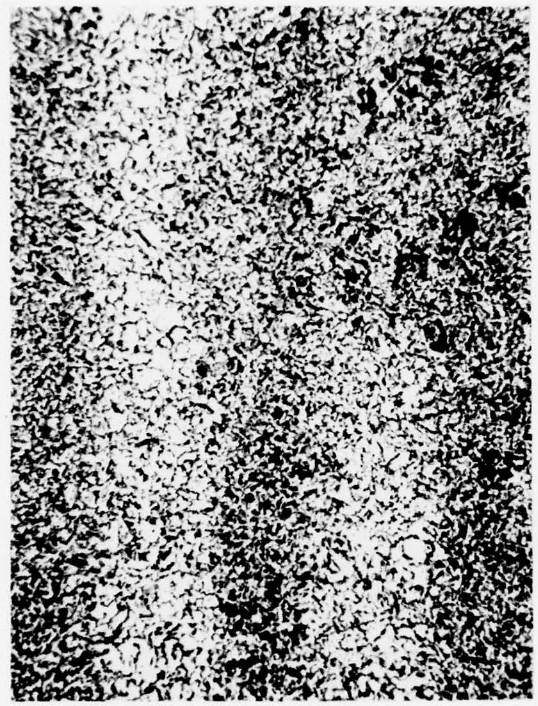
FIGURE 42. VARIATION IN MICROSTRUCTURE FROM OUTSIDE SURFACE TO CENTER OF LINK FROM SAMPLE C



250X IJ960

Picral Etch

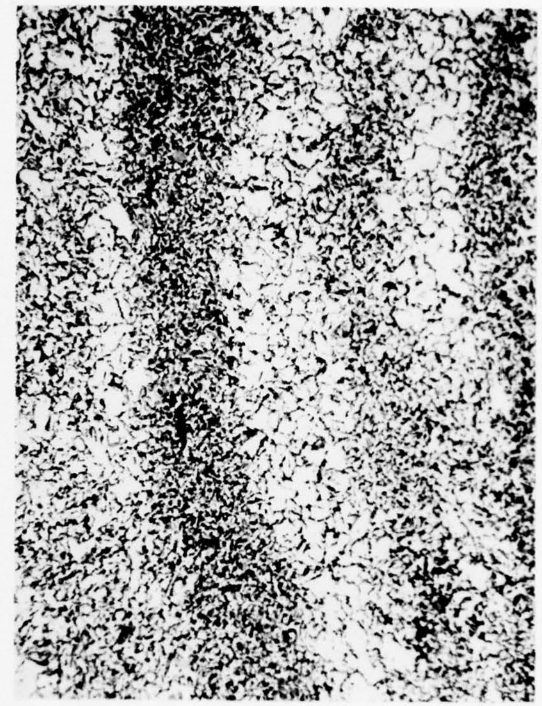
a. Near Outside Surface



250X IJ961

Picral Etch

b. Half-Radius



250X IJ962

Picral Etch

c. Near Center

FIGURE 43. VARIATION IN MICROSTRUCTURE FROM OUTSIDE SURFACE TO CENTER OF LINK FROM SAMPLE D