NRL Memorandum Report 878

EXPLOSION-BULGE TEST PERFORMANCE OF HY-80 WELDMENTS

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METALLURGY DIVISION

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U. S. NAVAL RESEARCH LABORATORY
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Details of illustrations in this document may be better studied on microfiche

by

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Welding Metallurgy Branch

Metallurgy Division

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CODE SHEET

CODE USED	EXPLANATION
B-Company	Alloy Rods Company 3100 West Market Street York, Pennsylvania
B-1	5/32-in. weld wire, Mil-11018, Type Atom Arc "T", Heat No. 78U530
C-Company	Air Reduction Company, Inc. Research Laboratories Murray Hill, New Jersey
C-2	1/16-in. weld wire A632, Heat No. X10059
E-Company	Development Laboratory LINDE Company Newark, New Jersey
E-1	5/32-in. weld wire Oxweld 68
E-2	Unionmelt flux - G80, 20 x 200 Mesh
E-3	1/8-in. weld wire Oxweld 68 - Heat No. X19813T
E-4	Unionmelt flux, G80, 20 x 200 Mesh, Lot 8625-Run 889
E-5	Unionmelt flux, G50, 8 x 48 Mesh, Lot 5150-Run 859
E-6	Unionmelt flux, G50, 8 x 48 Mesh, Lot 5986-Run 814
E-7	Unionmelt flux, G50, 8 x 48 Mesh, Lot 5151-Run 859
H-Company	ARCOS Corporation 1500 South 50th Street Philadelphia 43, Pennsylvania
H-1	5/32-in. weld wire, Mil-26015, Type Tensilend "120" Heat No. 5H32C
Y-Company	U. S. Steel Corporation 525 William Penn Place Pittsburgh 30, Pennsylvania
Z-Company	Lukens Steel Corporation Coatesville, Pennsylvania

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ABSTRACT

The increased use of HY-80 in recent years has made it desirable to develop satisfactory automatic welding methods for this steel. Based on requirements aimed at assuring notch tough weldment performance in cold water service, equipment and techniques of only one manufacturer have been approved to date by the Bureau of Ships for shipyard automatic welding of HY-80. The method involves the use of inert-gas-shielded metal-arc welding. The ready availability of submerged-arc equipment and operating personnel makes it desirable that satisfactory procedures be developed for this process. Previous submerged-arc weldment explosion tests had shown extensive weld or HAZ failures.

To evaluate weldments made with commercially available welding materials and relatively low welding-heat input, the Mare Island Naval Shipyard prepared submerged-arc weldments for explosion-bulge testing. For comparison purposes MINSY also submitted production-welded specimen weldments prepared by manual metal-arc (Mil-26015 and Mil-11018 electrodes) and inert-gas-shielded metal-arc (Mil-B-88 electrods) welding processes. Test results of six 2-in. thick manual metal-arc (Mil-11018) weldments fabricated by Industrial Testing Laboratory ~~(ITL)~~ and tested at Naval Proving Ground ~~(NPG)~~ were also included. These and two automatic submerged-arc welded samples which were laboratory-prepared by an industrial company were tested by explosion-bulge and Charpy V impact test procedures.

The impact test results showed that the Mil-11018 weld metal, and the inert-gas-shielded metal-arc weld metal exceeded minimum impact requirements of 20 ft-lb at -60°F. The Mil-26015 and submerged-arc weld metals did not meet these impact requirements. The submerged-arc weldments showed predominantly brittle weld-metal failures at 0°F and 30°F in both the conventional and crack-starter weld modified explosion-bulge test. The poor performance displayed by the submerged-arc weldments was due to the low notch toughness of the weld metal employed. The inert-gas-shielded metal-arc weldments had been prepared under rather high welding-heat conditions which resulted in a degraded HAZ and in failures in the HAZ of two of four weldments tested. Specimens manually welded with Mil-26015 and Mil-11018 electrodes developed small HAZ failures in three of four explosion-bulge tests. This performance indicated a small degradation of the HAZ owing to relatively high preheat (200°F) and interpass (300°F) temperatures. Both the inert-gas-shielded and the Mil-11018 metal-arc weldments indicated adequate notch toughness in the weld metal for cold water service. In all cases, specification quality HY-80 in either thickness (1- or 2-in.) was found to be highly resistant to fracture at test temperatures down to 0°F.

PROBLEM STATUS

This is a final report on one phase of HY-80 weldment studies; work on this problem is continuing.

AUTHORIZATION

NRL Problem M03-01

Project Nos. NS 021 200, NS 021 300

INTRODUCTION

During the past eight years, at the request of the Bureau of Ships, Code 637, the U. S. Naval Research Laboratory has conducted a continuing series of studies aimed at the establishment of factors which determine the performance of steel weldments. These studies have involved performance evaluations in explosion-bulge[1] and crack-starter[2] tests, the results of which have been correlated with conventional laboratory notch bend tests. From these and other related investigations conducted on mild, low alloy and quenched and tempered (Q&T) steels NRL has formulated new engineering principles and design concepts aimed at precluding service failures in specific structural applications[3,4,5].

In accordance with these concepts, "military case" structures (submarine hull, torpedo defense system, etc.), require materials possessing the maximum combination of strength and notch toughness so as to withstand the massive structural deformations expected under possible explosive attack. For "military case" service at temperatures of 0°F or below, the NRL studies have shown that only the Q&T alloy type steels are suitable. Fabrication difficulties encountered with the Q&T materials used previously, led to the development of an alloy designated as HY-80 (Mil-S-16216C) which was more weldable and still possessed adequate strength. Subsequent studies have demonstrated that specification quality HY-80 material is highly notch tough and completely resistant to brittle fracture (even if severely deformed) at temperatures of -20°F and higher[6].

As is common for high strength, Q&T materials, HY-80 displays a ready response to the thermal effects of welding. Accordingly, control of welding procedures and fabrication techniques are considered essential for the production of welded joints which are suitable for the dynamic loadings expected in "military case" service applications. From results of explosion-bulge tests of specimens involving variable welding conditions and from the investigations and fabricating experience of participating shipyards, summary instructions of the basic rules for welding of HY-80 have been prepared and issued by BuShips[7]. This instruction will be used for all future construction where critical loading may occur. Briefly, the requirements of this instruction include electrode handling to minimize moisture, application of moderate preheats, and welding procedures aimed at precluding a degradation of HAZ properties. These requirements are considered to be no more stringent than those required formerly for submarine construction utilizing medium-carbon high-tensile-strength steel (HTS) and considerably less stringent than would be required if similar construction was made with the Q&T special treatment steel (STS).

During recent years, the specified use of HY-80 has steadily increased for all critical Bureau construction. The need for the development and qualification of automatic welding methods was fully apparent from the magnitude of the contemplated HY-80 program. Accordingly, a comprehensive development and test program involving NRL, Naval and industrial shipyards, and industrial welding equipment companies was established by BuShips (Code 637). Considerable improvements in electrodes, welding procedures, and techniques have been developed since the World War II period. However, from the standpoint of notch toughness, it has not been possible to obtain weld metal deposits with notch toughness properties equivalent to that of specification quality HY-80 plate material. The ultimate goal of the BuShips HY-80 welding program is to obtain automatic weld metal deposits with notch toughness properties equal to or superior to those of HY-80. For practical purposes, however, this program was initially aimed for the development of materials and techniques for machine welding of HY-80 which would assure optimum weldment performance for "military case" service at all temperatures down to that of cold water (approximately 30° to 40°F). From NRL studies(8) it was indicated that the minimum starting point to assure notch tough weldment performance in cold water service should be the development of high strength (slightly over-matching that of the HY-80) automatic weld deposits which would exceed, if possible, 20 ft-lb Charpy V at -60°F.

Based upon meeting the minimum requirements stipulated above, and demonstrated excellent performance in explosion-bulge tests of 1-in.-thick machine welded HY-80 samples(6), the equipment and techniques of one industrial welding equipment company have received Bureau approval for shipyard applications of automatic welding of HY-80 (C-Company, inert-gas-shielded metal-arc equipment, Specification No. Mil-E-19822).

Because submerged-arc welding equipment and personnel experienced with such equipment already exist in the various shipyards, it would be economically desirable to develop submerged-arc welding processes suitable for automatic welding of HY-80. In addition to the development work conducted by industrial submerged-arc welding equipment companies, several Naval shipyards have been engaged in independent investigations aimed at the development of satisfactory high-strength, notch-tough submerged-arc weld deposits.

Initial studies conducted by the Mare Island Naval Shipyard appeared to indicate that commercially available submerged-arc welding materials could be employed to produce suitable weldments of HY-80. Weld metal specimens that were cut from test plates welded under optimum laboratory conditions were reported to give satisfactory tensile properties (95,000 psi Y.S. and 22% Elongation) and Charpy impact values (in excess of 40 ft-lb at -60°F). In order to evaluate the performance of such weldments and to obtain Bureau approval of the process and techniques employed, several weldments were prepared by the shipyard under production welding conditions and submitted for explosion-bulge tests. For comparative purposes, additional HY-80 weldments made under production welding conditions involving manual metal-arc (Type Mil-26015 and Mil-11018 electrodes) and inert-gas-shielded metal-arc (Type Mil-B-88 electrode) welding processes also were submitted for evaluation. Test results of six 2-in.-thick HY-80 weldments (Mil-11018 electrode) fabricated by Portsmouth Naval Shipyard and tested at U.S. Naval Proving Ground are also included for comparison. In addition to the above, explosion-bulge tests were made on two submerged-arc samples which were automatically welded by E-Company laboratory personnel.

PRIME PLATE AND WELD METAL TESTS

Explosion-bulge tests are conducted with samples measuring 20-in. square. All weldments requested for these tests were 24 x 24-in. Prior to the explosion-bulge testing, the surplus material removed from each weldment was used for NRL studies of plate and weld metal properties. Table 1 lists pertinent details concerning the five HY-80 plates used for the various weldments prepared for this investigation. Figure 1 depicts the average Charpy V curves for four of these plates; the heavy dots superimposed on these curves indicate the nil-ductility transition (NDT) temperatures established for these steels. It is readily apparent from these data that all plates conform to specification quality HY-80 (Charpy V impact requirements of 50 ft-lb at -120°F). From experience, it is estimated that all of these plates would be highly resistant to brittle fracture at test temperatures at least as low as -20°F.

Figure 2 (center and bottom) depicts the joint designs used for the various weldments fabricated by MINSY. From each of these latter weldments, eight weld metal Charpy V specimens (four each top and bottom) were machined as shown schematically in Fig. 2, top, and tested by NRL. From specimens machined from experimental test plates made under laboratory conditions, the shipyard had obtained weld metal Charpy impact values in excess of 40 ft-lb at -60°F. The NRL Charpy V tests of the submerged-arc weld deposits made under production conditions, however, differed greatly (Fig. 3, bottom) from the results originally reported by the shipyard. While explosion-bulge tests of these submerged-arc samples were being conducted at NRL, the shipyard discovered and reported that their original Charpy specimens had inadvertently been machined with an 0.024-in. radius V notch instead of the standard 0.010-in. radius V notch. Subsequently, Charpy specimens machined separately at NRL and the shipyard, involving both types of notches, were exchanged and tested by both activities. The results obtained at both laboratories proved that the high values were obtained with the "dull" notch specimens, and established the data of Fig. 3, bottom, as representative of the average (STANDARD) Charpy V notch transition curve obtained for this submerged-arc weld deposit made with commercially available materials.

Weld metal tests were not conducted for the two submerged-arc weldments fabricated by E-Company. The weld metal Charpy V data of Fig. 3, top, indicate an average 20 ft-lb Charpy V temperature of 0°F for the Mil-26015 electrodes used for this investigation. From previous NRL experience with this type of weld metal, it was expected that the 20 ft-lb Charpy V temperature would be approximately -60° to -70°F[8]. Recent quality control checks reported to the Bureau by various shipyards indicate that the Charpy V 20 ft-lb temperature of different heats of Mil-26015 electrodes have varied from -80° to 40°F.

Weld metal Charpy V transition curves for the manual Mil-11018 and the automatic inert-gas-shielded metal-arc weld deposit studies in this investigation are shown in Fig. 4. These electrodes are Bureau approved for the welding of HY-80. Both of these weld deposits surpass minimum specification requirements of average 20 ft-lb Charpy V impact values at

-60°F, and, therefore, are expected to be resistant to fracture at cold water temperatures. The transition curve of the inert-gas-shielded metal-arc weld deposit is seen to be moderately superior to that of the Mil-11018 weld deposit.

EXPLOSION-BULGE TESTS OF HY-80 WELDMENTS

Explosion-bulge test conditions established previously for 1-in.-thick HY-80 weldments were followed in this investigation. Conventional bulge test procedures require the application of repeated explosive shots in order to delineate the critical regions of the weldment and the level of deformation at which failures may start and subsequently propagate. For screening purposes, it is desirable to add a crack-starter weld because only one explosive shot* is required for bulge test evaluations of such samples. Explosion tests were conducted principally at 0°F test temperature to permit comparisons with previously reported explosion-bulge tests of various Q&T steels(6,9,10,11). However, a limited number of samples were tested at 30°F in order to indicate the relative performance at the minimum expected cold water service temperature.

The materials and procedures used for the various explosion test samples are detailed in Table 2. Half the specimens of each weld type were tested in a bulge test modified with crack-starter welds, and the other half of each group were tested in the conventional explosion-bulge test. Table 3 summarizes results obtained in the conventional explosion-bulge test. It should be noted that five of the eight submerged-arc weldments developed visible indications of transverse weld metal cracking or fusion line failures after the 1st shot. Thus, the bulge test performance exhibited by these submerged-arc weldments is considered to be poor.

Figures 5 to 9 illustrate the appearance of all submerged-arc welded HY-80 samples after the explosion tests were concluded. The numbers shown on each weldment represent sample number and test temperature (top) and total number of shots (lower right). The data of Table 2 and the welding sequence shown beneath each sample in Figs. 6 to 8 indicate that stringer bead welding techniques were employed so as to develop optimum HAZ properties in these submerged-arc weldments. The extensive longitudinal and transverse weld metal ruptures developed in the samples which were modified with the crack-starter weld are indicative of high brittleness at 0° and 30°F for these submerged-arc weld deposits made with commercially available materials. Transverse hairline crack indications also were found in the as-received condition of sample No. 15 (Fig. 9). In this sample, and all others as well, the HY-80 plate materials displayed a high resistance to fracture, and developed only short shear tears with no evidences of brittleness.

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*The purpose is to develop a crack which results in the catastrophic propagation of a fracture if the weld, HAZ, or fusion line have tendencies for low energy propagation of this crack. In the absence of such a condition of weakness, short tears result indicating desirable performance.

Figure 10 illustrates the appearance of the inert-gas-shielded metal-arc weldments. It should be noted that the welding sequence and the high welding energy input, Table 2, used for these samples are those which are not recommended by the Bureau for the welding of HY-80[7]. Such procedures previously have been shown to result in a degradation of HY-80 HAZ properties[6]. Accordingly, the HAZ failure developed on the 2nd shot at 0°F in sample No. 18 and the small HAZ failure developed in the modified crack-starter test of sample No. 20 are ascribed to the use of undesirable welding conditions. As would be predicted from the Charpy V impact tests, however, brittle failures were not developed in either weld metal or HY-80 plate metal areas of these inert-gas-shielded metal-arc weldments.

Similar welding procedures were employed for both sets of Mil-26015 and Mil-11018 samples which involved stringer bead welding techniques. However, 200°F preheats and 300°F interpass temperatures were used for these manually welded samples. The fracture appearances of all manually welded samples after the explosion tests were concluded are illustrated in Figs. 11 and 12.

In conventional bulge tests of these samples (Fig. Nos. 11 and 12, top) a moderate HAZ failure was developed after the 1st shot in sample No. 22, and small HAZ tears were developed in sample Nos. 23 and 25 after the 3rd shot. The failure which developed after the 3rd shot in sample No. 28 consisted of a short weld-metal shear tear. The samples which were modified with crack-starter welds (Fig. Nos. 11 and 12, bottom) exhibited only short, plate-metal shear tears. It is deduced that the use of moderately high preheat and interpass temperatures results in the development of some degradation of HY-80 HAZ properties. This degradation, however, is minor in comparison with that developed by the use of high welding energy heat inputs such as were used for the inert-gas-shielded metal-arc weldments.

Because of hardenability requirements, the chemical composition limits specified for HY-80 are increased for material of 1-3/8-in. and heavier thicknesses. Explosive limitations of the NRL test facilities have resulted in bulge test evaluations only of 1-in.-thick HY-80 weldments. Satisfactory notch toughness characteristics in the high-chemistry heavy HY-80 steels have been predicated upon Charpy V tests exceeding the minimum specified requirements of 30 ft-lb at -120°F. In order to demonstrate the fracture resistance of thick HY-80 weldments, the ITL of Philadelphia Naval Shipyard was asked to select at random a 2-in.-thick HY-80 plate from the shipyard stock and to prepare 30-in. square weldments in accordance with the practices recommended by the Bureau of Ships instruction[7]. Mil-E-11018 electrodes were also selected at random from available stock and used for these test specimens. The samples were explosion-bulge tested by the Armor and Projectile Laboratory of the NPG using 25-pound explosive charges. Testing was discontinued for two samples which were explosion-bulge tested at ambient temperature (70°F) because no visible indications of failure were apparent after approximately 15% thickness reduction had been developed by six shots (Figs. 13 and 14). High resistance to fracture was also obtained with four additional 2-in.-thick weldments which were bulge-tested at 30° and 0°F (Figs. 15 to 18).

In these tests, initial indications of failure were evident as small (1-in. long or less) toe cracks only after either the 3rd or 4th shot (approximately 7 to 9% thickness reduction). Additional explosive shots were used on these samples in order to force the failures and to observe the existance, if any, of preferred fracture propagation paths. High resistance to fracture propagation is demonstrated in these weldments by the fact that even after the appearance of the initial toe cracks two or three additional 25-pound explosive shots were required to penetrate the weldment thickness of three of these weldments. No evidences of preferred fracture propagation paths were observed.

SUMMARY AND CONCLUSIONS

In previous investigations, HY-80 weldments made with commercially available submerged-arc process materials and high energy input welding conditions were found to be characterized by high brittleness of the weld or the HAZ[6]. The submerged-arc process weldments studied in this investigation also were made with commercially available materials; however, much lower energy input welding conditions generally were employed to minimize the HAZ degradation which always occurs to some extent in a weldment. Consequently, the failures which developed in explosion tests of these submerged-arc process weldments were found to be predominantly fractures within the weld metal region. The unsatisfactory fracture performance exhibited by these submerged-arc process welds is in conformance with predictions that could be made from standard Charpy V tests of this weld metal. The Charpy V results also indicated that these commercially available submerged-arc process materials develop weld deposits which display low energy absorption characteristics at all temperatures. Steels which display similar low energy absorption characteristics, previously tested, have been shown to be unsatisfactory at all temperatures for "military case" applications[11].

The test results obtained with the inert-gas-shielded metal-arc process weldments generally have corroborated previously established data. Adequate notch toughness at cold water service is insured in the weld deposit by the specification under which this weld metal is procured. Consequently, the resulting failures developed in weldments made with specification quality HY-80 were found to be limited to HAZ regions which were adversely affected by the use of unusually high energy input welding conditions. As expected for this group of samples, brittle failures were not obtained at the test temperatures studied in either weld metal or prime plate metal areas.

The limited number of tests of manually welded 1-in.-thick samples did not permit a clear definition of the relative performance of the Mil-11018 electrodes compared to that of the Mil-26015 type. Charpy V test results for these weld metals, however, indicated that the notch ductility of the Mil-11018 deposit was superior to that of the Mil-26015 deposit. Both types of manual weldments were made with the maximum allowable interpass temperature (300°F), and the explosion test results indicated a moderate degradation of the HAZ was developed. The tests indicate that preheat and interpass temperatures above 300°F should not be permitted.

With respect to the various weldments investigated herein, the following general conclusions are warranted:

1. The D-Company submerged-arc process weldments employing commercially available materials were characterized by brittleness of the weld at 0° and 30°F and low energy absorption properties at all temperatures. Accordingly, in their present state of development, these materials cannot be considered suitable for use at any temperature in military structures in which high resistance to fracture is required.

2. Weldments involving inert-gas-shielded metal-arc processes have been shown to develop notch ductile weld deposits which are suitable for "military case" structures in cold water service. In order to obtain optimum fracture performance with specification quality HY-80 automatically welded by this process, it is essential to control welding conditions so as to minimize the degradation of the HAZ area which results from the use of high energy input welding conditions. Welding techniques and conditions which conform to the Bureau instruction regarding basic rules for welding HY-80 should be employed when using this welding process.

3. Of the manual electrodes studied in this investigation, the Mil-11018 type indicate a greater resistance to fracture at cold water temperatures than that obtainable with the Mil-26015 type.

4. Specification quality HY-80 was employed throughout this investigation and both low- and high-chemistry HY-80 plates were demonstrated to be highly resistant to fracture at both 30° and 0°F. Because of thermal effects of welding the fracture resistance of HAZ areas of HY-80 plates are shown to be decreased by the use of high energy input welding conditions. High preheats and interpass temperatures are moderately detrimental to the properties of the heat affected zone.

REFERENCES

1. Hartbower, C. E. and Pellini, W. S., "Explosion-Bulge Test Studies of the Deformation of Weldments," WELDING JOURNAL, June 1951.

2. Puzak, P. P., Schuster, M., and Pellini, W. S., "Crack-Starter Tests of Ship Fracture and Project Steels," WELDING JOURNAL, October 1954; and Ship Structure Committee Report, SSC-77.

3. Puzak, P. P. and Pellini, W. S., "Effect of Temperature on the Ductility of High-Strength Structural Steels Loaded in the Presence of Sharp Cracks," NRL Report 4545, June 1955.

4. Puzak, P. P. and Pellini, W. S., "Evaluation of the Significance of Charpy Tests for Quenched and Tempered Steels," WELDING JOURNAL Research Suppl., June 1956.

5. Pellini, W. S. and Puzak, P. P., "Development of An Engineering Approach to the Problems of the Brittle Fracture of Steels," to be issued as an NRL Report.

6. Puzak, P. P., "Explosion-Bulge Test Performance of Machine Welded 1 Inch Thick HY-80 Steel," NRL Memo Report 691, April 1957.

7. Bureau of Ships Notice 9110, Ser 637-735, "Welding of HY-80 - General Rules for," 2 July 1958.

8. Pellini, W. S., "Notch Ductility of Weld Metal," WELDING JOURNAL, May 1956.

9. Pellini, W. S. and Eschbacher, E. W., "Investigation of the Performance of 1-In. S.T.S. Weldments of G260 and 25-20 Types," NRL Memo Report 191, July 1953.

10. Puzak, P. P. and Pellini, W. S., "Explosion-Bulge Test Performance of 1-In. S.T.S. Semi-Automatic Inert-Gas Metal-Arc Weldments," NRL Memo Report 391, November 1954.

11. Puzak, P. P., "Explosion-Bulge Test Performance of Low Carbon Ni-Cr-Mo-B Quenched and Tempered Steel," NRL Report 4919, May 1957.

Navy - NRL, Bellevue, D. C.

Table 1

Test Data for 1-Inch-Thick HY-80 Plate Materials

Plate No.	Mfr.	Heat No.	%C	%Mn	%Si	%Ni	%Cr	%Mo	%Cu	T.S.** (psi)	Y.S.** (psi)	El.** (% in 2-in.)	R.A.** (%)	NDT*** (oF)	
1	Code Y	097491	0.13	0.23	0.25	2.06	1.14	0.19	0.04	*	*	*	*	-120	NRL
2	*	*	0.14	0.34	0.24	2.35	1.05	0.29	0.06	*	*	*	*	-150	NRL
			0.15	0.33	0.26	2.30	1.20	0.26	*	105,800	95,200	28.2	66.9		MINSY
3	*	*	0.16	0.23	0.22	2.20	1.02	0.29	0.02	102,600	85,400	24.5	73.7	-140	NRL
			0.15	0.22	0.25	2.14	0.99	0.27	*	103,600	96,200	28.5	70.5		MINSY
4	Code Y	*	0.14	0.24	0.23	2.12	1.51	0.25	0.02	*	*	*	*	-160	NRL
			0.14	0.22	0.34	2.16	1.40	0.26	*	109,600	88,200	32.5	68.1		MINSY
5	Code Z	*	0.14	0.29	0.23	2.28	1.30	0.26	0.07	*	*	*	*	-150	NRL
			0.15	0.33	0.30	2.26	1.20	0.26	*	100,900	87,000	40.0	71.0		MINSY

* Not established.

** Average of two specimens.

*** NDT temperature established with 5/8 x 2 x 5-in. specimens cut from the plate surface and tested with a 0.075-in. anvil stop. NRL studies of drop-weight testing variables indicate that such procedures result in NDT determinations which are within ± 10oF of full thickness, standard drop-weight specimen test results.

Table 2

Materials and Procedures for Explosion Test Samples

Sample No.	HY-80 Plate No.	Amps.	Volts	Speed (ipm)	No. of Passes	Energy (Joules/in.)	Weld	Preheat (°F)	Interpass (°F)
1*	1	600	32	24	16	48,000	Submerged Arc	None	225
2*	1	320	27	18	31	28,800	"	"	225
3	2	475/500	27/30	19/29	12	32,000 to 40,500	"	"	200
4	2	475/520	27/30	19/29	12	32,250 to 42,400	"	"	200
5	3	540	27/31	24/26	12	38,600 to 43,600	"	"	200
6	3	540	27/32	20/26	12	40,000 to 43,600	"	"	200
7	3	540	27/31	20/26	12	38,500 to 43,600	"	"	200
8	3	540	27/31	20/26	12	38,500 to 43,600	"	"	200
9	3	540	27/33	20/26	12	38,500 to 43,500	"	"	200
10	3	540	27/31	20/26	12	38,500 to 43,500	"	"	200
11	3	540	27/31	20/27	12	37,200 to 43,740	"	"	200
12	3	540	27/31	20/27	12	37,200 to 43,740	"	"	200
13	4	440	34/36	28	19	32,000 to 33,950**	"	"	200
14	4	440	35	28/30	20	30,600 to 33,000**	"	"	200
15	4	440	35	28	20	33,000**	"	"	200
16	4	440	35	28	21	33,000**	"	"	200
17	5	310	29	8/10½	6	51,500 to 67,200	Inert-Gas-Mil B-88	"	200
18	5	310	29	8/14	10	38,500 to 67,200	" " "	"	200
19	5	310	29	8/12	8	45,000 to 67,200	" " "	"	200
20	5	310	29	8/14	10	38,500 to 67,200	" " "	"	200

Table 2 (Cont.)

Sample No.	HY-80 Plate No.	Amps.	Volts	Speed (ipm)	No. of Passes	Energy (Joules/in.)	Weld	Preheat (°F)	Interpass (°F)
21	4	200	19	Manual DCRP	14	5/32-in. Electrode	Mil 26015	200	300
22	5	200	19	"	14	" "	"	200	300
23	5	200	19	"	14	" "	"	200	300
24	5	200	19	"	14	" "	"	200	300
25	4	200	19	Manual A.C.	14	" "	Mil 11018	200	300
26	4	200	19	"	14	" "	"	200	300
27	4	200	19	"	14	" "	"	200	300
28	4	200	19	"	14	" "	"	200	300

* Single V, 60° included angle weldments fabricated by E-Company.

** 1st two root passes made with 43,600 Joules/in.

Table 3

Explosion-Bulge Test Data

Sample No.*	HY-80 Plate No.	Weld	Charge (lb)	Stand off (in.)	Test Temperature (°F)	1st Shot	2nd Shot	3rd Shot
1	1	Submerged Arc	7	15	0	F		
3	2	"	7	15	0	F		
5	3	"	7	15	0	N	N	N
6	3	"	7	15	0	N	N	N
11	3	"	7	15	0	F		
12	3	"	7	15	0	N	N	N
14	4	"	7	15	0	F		
15**	4	"	7	15	30	F		
18	5	Inert Gas	7	15	0	N	F	
19	5	"	7	15	30	N	N	N
22	5	26015	7	15	0	F		
23	5	"	7	15	30	N	N	F
25	4	11018	7	15	0	N	N	F
28	4	"	7	15	30	N	N	F

* Sample Nos. which are omitted were given one shot in bulge test modified with crack-starter weld.

** Weldment contained visible transverse weld cracks in as-received condition.

N = No visible indication of failure. Testing was discontinued after the 3rd shot.

F = Failure as shown in photographs (Figs. 5 to 12).

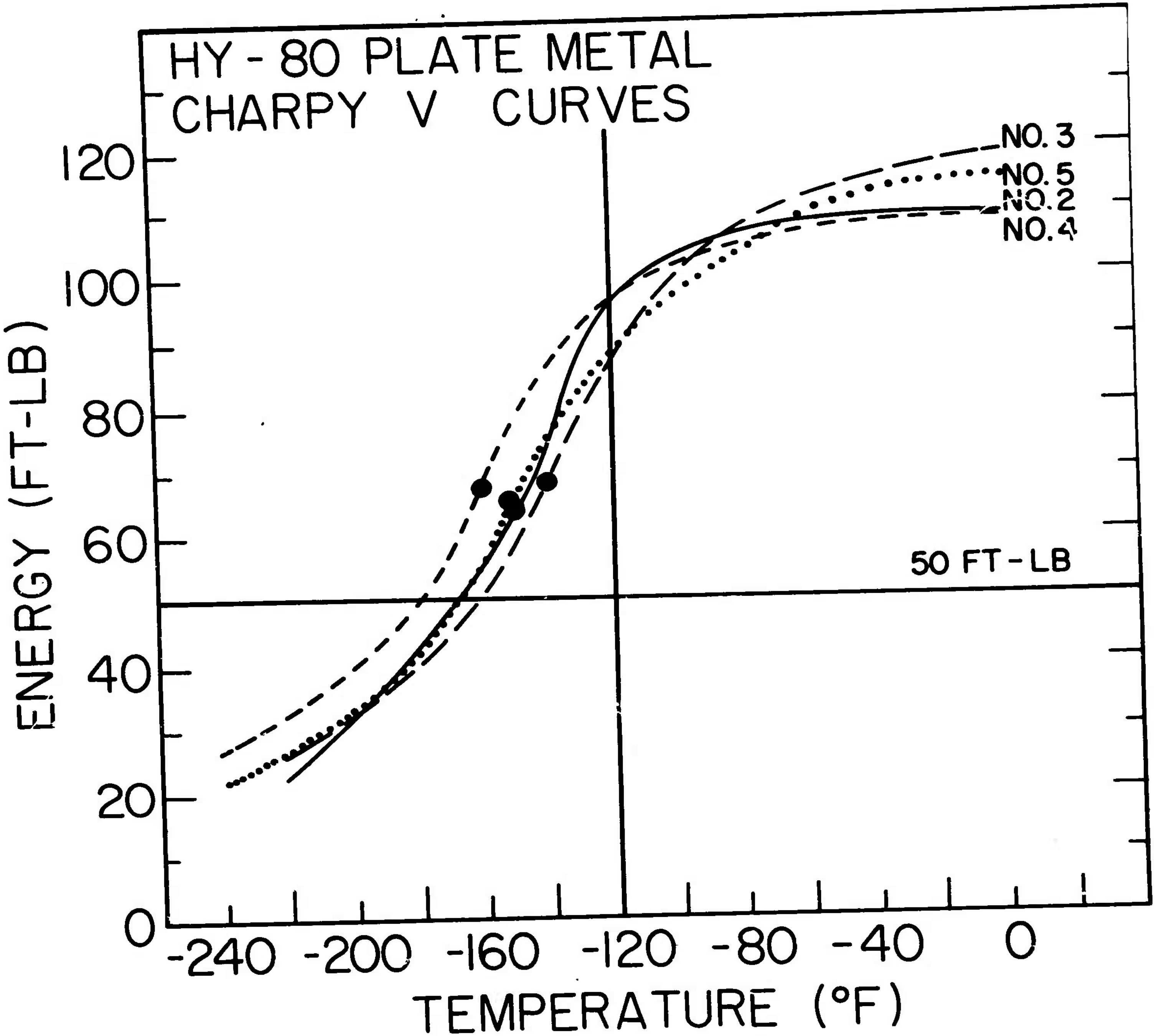


Fig. 1 - Charpy V transition curves and NDT results (heavy dots) for HY-80 prime plate materials

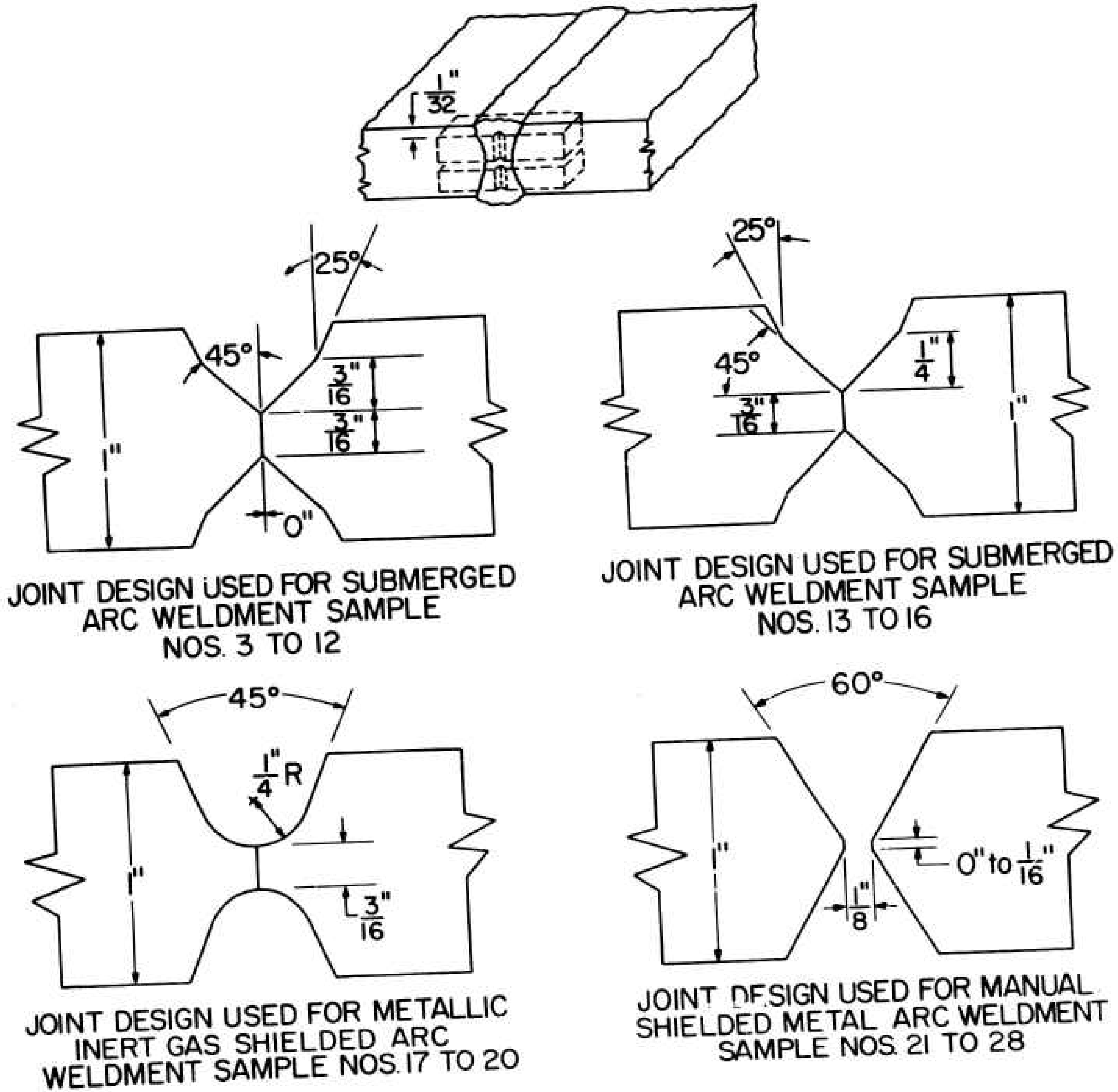


Fig. 2 - Details of specimen preparation (top) and joint designs used for various weldment samples (center and bottom)

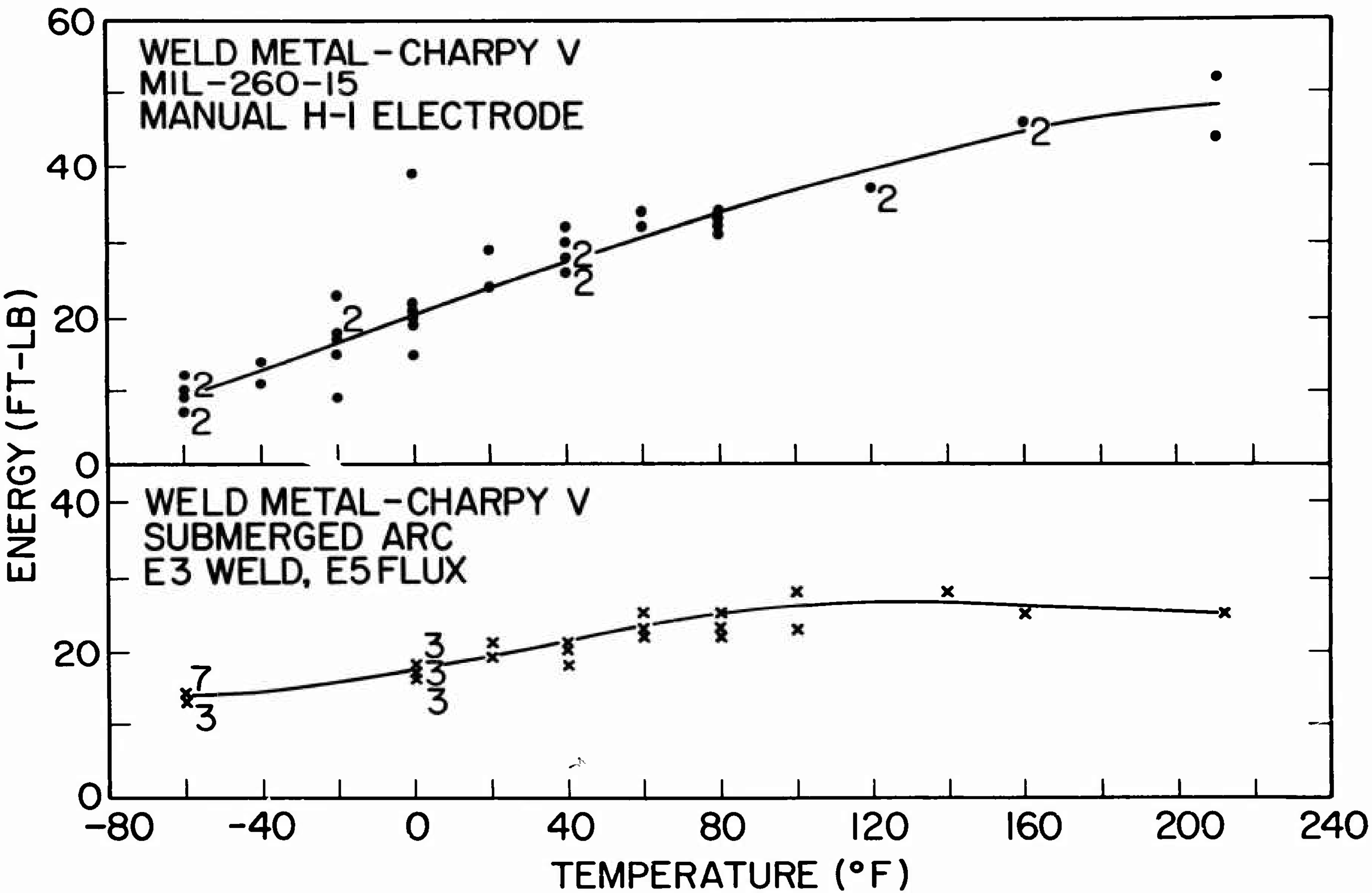


Fig. 3 - Charpy V transition curves for automatic submerged-arc and manual Mil 26015 weld deposits. Note low maximum energy shelf values obtained with submerged-arc weld metal.

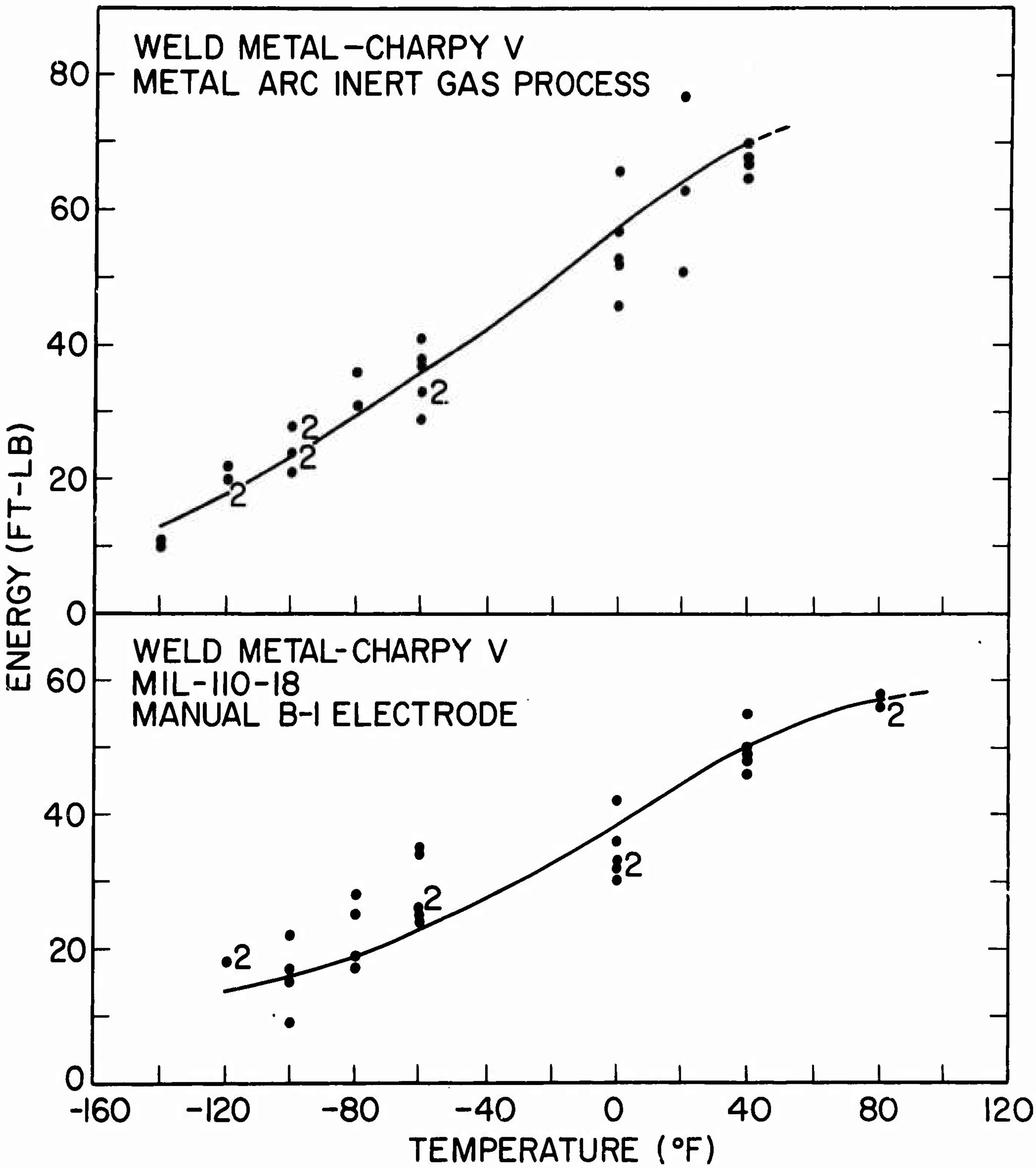


Fig. 4 - Charpy V transition curves for automatic inert-gas-shielded and manual Mil 11018 weld deposits

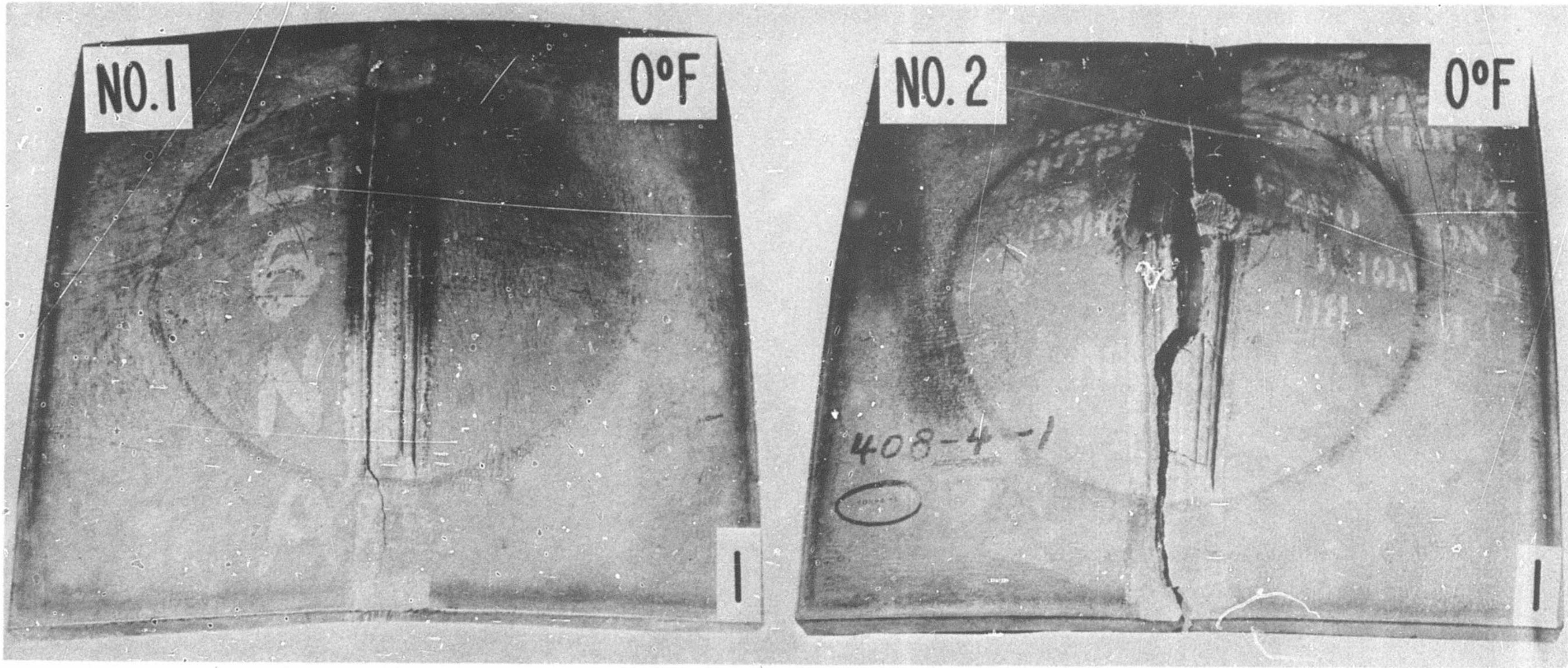


Fig. 5 - Explosion-bulge test fracture characteristics of submerged-arc weldments fabricated by E-Company. Sample No. 2 was modified with crack-starter weld.

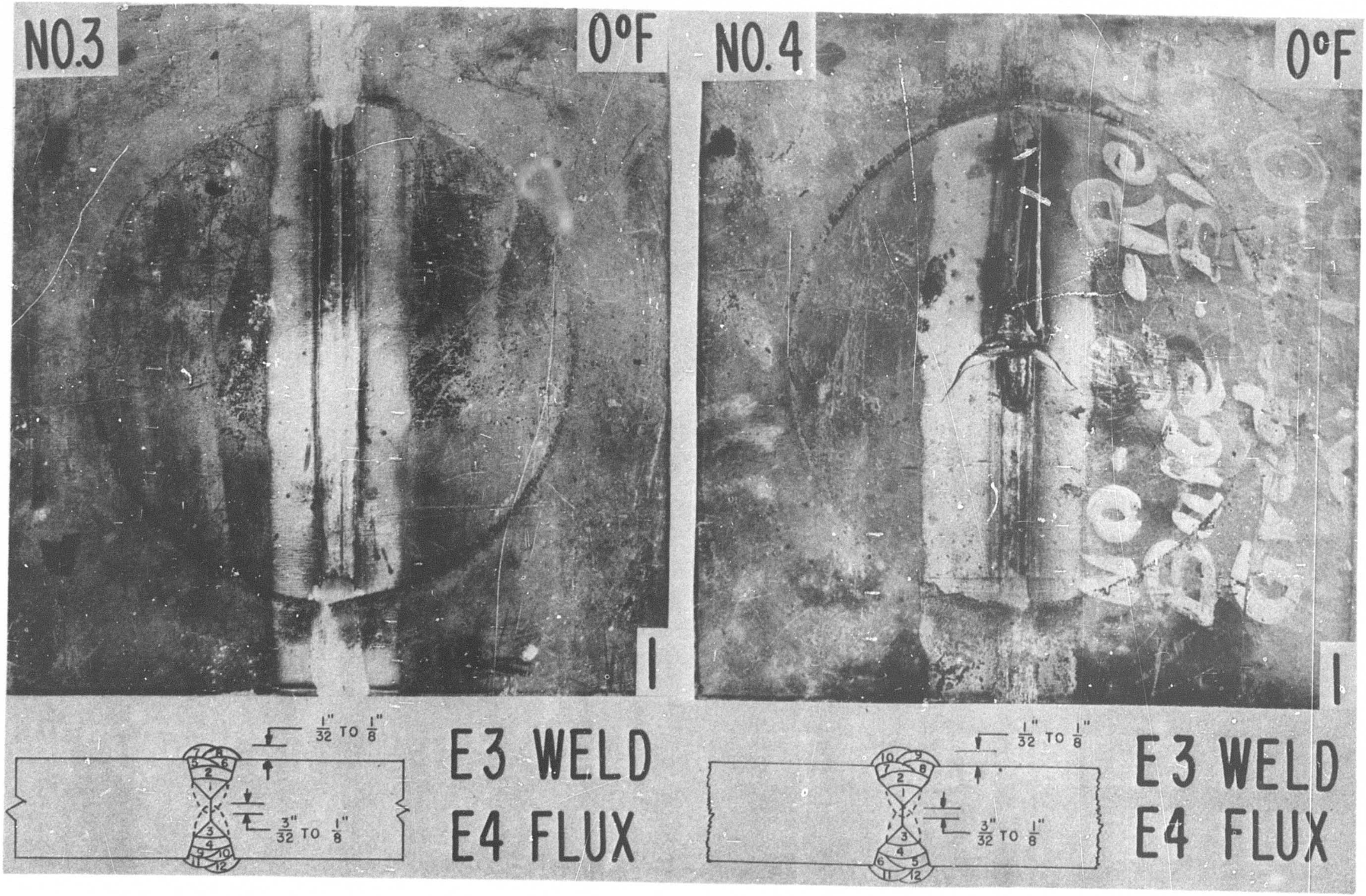


Fig. 6 - Explosion-bulge test fracture characteristics of submerged-arc weldments fabricated by MINSY. Sample No. 4 was modified with crack-starter weld.

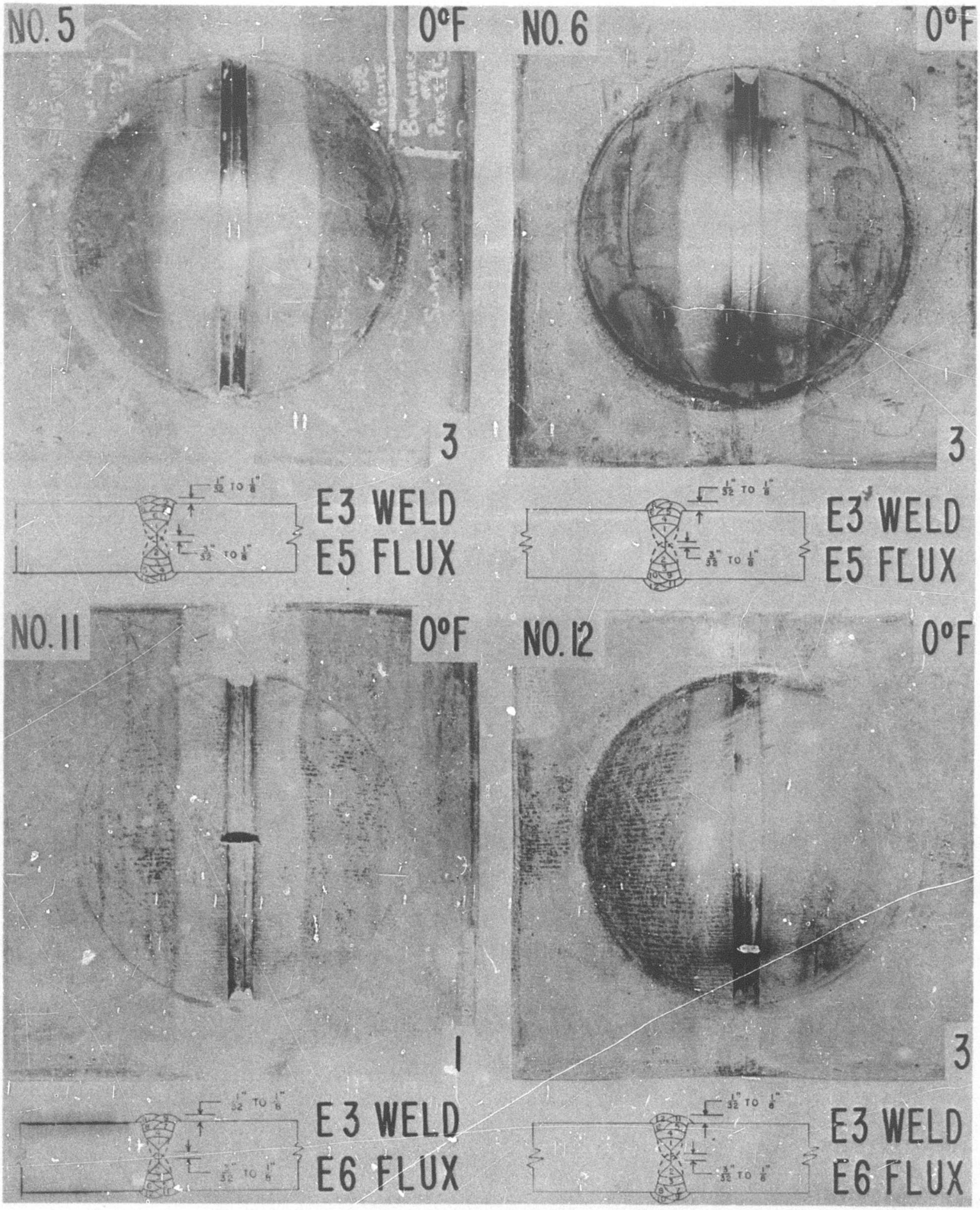


Fig. 7 - Explosion-bulge test fracture characteristics of submerged-arc weldments fabricated by MINSY

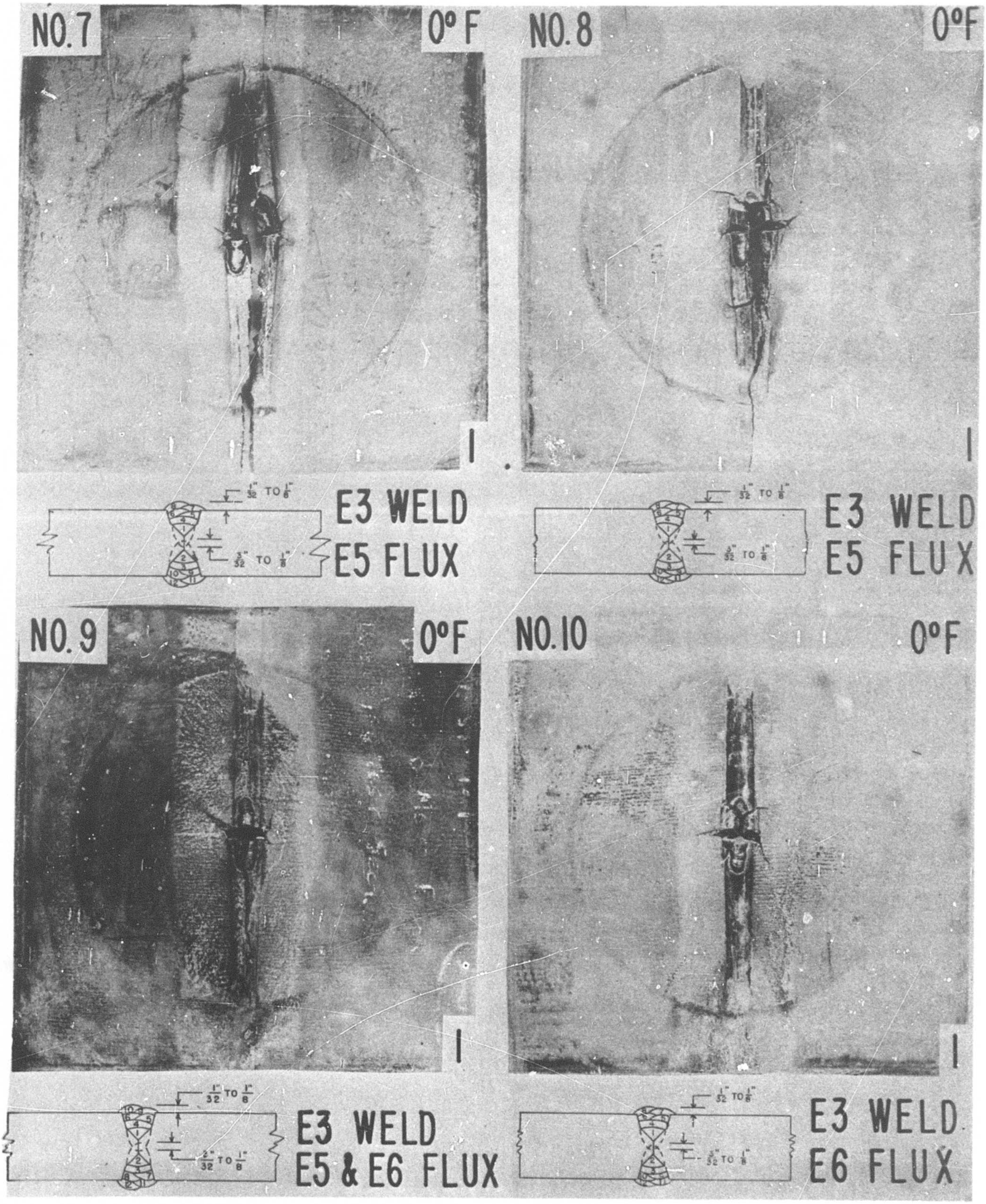


Fig. 8 - Explosion-bulge test fracture characteristics of submerged-arc weldments fabricated by MINSY. All samples modified with crack-starter weld.

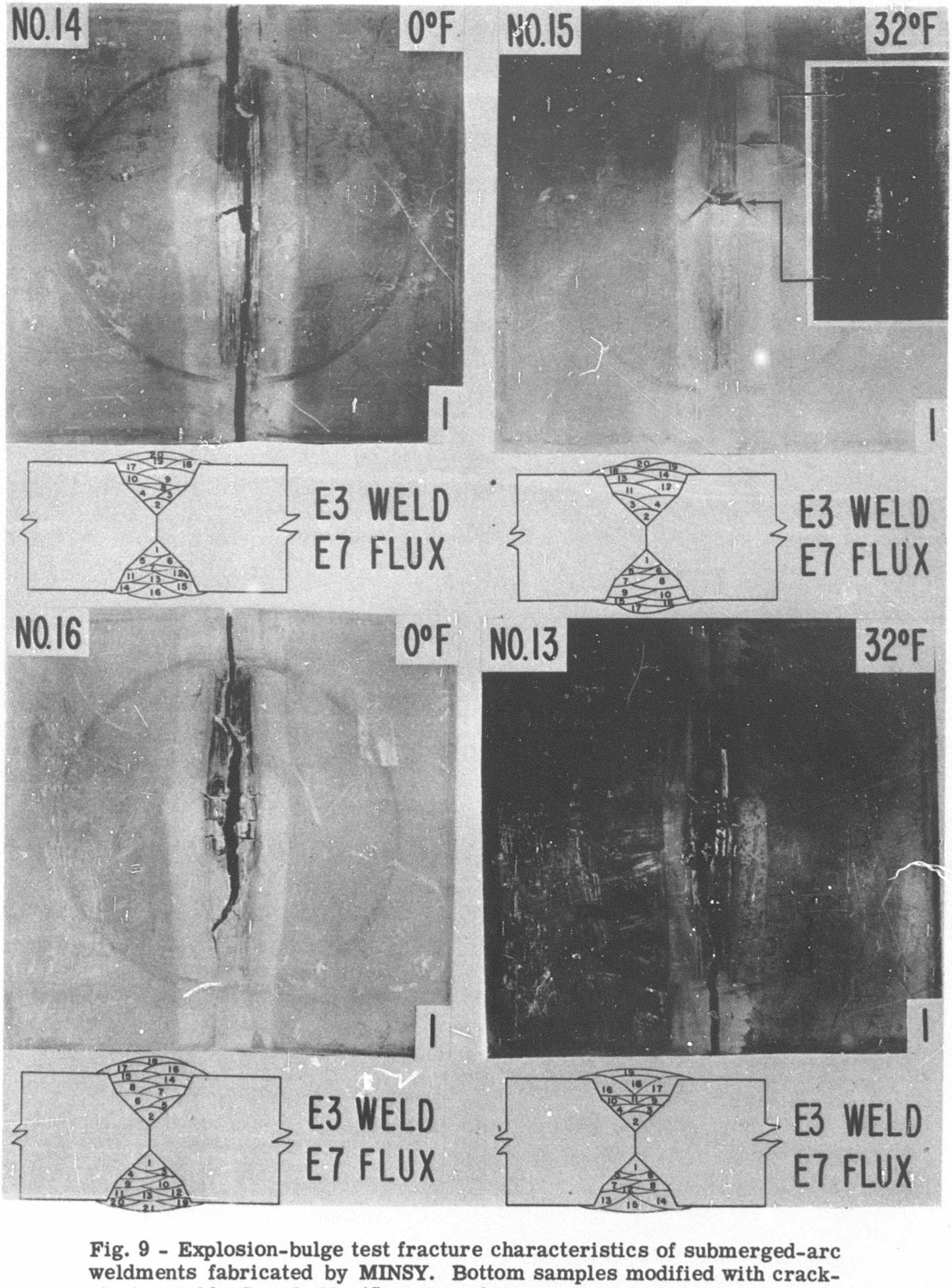


Fig. 9 - Explosion-bulge test fracture characteristics of submerged-arc weldments fabricated by MINSY. Bottom samples modified with crack-starter weld. Sample No. 15 contained transverse cracks in as-received condition (see photo inset at top right).

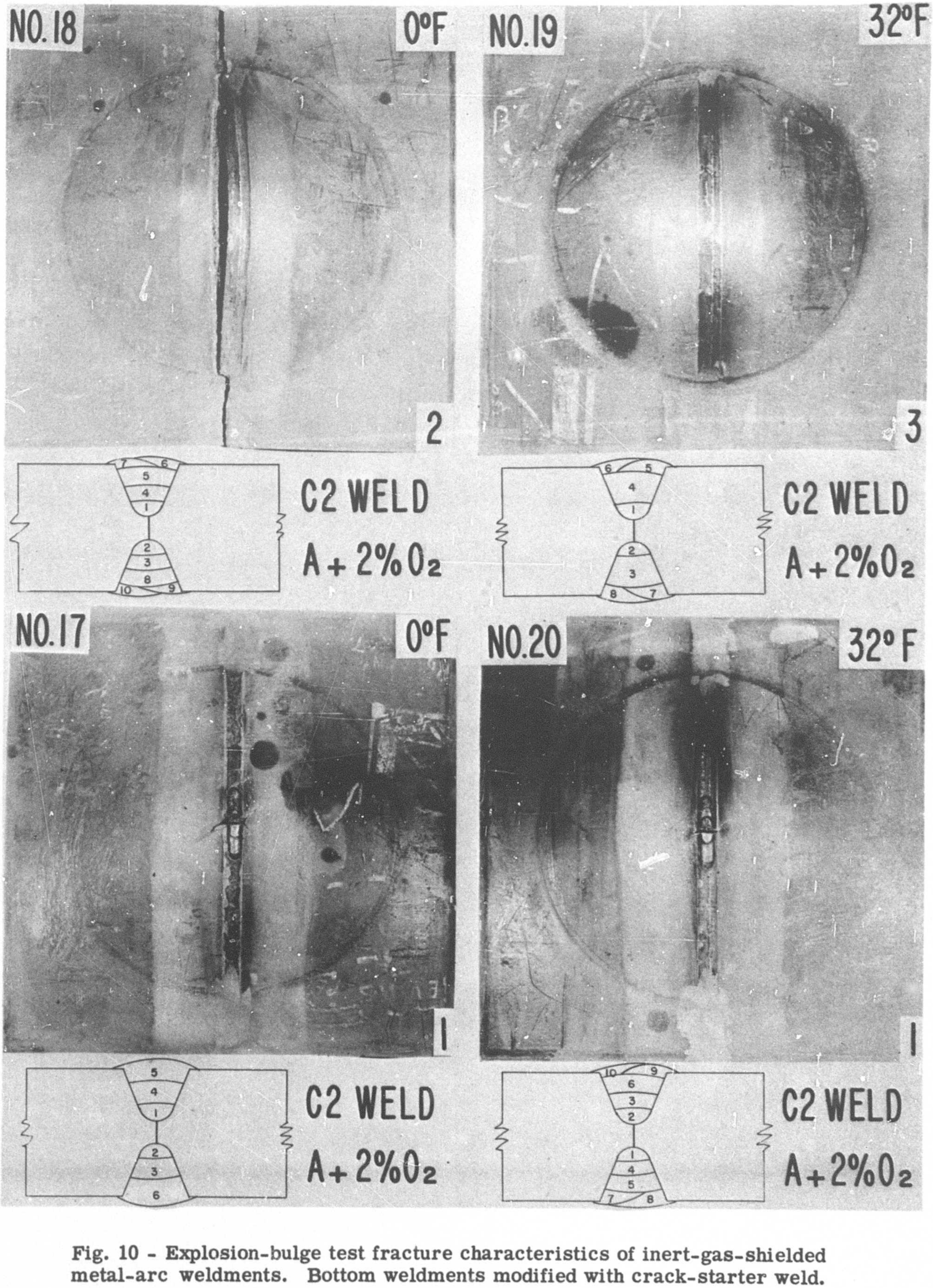


Fig. 10 - Explosion-bulge test fracture characteristics of inert-gas-shielded metal-arc weldments. Bottom weldments modified with crack-starter weld.

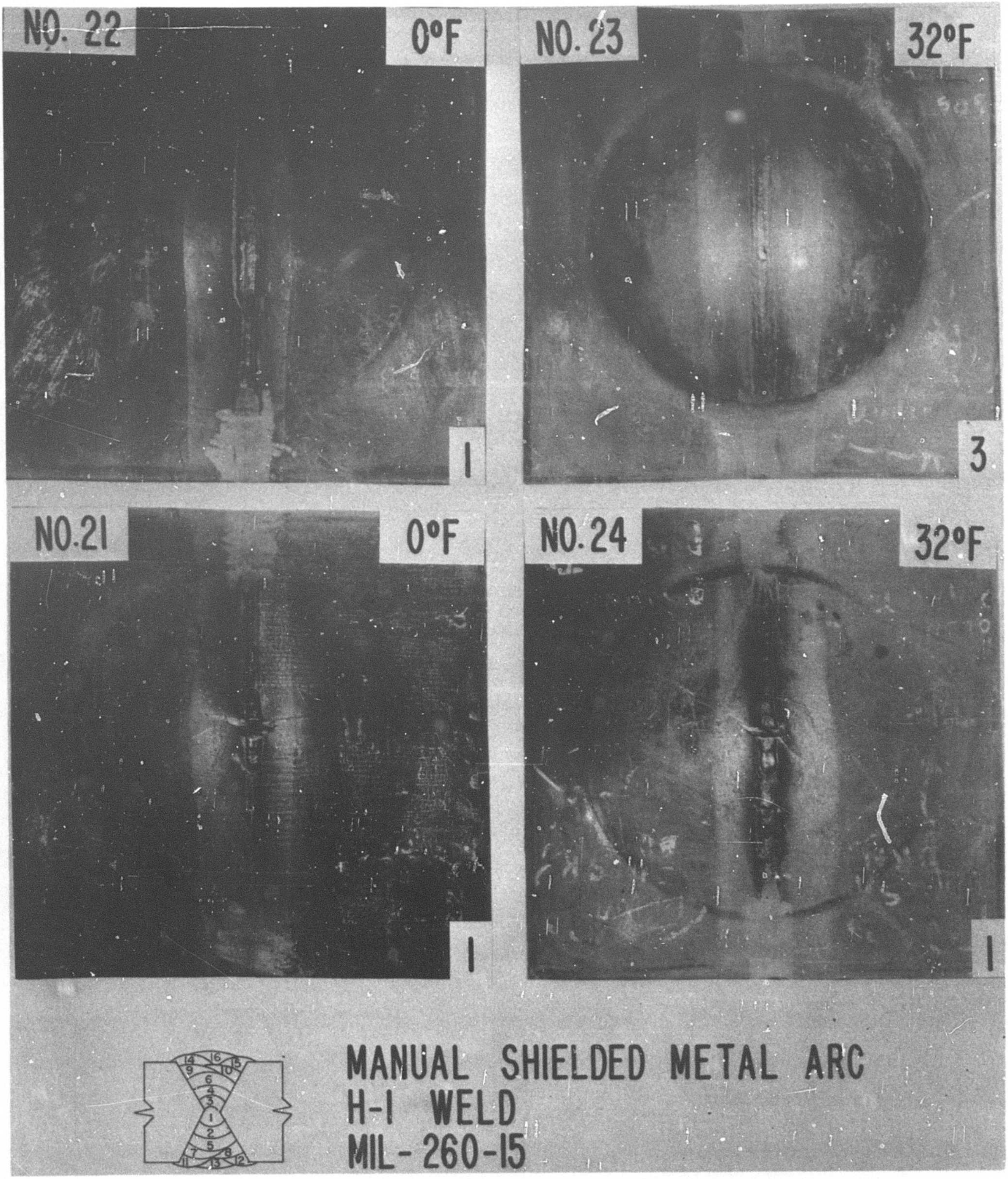
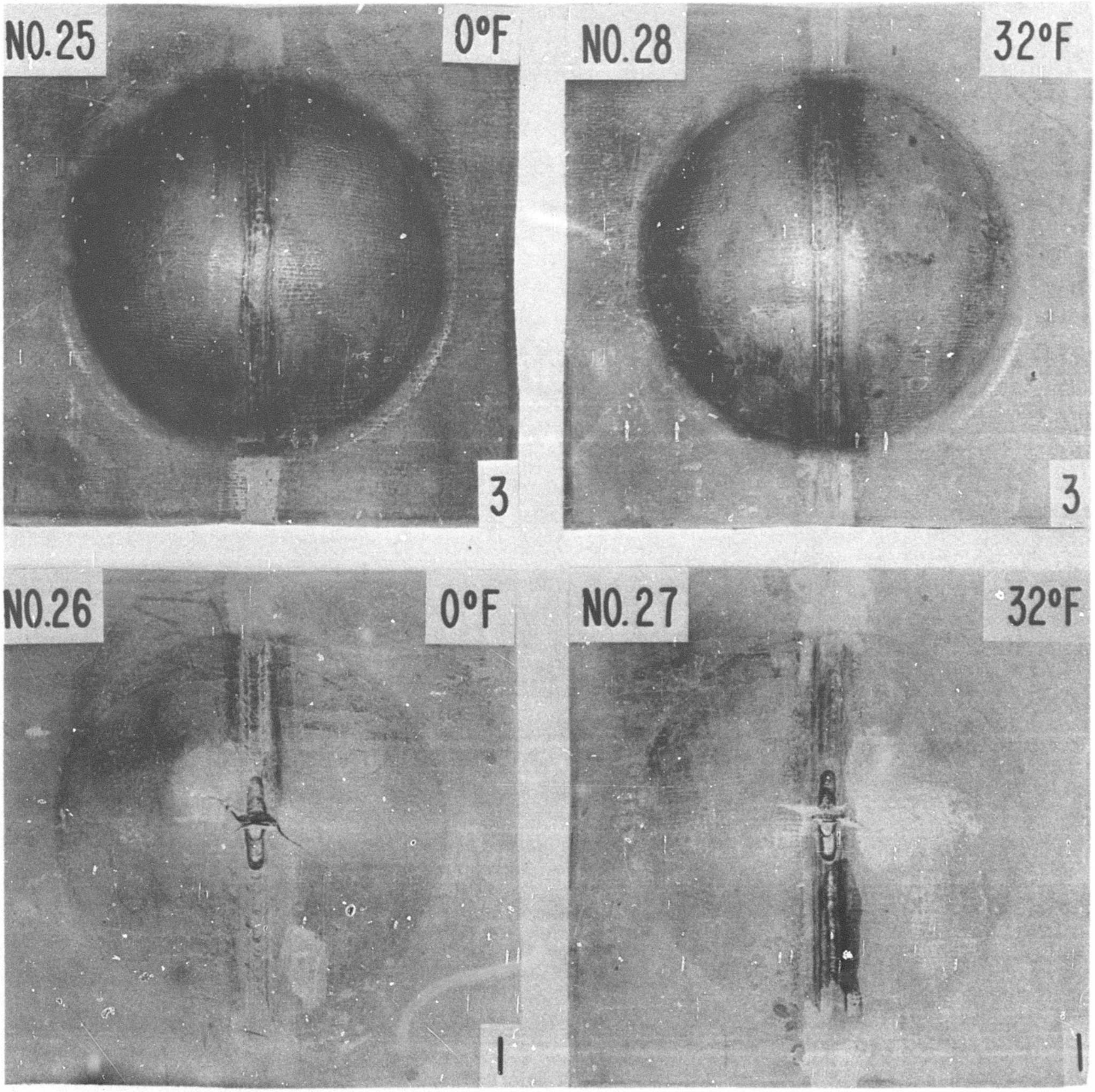


Fig. 11 - Explosion-bulge test fracture characteristics of manual Mil 26015 weldments. Bottom samples modified with crack-starter weld.



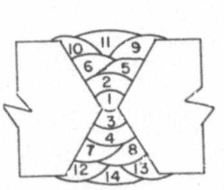


Fig. 12 - Explosion-bulge test fracture characteristics of manual Mil 11018 weldments. Bottom samples modified with crack-starter weld.

Fig. 13 - Explosion bulge test fracture characteristics of manual Mil 11018 weldment of 2-in.-thick HY-80 steel

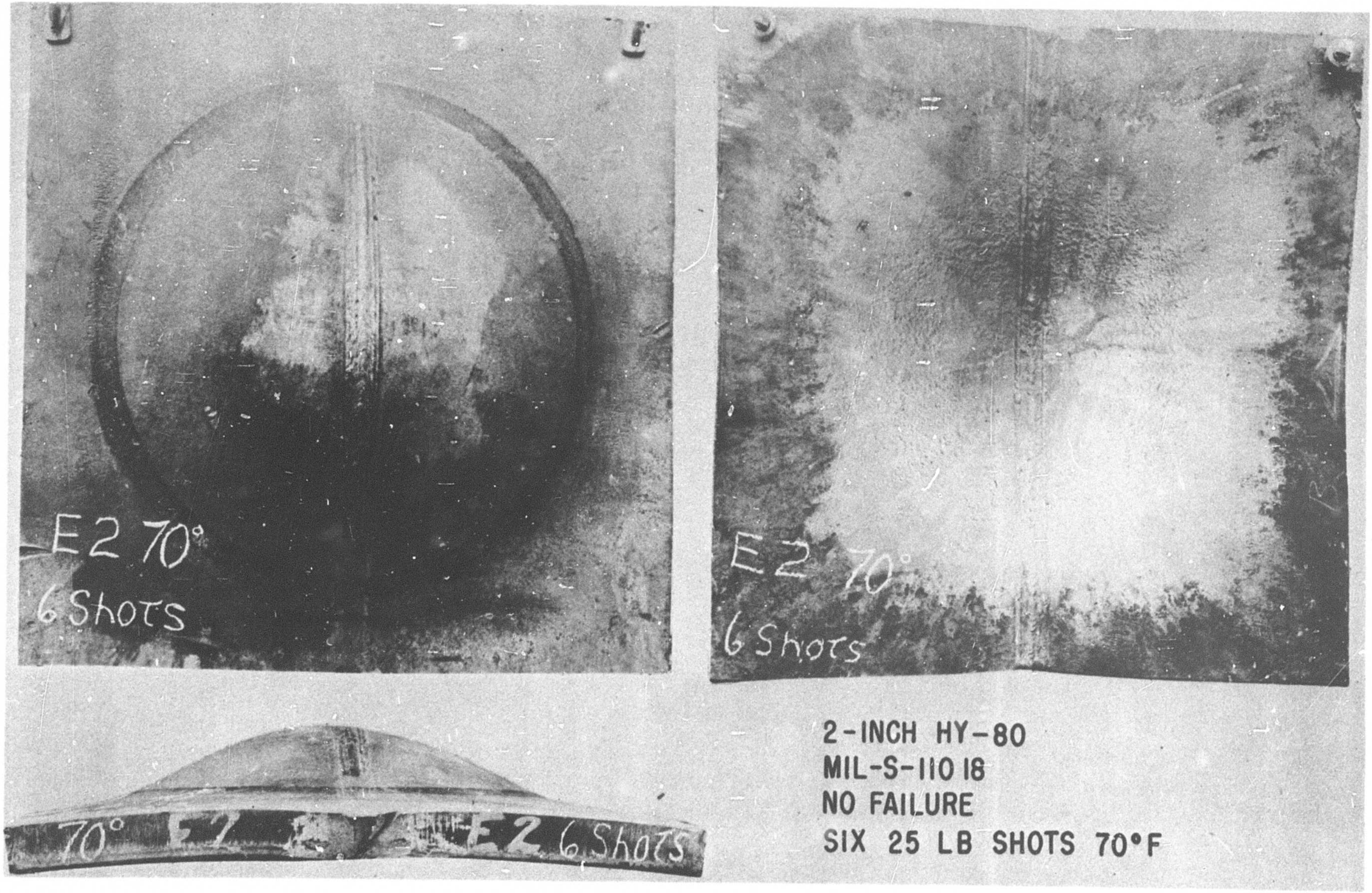


Fig. 14 - Explosion-bulge test fracture characteristics of manual Mil 11018 weldment of 2-in.-thick HY-80 steel

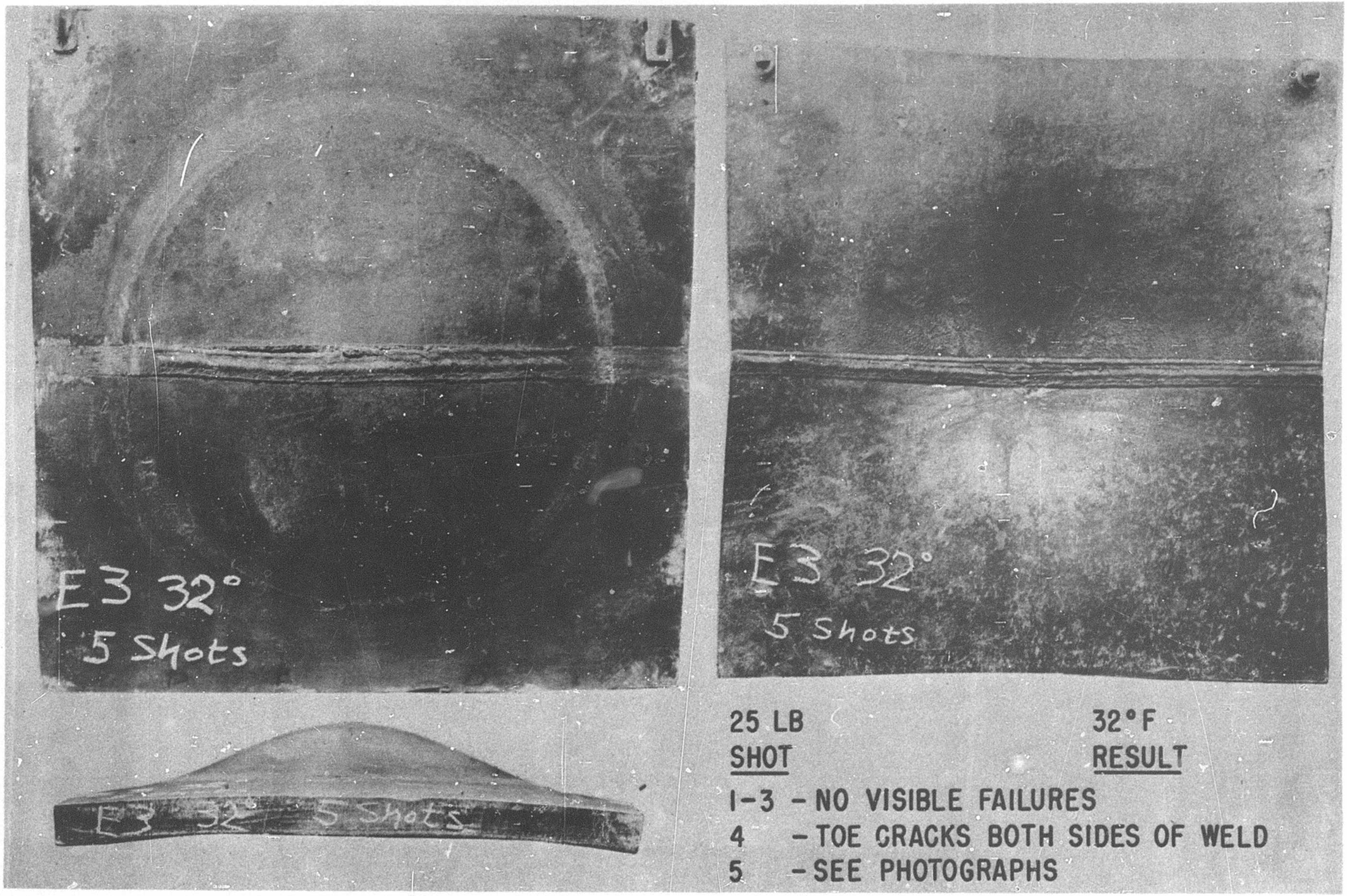


Fig. 15 - Explosion-bulge test fracture characteristics of manual Mil 11018 weldment of 2-in.-thick HY-80 steel

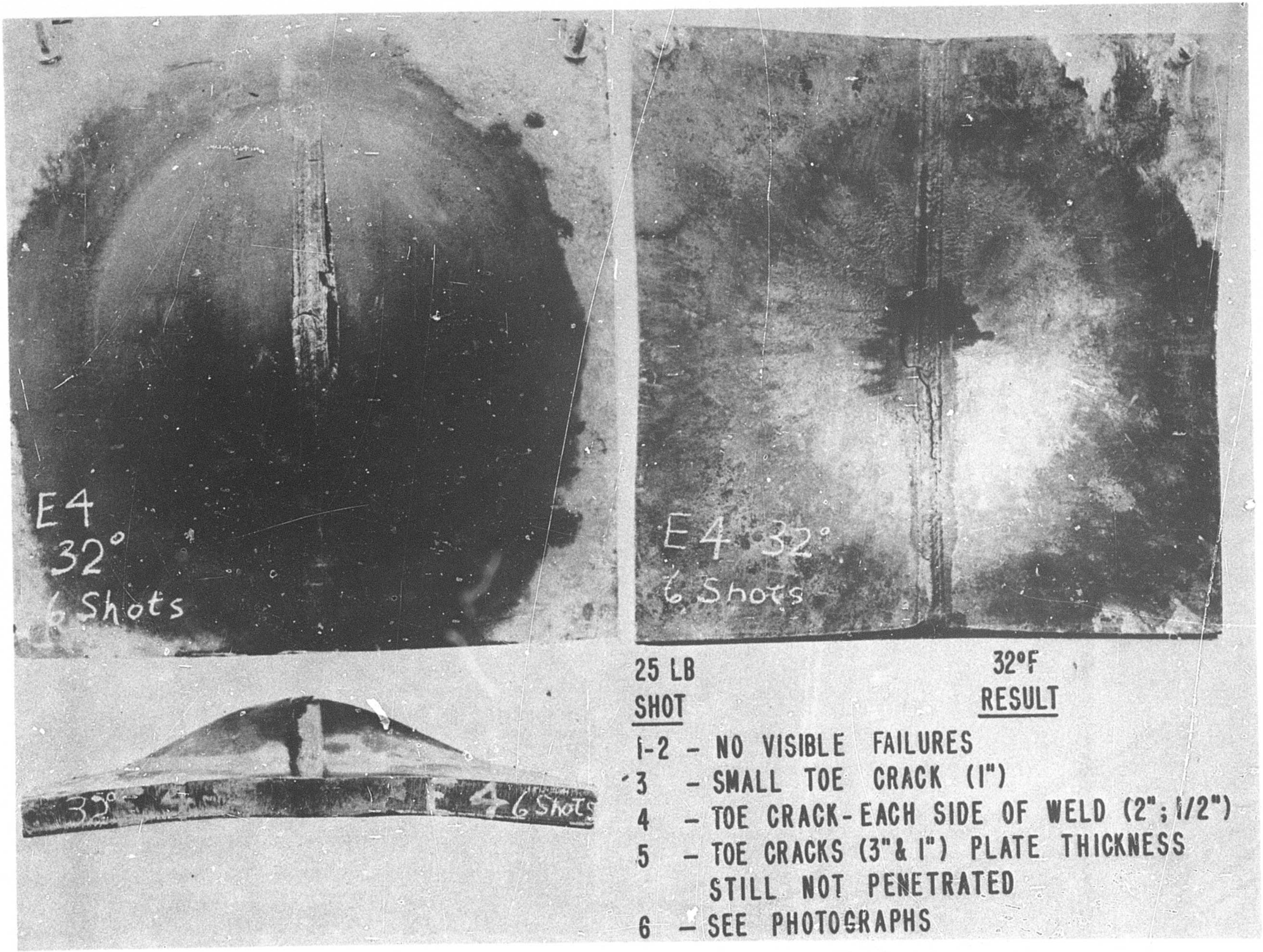


Fig. 16 - Explosion-bulge test fracture characteristics of manual Mil 11018 weldment of 2-in.-thick HY-80 steel

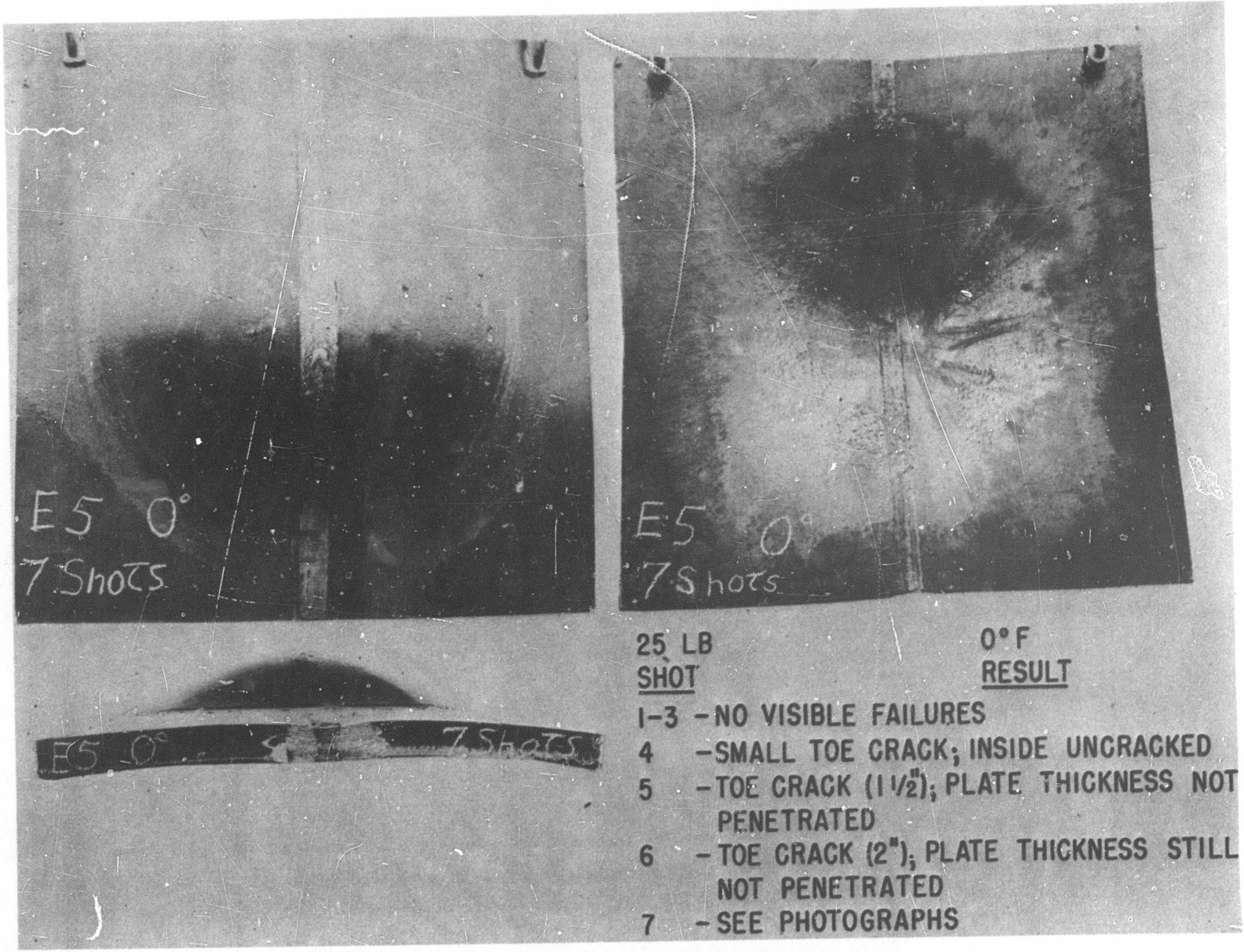


Fig. 17 - Explosion-bulge test fracture characteristics of manual Mil 11018 weldment of 2-in.-thick HY-80 steel