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BUREAU OF SHIPS CONFERENCE

HY-80 STEEL FABRICATION IN SUBMARINE CONSTRUCTION

AT BUREAU OF SHIPS
21-22 MARCH 1960

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Here is the corrected Table of Contents for the Bureau of Ships Conference, HY-80 Steel Fabrication in Submarine Construction, at Bureau of Ships, 21-22 March 1960.

INTRODUCTION

A seminar, sponsored by the Bureau of Ships, on the Weldability of HY-80 Steel as applied to submarine construction was held at the Bureau of Ships, Washington. D.C. on 21 - 22 March 1960. Technical papers presented and a list of attendees are included herein.

The book is intended to be a matter of interest to production personnel engaged in fabrication of submarine hulls from HY-80 steel as well as to engineers and architects. It presents potential as well as new developments in weld fabrication materials and methods.

R.E. Ball

R.E. BALL
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INVESTIGATION OF WELDABILITY
OF NAVY GRADE
HY-80 STEEL

by
G. Emmanual, Babcock & Wilcox Co.

INTRODUCTION:

Under BuShips Contract NObs-77064, the Babcock & Wilcox Company has been engaged in an investigation primarily aimed at improving the weldability of HY-80 steel under the conditions required for the construction of submarine hulls.

This discussion is in the nature of a progress report of our findings to date. Briefly, the problem has been approached from the following angles:

1. Behavior of the heat-affected zone with respect to its transformation characteristics and mechanical properties.
2. Development of weldability test which would consistently produce cracking of commercial plate.
3. Study of welding variables on susceptibility of cracking.
4. Effect of compositional variations on tendency for cracking.
5. Miscellaneous Tests:
   (a) Thermal expansion characteristics of 11018 weld deposit and HY-80 plate.
   (b) Submerged arc welding tests on a limited basis.

TEST PROCEDURES:

Heat Affected Zone - One of the few aspects of the HY-80 problem on which there is almost universal agreement is that cracking originates and propagates from the heat-affected zone. It was, therefore, decided to study this segment first.

Our original studies were made on a commercial heat of steel (Table I) using a high temperature vacuum microscope (Figure 1) for direct observation of the M_s and M_f temperatures. A peak austenitizing temperature of 2230 F was attained. After holding at this temperature for 3 minutes, the sample was allowed to cool and observed. At a temperature of 890 F, the first needles of martensite appeared. With decreasing temperature, more and more martensite appeared until at 830 F, the reaction was virtually complete. The sequence of transformation is shown in Figure 2. The cooling time from 2230 F to 890 F was 14 minutes, and time in the martensite transformation zone was 9 minutes.

Published information on the transformation characteristics from an austenitizing temperature of 1650 F indicated an M_s temperature of 680 F, and no information relative to the M_f temperature.

Since the heat-affected zone reaches temperature of the order of 2400 F, it was decided to determine experimentally the transformation characteristics of HY-80 material from that temperature. This was done by resistance heating 4" x 1/4" diameter bar to 2400 F in 16 seconds, followed by immediately quenching into lead baths at various temperatures, and holding for different periods of time and then water quenching. By this procedure, it was possible to determine the beginning of isothermal transformation of HY-80 at various temperatures.

In order to determine the M_s temperature, a somewhat different procedure was followed. In this case, samples were quenched into lead baths at various temperatures held for short times (less than 1 minute), transferred to another lead bath at 1250-1275 F for 1-2 minutes and water quenched. If the temperature to which the sample had been quenched was below the M_s point, martensite will form. Upon reheating to 1250-1275 F, the martensite is tempered and subsequent metallographic examination differentiates between tempered and untempered martensite. Thus, the T-T-T diagram (Figure 3) was developed.

Examination of this diagram readily shows the extreme sluggishness with which HY-80 will transform as well as a surprisingly high martensite transformation temperature when the peak austenitizing temperature is 2400 F.

From these observations, the following conclusions appear to be warranted:

1. The formation of bainite in the portion of the heat-affected zone is not likely.
2. The high M_s and M_f temperatures do not favor the formation of cold cracks since it is generally accepted that as the temperature for martensite transformation is increased, the susceptibility for cold cracking is decreased.
3. The present limit of 300 F on interpass temperature appears to be overly stringent for high chemistry HY-80. This should be checked by explosion bulge tests with higher interpass temperatures.

Hot Ductility Tests - A test developed at the Rensselaer Polytechnic Institute has had some success in predicting the weldability characteristics of heavy stainless pipe. Briefly, this tests consists of heating a small specimen at controlled rates equivalent to those encountered during welding. The procedure involves heating series of samples to increasing temperatures, and breaking the samples and measuring reduction of area. As would be expected, reduction of area values increase with temperature until at some temperature (depending on the material) the ductility drops to essentially zero. Once this temperature is determined, another series of samples is heated to that temperature, cooled to various temperatures broken, and reduction of area determined. In the case of stainless steel, it was noted that when the reduction of area on cooling was markedly lower than that determined during heating, the weldability was poor. When the reduction of area curve on cooling was essentially similar to the curve on heating, no trouble was experienced during welding.

A curve of this type (Figure 4) was determined for the analysis shown in Table I. It will be noted that there is a substantial difference between the heating and cooling curve. We plan to have a number of these tests made on experimental material, and see if a correlation between the results of the R.P.I. test and weldability exists.

A series of convential high temperature tests were run following the same procedure. The results are shown in Table II. It is interesting to note that up to the peak temperature available (2400 F) there is no apparent damage to the material as evidenced by reduction of area measurements. This observation tends to indicate that damage takes place between 2400 and 2510 F.

Weldability Tests - It was felt that one of our primary problems was to find or develop a simple weldability test, which would consistently produce cracks under a given set of welding conditions. The nature of the welding condition was felt to be relatively immaterial, since we would vary only one factor at a time, and all results could be judged on the same basis.

After examining a number of possible tests, it was finally decided to use the Controlled Thermal Severity (CTS) test developed by the British Welding Research Association. Figure 5 shows the configuration of this test. Essentially, this consists of fillet welding one (1) 3" x 3" block to a 4" x 7" block of HY-80 as indicated. The two welds parallel to the long axis of the bottom block are two (2) pass welds, and are known as the "anchor" or "restraining" welds. The two transverse welds are single pass, and are the test welds. For a fuller description of this test, the reader is referred to the December 1959 issue of "Welding Research Abroad."

Under the welding condition employed, (30,000 joules/inch 1/8", 11018 electrode, room temperature preheat, and 2-inch thick commercial HY-80 plate) it was found possible to consistently produce cracks in the heat-affected zone.

Admittedly, these welding conditions bear little resemblance to those employed in the shipyards, however, it was realized that producing restraint in the Laboratory, comparable to that experienced in actual submarine construction, would be difficult. In an attempt to compensate for this lack, the welding conditions were made unrealistically severe.

Welding Variables - Holding all other conditions constant, preheat, hydrogen content, electrode and heat input were varied. It was found that varying preheat between 32 and 1050 F, hydrogen between 1.5 and 3 ppm (Figure 6), heat input between 30,000 and 70,000 joules. in. (Figure 7) and using lower yield strength electrodes (16-8-2 and 9018) did not reduce the tendency for cracking (Figure 8). As a matter of fact, it was possible to produce cracking by the mere application of heat by puddling the surface with heliarc or atomic hydrogen torches (Figure 9).

Since it appeared that welding variables were not the primary factors in initiating cracking, it was decided to investigate the effect of compositional variations within the specified range for HY-80.

COMPOSITIONAL VARIATION:

A number of experimental induction heats were melted both in air and in vacuum. The nominal analyses of these heats are shown in Table III. It will be noted that these heats were planned to hold all elements but one in the approximate center of their specified range. Each element was then varied within its specified limits. The only exceptions to this rule occurs in the phosphorous and sulfur variations.

The ingots thus produced were then either forged or rolled, heat treated, welded as CTS tests, and examined. The results are shown in Figures 10 through 12. It will be noted that the only sample which did not show any cracking at all was the one with the lowest sulfur contents.

MISCELLANEOUS TESTS:

Expansion rates of HY-80 and 11018 weld deposits were determined. As shown in Table IV, maximum difference of approximately 24% in coefficient expansion exists between these two materials at 1400 F.

As part of our efforts to investigate automatic methods for welding HY-80 material, some experimental wire was produced, and a submerged arc weld produced in 1" thick lean chemistry plate. The results are shown in Figure 13.

EQUIPMENT:

As a matter of general interest, Figure 14 illustrates some of the equipment that is being used in this program. Having the facilities to produce experimental heats, process them into plate, rod or wire has greatly expedited the progress of this program.

SUMMARY AND CONCLUSIONS:

From the results of the foregoing tests, it is our belief that the cracking observed in the heat-affected zone of HY-80 material is of high temperature origin, and can be initiated by the mere application of heat. Reduction of the sulfur content to rather low levels appears to be effective in reducing the tendency to crack. Since the cracking observed is microscopic in nature, it must be shown that it is these microscopic cracks which propogate into detectable cracks of macroscopic size. It must, also, be shown whether propogation occurs at relatively low temperatures, and is the result of transformation stresses and/or the action of hydrogen, or whether the cracks both originate and propagate at temperatures close to fusion temperatures.

G. N. Emmanuel
THE BABCOCK & WILCOX COMPANY

GNE:ds

April 14, 1960

Talk given at the Bureau of Ships
HY-80 Conference March 21, 1960.

TABLE I

ANALYSIS AND PROPERTIES OF 1.988" HY-80 MATERIAL LUKENS STEEL HEAT NO. 21228

	C	Mn	P	S	Si	Ni	Cr	Mo
Test Report -	.16	.34	.014	.024	.25	2.87	1.52	.41
B&W Analysis -	.18	.32	.011	.027	.25	2.90	1.50	.40

Heat Treatment: 1650 F - W.Q.
Tempered 1150-1250 F.

Mechanical Properties

	T.S. psi. X 1000	Y.S. psi. X 1000	ELONG. % IN 2"	R.A. %	CHARPY V FT-LBS @ 120 F.
Test Report	103-103.1	86.8-87.2	26-27	-	72, 73, 74
B&W	104.2-104.5	94-98.1	26.5-28.5	66.4-73.3	98, 102, 106*

* B&W tests run at - 100F.

TABLE II

HIGH TERMPERATURE MECHANICAL PROPERTIES OF HY-80

TEST TEMP. F	TENSILE STRENGTH PSI	YIELD STRENGTH PSI .2% OFFSET	ELONG. % IN 2"	R.A. - %
1600	9800	6400	25.0	24.6
1700	7700	5500	27.5	25.6
1800	6000	4200	29.5	30.4
1900	4700	2900	38.5	35.2
2000	4000	2600	74.5	69.3
2100	3200	1800	103.5	Infinite
2200	2500	-	120.5	Infinite
2300	1900	1100	113.5	Infinite
2400	1400	600	113.5	Infinite
Heated to 2400 F and tested at:				
2300	1900	1100	129.5	Infinite
2200	2400	1200	130.0	Infinite
2100	3100	1700	110.5	Infinite
2000	4000	2500	123.5	99.4
1900	4900	2700	107.5	96.5
1800	6300	2900	75.5	64.7
1700	7900	5000	51.0	44.3
1600	10100	-	63.0	55.0

TABLE III

EXPERIMENTAL COMPOSITIONS (AIR & VACUUM MELTED)

	C	Mn	Si	Ni	Cr	Mo	P	S
Median Analysis	.16	.30	.25	2.80	1.60	.45	.020	.025
C Variation	.08	.30	.25	2.80	1.60	.45	.020	.025
	.23	.30	.25	2.80	1.60	.45	.020	.025
Mn Variation	.16	.10	.25	2.80	1.60	.45	.020	.025
	.16	.70	.25	2.80	1.60	.45	.020	.025
Ni Variation	.16	.30	.25	0	1.60	.45	.020	.025
	.16	.30	.25	2.40	1.60	.45	.020	.025
	.16	.30	.25	3.20	1.60	.45	.020	.025
Cr Variation*	.16	.30	.25	2.80	[illegible]0	.45	.020	.025
	.16	.30	.25	2.80	[illegible]90	.45	.020	.025
	.16	.30	.25	2.80	1.90	.45	.020	.025
Mo Variation*	.16	.30	.25	2.80	1.60	0	.020	.025
	.16	.30	.25	2.80	1.60	.20	.020	.025
	.16	.30	.25	2.80	1.60	.60	.020	.025
P & S Variation	.16	.30	.25	2.80	1.60	.45	0	0
	.16	.30	.25	2.80	1.60	.45	.035	0
	.16	.30	.25	2.80	1.60	.45	0	.040
	.16	.30	.25	2.80	1.60	.45	.035	.040

*These analyses have not yet been tested.

TABLE IV

COMPARISON OF THERMAL EXPANSION CHARACTERISTICS OF HY-80 AND 11018 WELD METAL

	RT-200F	RT-400F	RT-600F	RT-800F	RT-1000F	RT-1200F	RT-1400F	RT-1600F	RT-1800F
1" Plate	6.3-6.4	6.7-6.7	7.0-7.0	7.2-7.2	7.3-7.6	7.4-7.7	5.5-6.1	5.6-5.8	6.2-6.4
6" Plate	6.3-6.4	6.6-6.6	6.8-6.9	7.1-7.3	7.1-7.5	7.1-7.1	5.8-5.9	5.7-5.7	5.9-6.0
11018 Weld Deposit	6.6-6.8	7.3-7.5	8.1-8.1	8.2-8.3	8.2-8.2	7.9-8.0	7.2-7.2	6.1-6.2	6.4-6.4

CHEMICAL ANALYSES

	C	Mn	Si	Cr	Ni	Mo	Cu	P	S
1" Plate	.16	.25	.17	1.16	2.29	.25	-	.012	.017
6" Plate	.25	.30	.17	1.58	2.98	.50	-	-	-
11018 Deposit	.03	1.67	.3	.12	2.38	.44	.05	.013	.024

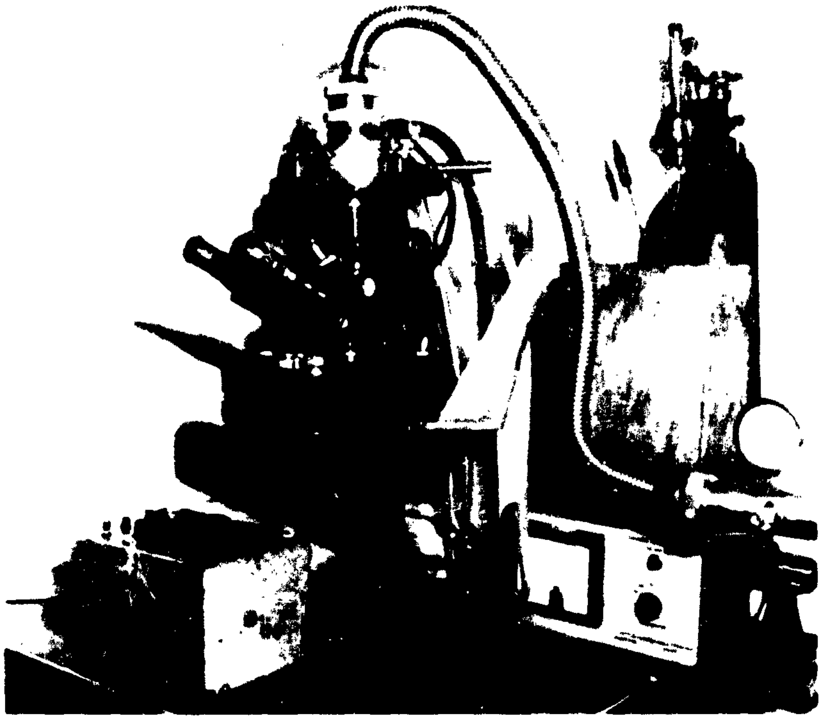


Figure 1 – High Temperature Vacuum Microscope Used For Direct Observation of Martensite Transformation in HY-80 Steel.

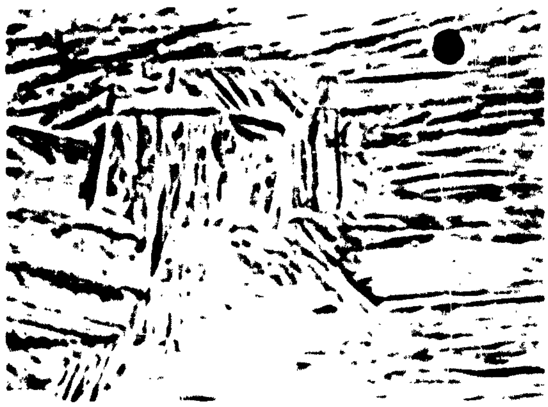
(a) Austenite at 2230 F, Time - 0

(d) Time - 18 Minutes

(b) M_s - 890 F, Time - 14 Minutes

(e) Time - 20 Minutes

(c) Time - 16 Minutes



(f) M_f - 830 F, Time 23 Minutes

Figure 2 — Martensite Transformation Occurring Over Range Of Temperatures. Original Magnification 205X, Enlarged 2.5 Times.

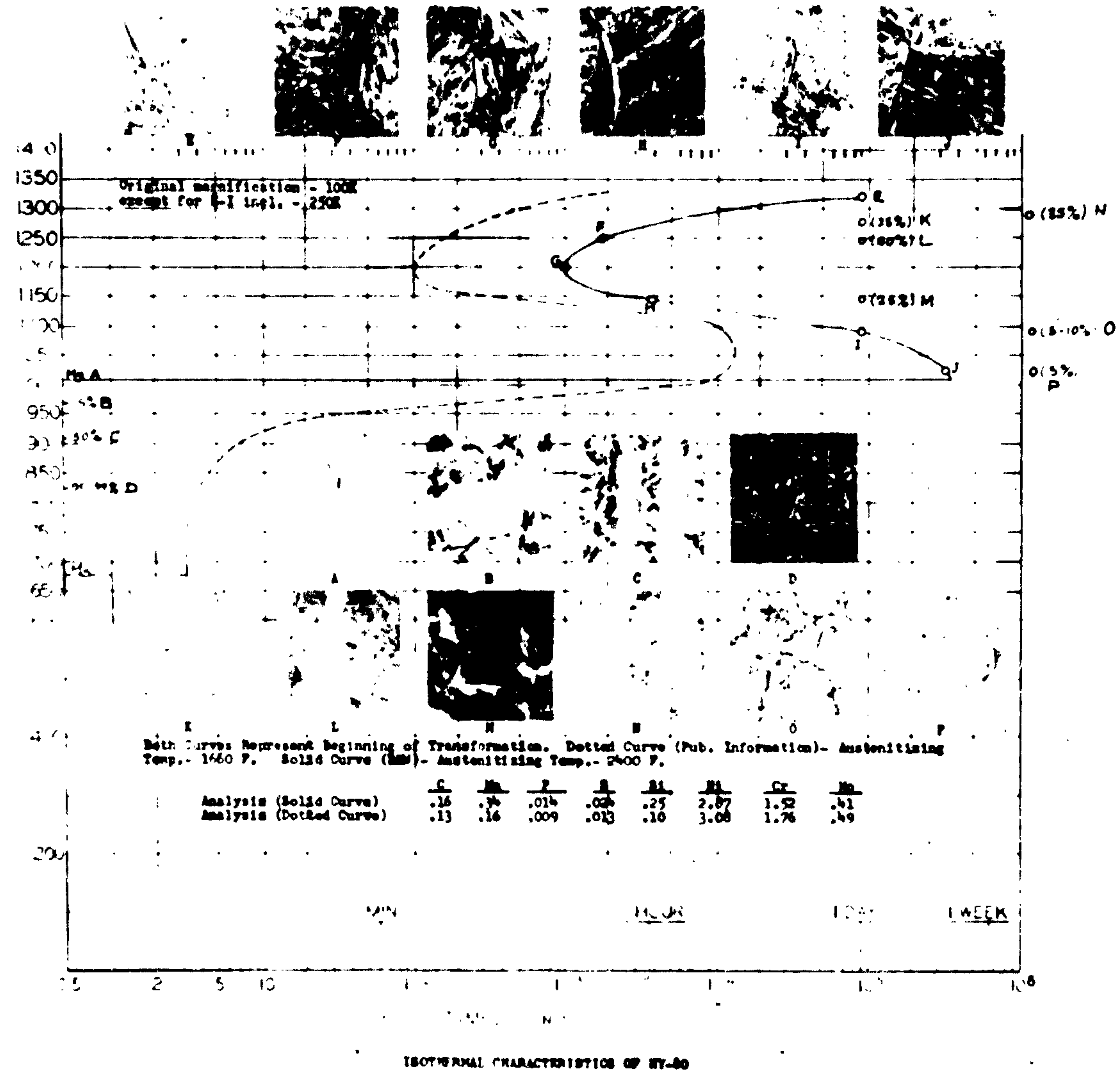


Figure 3 — TTT Curve Developed From Austenitizing Temperature Of 2400 F. Note Increase In Transformation Time And Increase In M_s Temperature As Compared With Curve Developed From 1650 F.

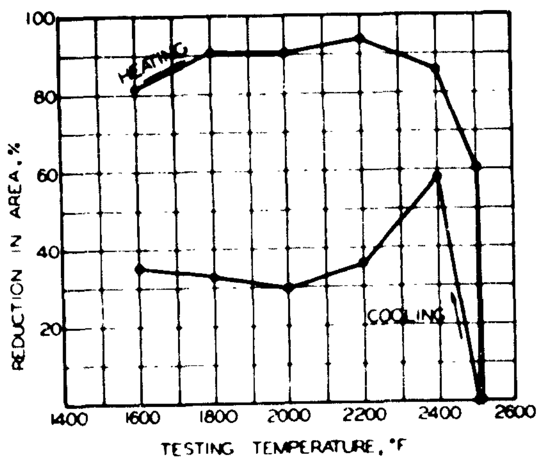
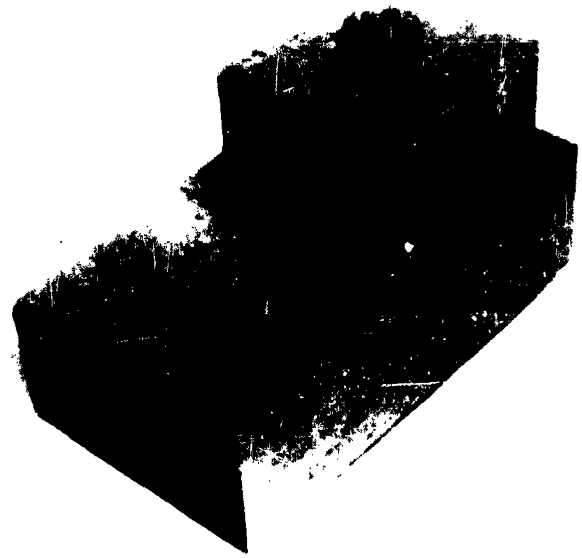


Figure 4 — Results of R.P.I. Hot Ductility Test Conducted ON HY-80 Material. Note Substantial Difference In Reduction Of Area Values On Cooling As Compared With Values Obtained During Heating Cycle. It Is Believed That This Indicates Damage To Material As A Result Of Heating To 2510 F.



Reduced To Approximately 1/3 Size

Figure 5 — Photograph Of CTS Test.

1.5 ppm H_2 **3 ppm H_2**

Magnification - 500X

Figure 6 — Effect Of Hydrogen Content Between 1.5 And 3 ppm On Cracking Tendency.

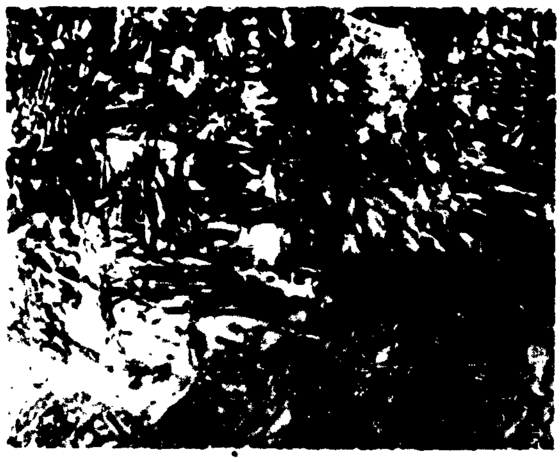
(See Figure 6 Left Side)

30,000 Joules/In.

70,000 Joules/In.

Magnification - 500X

Figure 7 – Effect Of Heat Input On Cracking Tendency.



16Cr-8Ni-2Mo Electrode

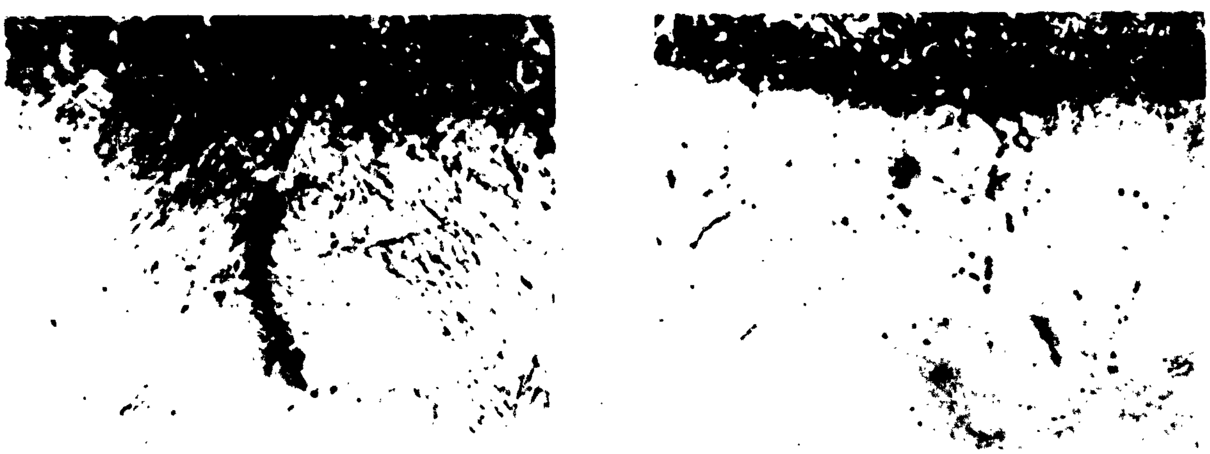
3018 Electrode

Magnification - 500X

Figure 8 – Effect Of Varying Electrode Composition On Cracking Tendency.

Magnification - 500X

Figure 9 — Showing Crack Produced By Puddling Surface Of HY-80 With Atomic Hydrogen Torch. Same Phenomenon, But To A Lesser Degree Observed When Heliarc Torch Employed.

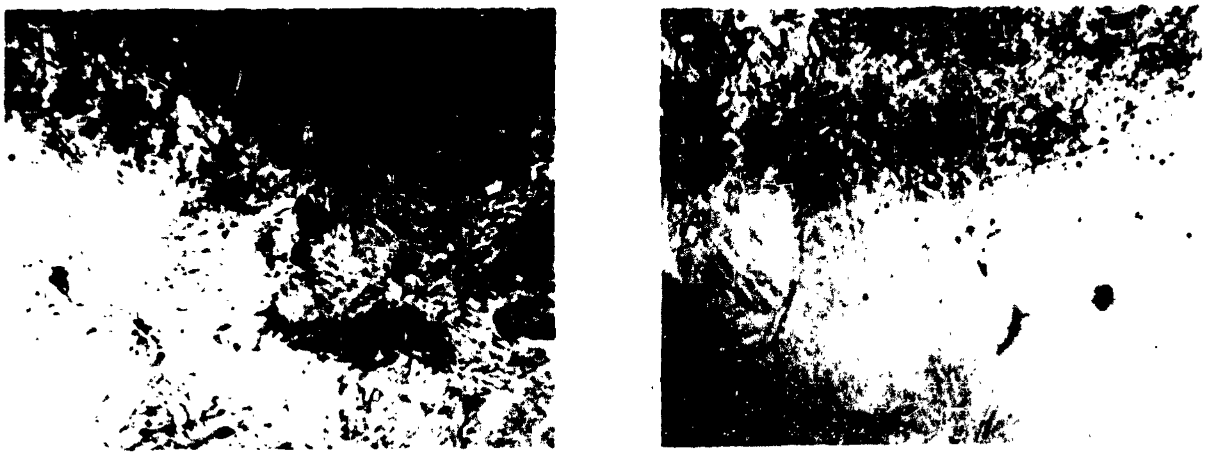


(a) Carbon - 0.09%

(b) Carbon - 0.23%

Magnification - 500X

Figure 10 — Showing Effect Of Carbon And Nickel Variations On Cracking Tendency.

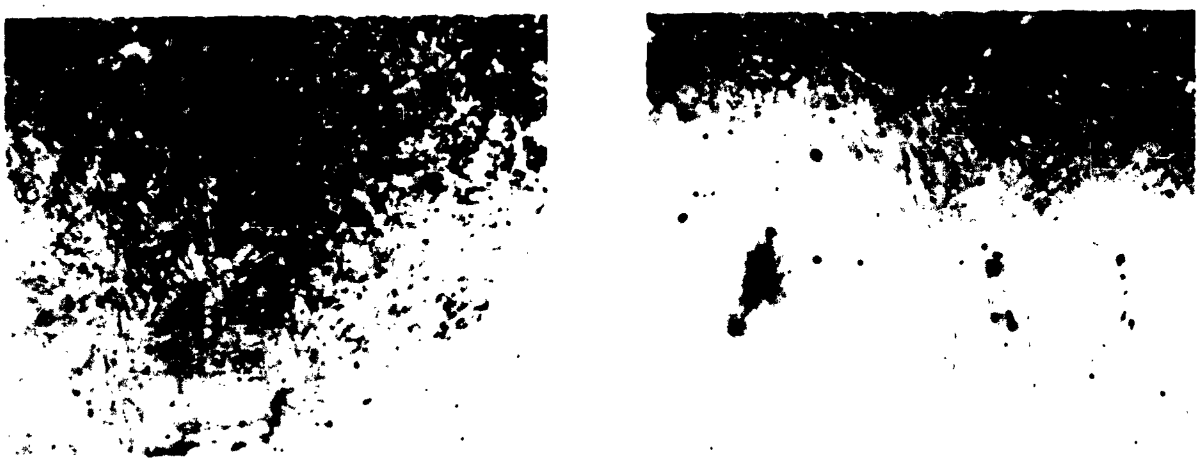


(c) Nickel - 0.02%

(d) Nickel - 3.22%

Magnification - 500X

Figure 10 – Showing Effect Of Carbon And Nickel Variations On Cracking Tendency. - continued

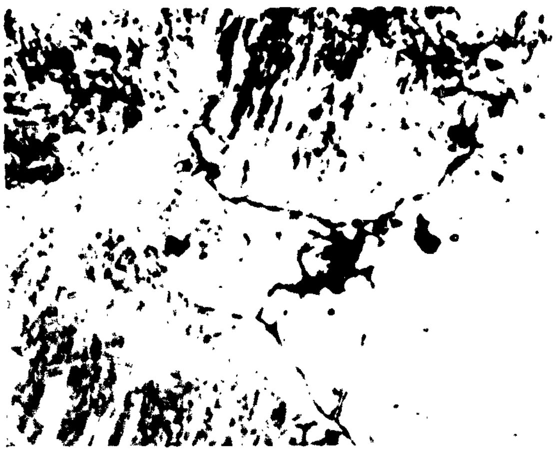


Manganese - 0.11%

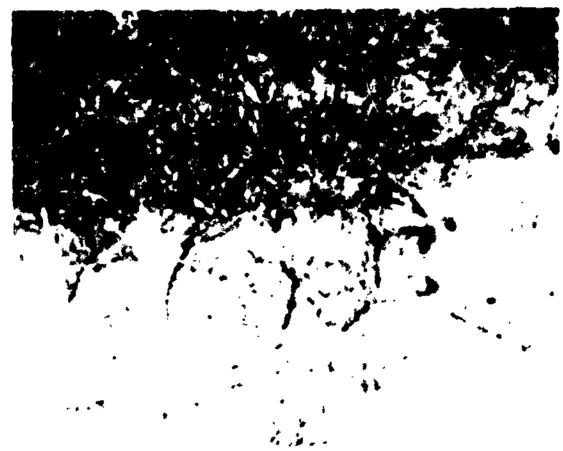
Manganese - 0.56%

Magnification - 500X

Figure 11 – Showing Effect Of Manganese Variations On Cracking Tendency.

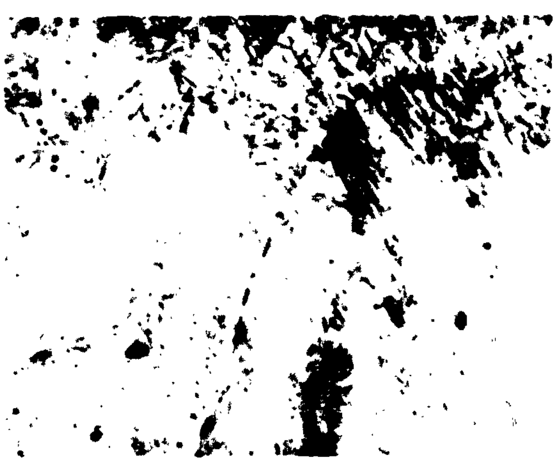


(a) P-O.006%, S-O.081%



(b) P-O.044%, S-O.033%

Magnification - 500X



(c) P-O.005%, S-O.041%

(d) P-O.004%, S-O.004%

Magnification - 500X

Figure 12 — Effect Of Phosphorous And Sulfur On Cracking Tendency.

Welding Condition - 250a, 30v, 6"/min.
Flux - 80 Baked at 350 F - 12-hours prior to use.
Plate Thickness - 1-inch, Groove -5/8" root spacing, 1-1/4" wide at top of groove.
Preheat - 200 F, Interpass - 300 F max.

	C	Cr	Ni	Mo	Mn	Si	S	P
Plate Composition	.16	1.15	2.22	.22	.26	.17	.019	.013
Deposit Composition	.06	1.40	2.97	.51	.95	.53	.02	.013

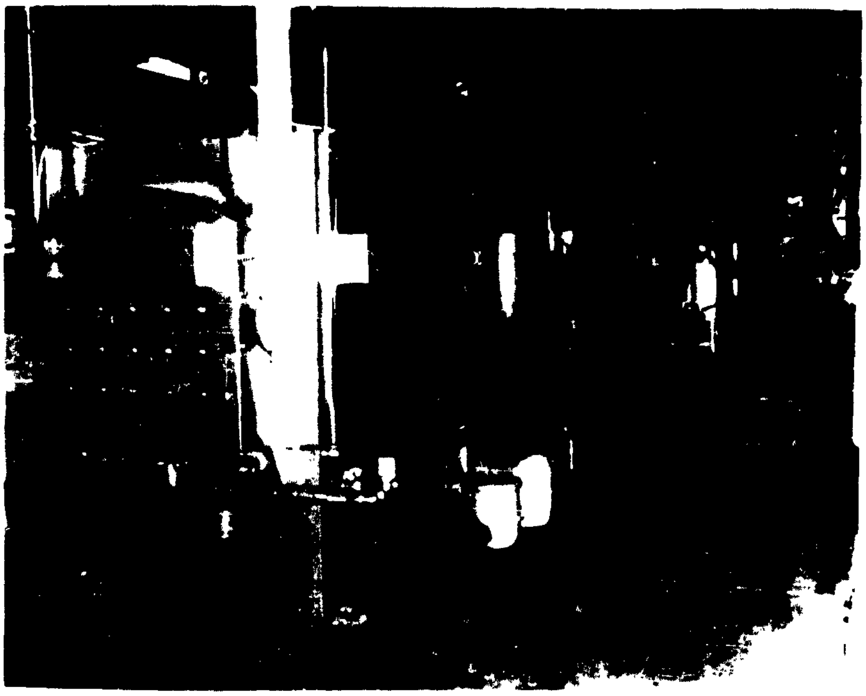
All Weld Deposit - T.S.-139,000 psi, Y.S.-117,000 psi, El. in 2"-15%, R.A.-38%
Impack Properties @ -60 F. 19-24 Ft-Lbs Charpy V-notch.

Side Bends - OK

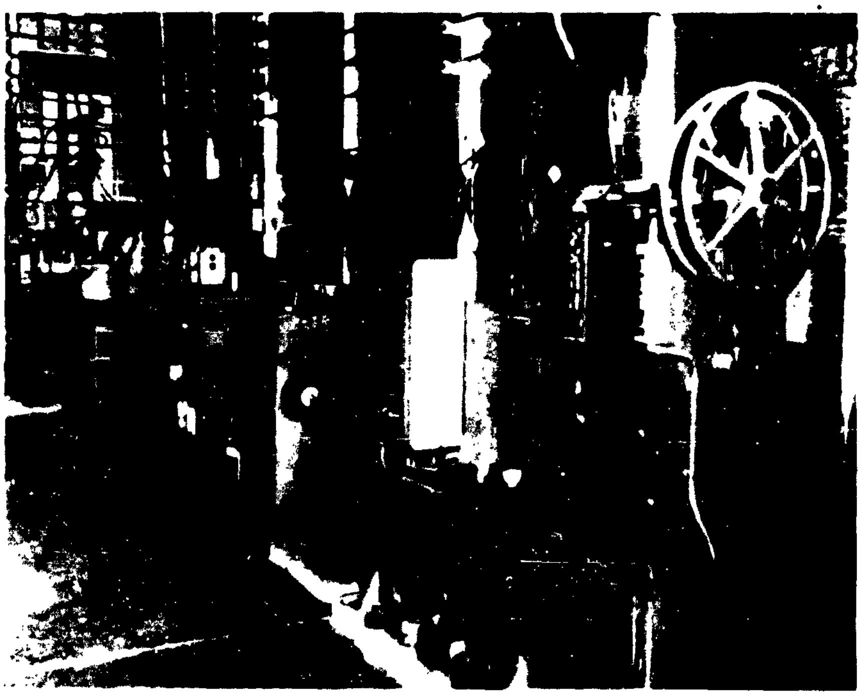
Transverse Tensile Test Across Weld - Failed in Plate at 113,700 psi.

Full Size

Figure 13 – Submerged Arc Weld Made With Experimental Wire.

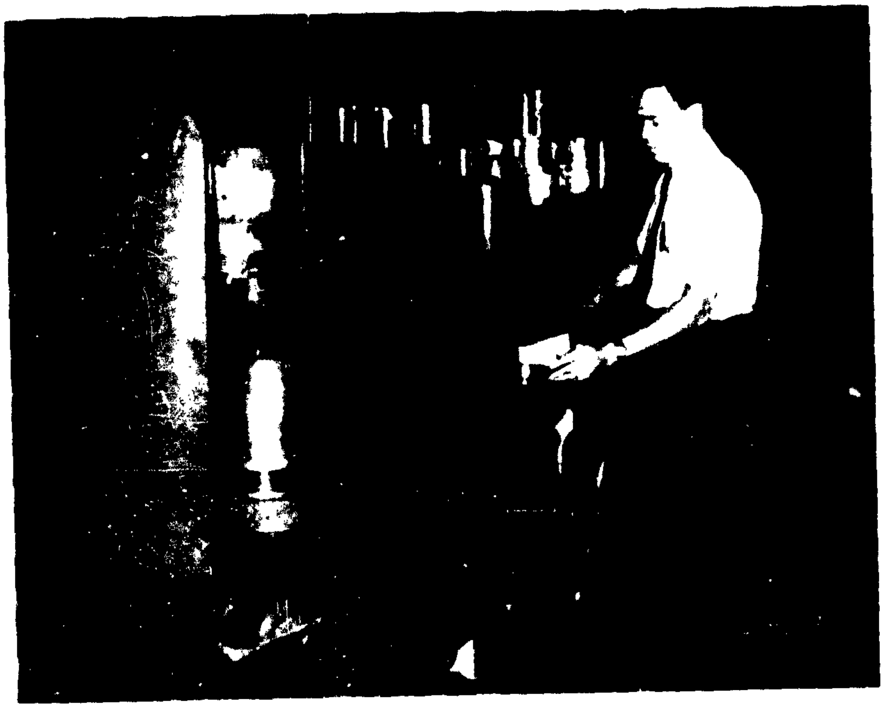


(a)
Left View Of The Work Area Showing Heating Furnace, Wire Drawing And Induction Melting Equipment.



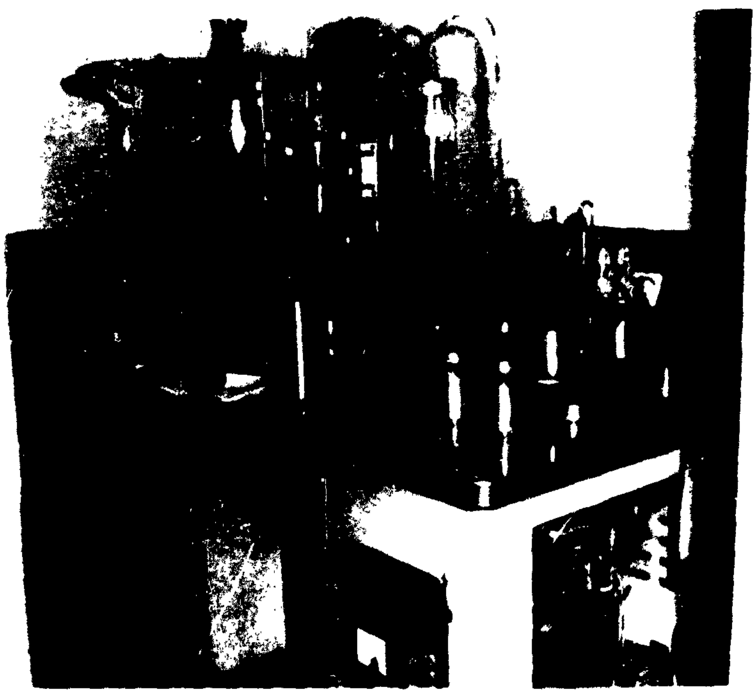
(b)
Right View Of Work Area Showing Rolling Mill And Small Electric Furnace.

Figure 14 — a and b



(c)

Close-up Of Wire Drawing Equipment In Operation.



(d)

Gas Analysis Equipment For Determining H_2, O_2, and N_2.

Figure 14 – c and d

FLUX DEVELOPMENTS FOR WELDING HY-80

by

D. C. Martin*

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FLUX DEVELOPMENTS FOR WELDING HY-80

D. C. Martin

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About a year and a half ago, the research being done on HY-80 at Battelle Institute was described at a Bureau of Ships Seminar. A number of commercial fluxes and several commercial and experimental wires had been studied. In these experiments, the results of vee-notch Charpy tests were used to compare weld metals made with the commercial materials.

Throughout all of this research, the results of submerged-arc welds have been compared with the results obtained from argon-shielded consumable-electrode welds. The major requirements for welds in HY-80 are a minimum yield strength of 80,000 psi and a 20-ft-lb Charpy vee-notch value at -80 F. Table 1 compares the tensile strengths, elongation and ductilities of welds made by submerged-arc welding with commercial fluxes and argon welding. So far as the tensile properties are concerned, there is little to choose between the two welding techniques. Welds made by either method have about the same yield strength, ultimate strength, elongation, and reduction in area. However, this is not so for impact properties as can be seen in Figure 1. When you consider that a minimum of 20 ft-lb at -80 F and 50 ft-lb at room temperature is desirable in a weld in HY-80 plate, it is obvious that the submerged-arc weld is unacceptable. Such impact results are not surprising in submerged-arc welds. They have been accepted in the past. The results shown in the lower curve were obtained with the commercial flux shown to be best in our tests and with a commercial filler wire which is used in inert-gas-shielded welding of HY-80. In these and subsequent tests, all impact properties were obtained from welds having a yield strength of more than 80,000 psi.

TABLE 1. TENSILE PROPERTIES OF SUBMERGED-ARC AND INERT-GAS WELDS MADE WITH SAME FILLER WIRE AND HEAT INPUTS

Welding Process	Yield Strength (0.2% Offset), psi	Ultimate Tensile Strength, psi	Elongation in 2 Inches, per cent	Reduction in area, per cent
Submerged arc	100,000	114,250	17.1	52.6
	100,000	114,250	19.8	52.3
Inert gas	98,000	107,750	18.2	51.0
	102,500	117,750	21.4	68.3

Since it was obvious that impact properties had to be improved, efforts were made to do this by modifying filler-wire compositions. However, wire compositions which produced outstandingly better results than the commercial wire shown in Figure 1 were not developed. Finally, a look was taken at some of the results obtained in metallographic examinations and analyses of submerged-arc welds. This indicated that the proper way to improve the notch-bar properties of submerged-arc welds was to modify the welding fluxes.

Two striking differences were found between the compositions of welds made by submerged-arc welding and by inert-gas-shielded welding. First, the silicon content was much higher in the submerged-arc weld. Second the oxygen content of the submerged-arc weld was considerably higher. Fractional gas analyses of submerged-arc welds showed that part of the extra oxygen was tied up in silicates. However, part was dissolved in the iron and this was felt to have a bad effect on the properties of the weld metal.

When the weld metals were examined metallographically, quite a difference was found between the argon-shielded weld metal and the submerged-arc weld metal. Figure 2 shows photomicrographs of a polished but unetched section of inert-gas-shielded weld metal and submerged-arc weld metal.

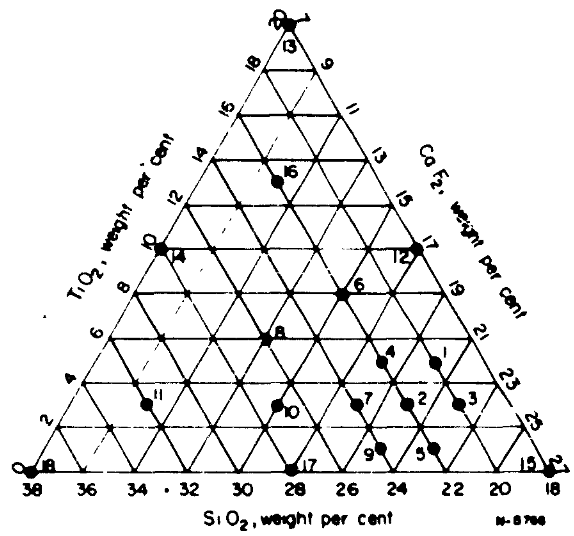


Figure 1. Comparison of Temperature Dependence of Notched-Bar Properties of Submerged-Arc and Inert-Gas Welds Made With Same Filler Wire and Heat Input

N53374 N53372

(a) Inert-Gas-Shielded Arc Weld

(b) Submerged-Arc Weld

Figure 2. Comparison Of Inclusions In Inert-Gas-Shielded And Submerged-Arc Weld Made With Standard Flux

The inert-gas-shielded weld metal is relatively clean. There are a few very small globular silicates in the structure. The block-like inclusions have not been identified, but are probably complex aluminates.

The submerged-arc weld metal contains a large number of silicate inclusions some of which are large. The difference in cleanliness in the two weld metals is obvious.

The chemical and metallographic analyses indicated that improvements in submerged-arc weld-metal properties might be obtained by reducing the oxygen content as well as the number and sizes of inclusions. It was reasoned that oxygen along with the number of inclusions might be reduced by increasing the fluidity of the molten slag. The obvious way to increase the fluidity was to lower the melting point. A number of additions were made to the standard commercial flux that was being used in an effort to lower its melting points. In preliminary tests, these additions were made by mixing powdered additive with the ground fluxes.

The first additive that was tried was calcium fluoride. This addition was made because it is known to lower the melting point and increase the fluidity of neutral fluxes. As can be seen in Figure 3, fluxes with 10 per cent and 20 per cent calcium fluoride were tested. The larger addition was the most effective. It was found that calcium fluoride additions did not affect the low-temperature impact properties greatly but did raise the room-temperature properties appreciably. In fact, the flux containing 20 per cent calcium fluoride produced welds which had room-temperature notch impact properties that were quite good. They were high enough to be of interest for HY-80 weldments.

The second addition made was titanium dioxide. Here again, as shown in Figure 4, two different amounts of titania, 5 per cent and 20 per cent, were used. In this case, the lower quantity produced the greatest improvement in notch toughness. The effect of the titania addition was different from that of the calcium fluoride addition in that with titania low-temperature properties were increased without affecting the room-temperature properties a great deal. The -80 F notch-toughness value of 30 ft-lb obtained with the flux containing 5 per cent titania was especially interesting from the viewpoint of requirements of weldments in HY-80 steel.

Up to this point, two additions to the standard flux had been tried, one raised the low-temperature notch impact properties and the other raised the room-temperature notch impact properties. Combinations of the two were then tried to see if both the low- and the high-temperature impact properties could be raised. Powder mixes of the standard flux plus 5 per cent titania and 20 per cent calcium fluoride were used first. The notch impact properties of the welds were good both at low temperature and at room temperature.

Having found that a flux containing both titania and calcium fluoride would produce welds with good impact properties, the next step was to find out whether there were still better combinations of the two additives. It was also decided to use fused fluxes. Consequently, all of the flux compositions shown by the dots on the diagram in Figure 5 were prepared and used in welding tests. In their preparation, the standard flux composition was used to which was added various amounts of titania and calcium fluoride. Further adjustments were made by varying the silica content of the standard flux.

The numbers on the figure at the various flux compositions correspond to an arbitrary rating of the notch impact behavior of welds made with the fluxes. Welds made with the flux having a rating of 1 had the best impact behavior. Welds made with the composition having a rating of 18 had the poorest impact behavior. A standard commercial wire was used in all experiments. This wire is the one which was developed for inert-gas-shielded welding of HY-80. All results discussed hereafter were obtained using this wire, because it was available in sufficient quantities and eliminated from the flux experiments any variability from the wire itself.

As can be seen in Figure 5, the best results were obtained with fluxes containing around 5 per cent titania and 20 per cent calcium fluoride. Consequently, for subsequent developments on fluxes these amounts of titania and calcium fluoride were used as basic additions.

The standard flux used in preparing the experimental compositions is said to be neutral. Figure 5 shows that the best of the experimental fluxes not only contained 5 per cent titania and 20 per cent calcium fluoride, but also had lower amounts of silica than the poorer fluxes. This suggests that reducing the acidity of the flux might also play a part in improving the notch-bar properties of submerged-arc welds. Consequently, steps were taken to determine the influence of still greater reductions in acidity. A series of fluxes having different silica to calcium oxide ratios was therefore prepared. As the ratio of silica to lime decreased in the fluxes the welds tended to become cleaner. From this series of experiments a flux was compounded which gave the best results obtained thus far. Table 2 compares the composition of this flux with that of the standard. Its calcium oxide content is twice that of the standard and its silica content is one-half. In addition,

TABLE 2. Comparison Of Nominal Compositions Of Standard And Best Experimental Flux

Flux Number	Calculated Compositions, parts by weight								
	Na_2O	K_2O	MgO	CaO	MnO	Al_2O_3	SiO_2	TiO_2	CaF_2
Standard	2.2	0.35	12.1	20.3	7.2	10.6	38.0	0.0	7.0
47 (experimental)	2.2	0.5	10.0	40.0	0.0	0.6	20.0	5.0	20.0

titania and calcium fluoride have been added and both alumina and manganese oxide have been eliminated. Figure 6 shows the effects of these changes in flux composition on weld cleanliness. The left-hand photomicrograph is that of a submerged-arc weld made with the standard flux and shown earlier in Figure 2. It will refresh your memory of the quantity, size, and type of inclusions formed on using the standard flux. This is not an unusual area but is fairly representative of the whole weld. This weld has an oxygen content of 900 ppm.

The right-hand photomicrograph is that of a weld made with the best of the experimental fluxes. It is easy to see that this weld is much freer of inclusions than the weld made with the standard flux. The oxygen content of the weld metal in this case is 300 ppm.

It can be seen that the best experimental flux has a high calcium oxide content, contains calcium fluoride and titania, and has a low silica content. If it were an open-hearth slag, it would be called a basic slag because of its high ratio of calcium oxide to silica.

The impact properties of welds produced with the best experimental flux are shown in the upper curve in Figure 7. They are compared with the impact properties of welds made with the same filler wire by inert-gas-shielded welding and with the standard flux. Although these same results may not be obtainable with this flux if produced commercially yet they do show the latitude in notch impact properties that can be obtained in welds prepared by the submerged-arc process by varying the flux composition.

It is entirely possible that the wire used may not have been the best for submerged-arc welding. It was specifically developed for inert-gas-shielded welding. Wires of other compositions may produce better results in submerged-arc welding. This possibility had not been investigated.

To indicate what might be expected from the experimental flux when produced commercially, some experimental batches were prepared by different production methods. The notch impact properties of welds made with the flux prepared in various ways are compared in Figure 8. The top curve is for welds using a flux prepared from commercially pure materials melted in graphite. The same materials melted in a fire-clay crucible gave welds with impact properties that were considerably lower. Even welds prepared with flux prepared from high-purity materials melted in a fire-clay crucible had impact properties that were not so good as those made with the flux described above melted in graphite. Figure 8 indicates only one of the variables that needs to be taken into account in producing the experimental flux commercially, if maximum notch impact properties are to be achieved in the welds.

To sum up, both filler wire and flux modifications have been tried to overcome the problem of producing submerged-arc welds with acceptable properties in HY-80. The results obtained indicate that available commercial wires can be used if proper fluxes are used It is believed that these fluxes should be chemically basic in character, should contain additions of titanium and calcium fluoride, and should not contain manganese dioxide. Using experimental fluxes made according to these premises, vee-notch impact values of 55 ft-lb at -80 F and as high as 90 ft-lb at room temperature have been obtained. It is believed that commercially produced fluxes made to the same composition will make it possible to have submerged-arc welds in HY-80 steel that have impact values of between 30 to 40 ft-lb at 80 F and between 60 to 70 ft-lb at room temperature. These Charpy values can be obtained in welds having minimum yield strengths of 80,000 psi.

At present, further studies of the effects of wire compositions are being made to see if changes in composition will develop even further improvements in notch-bar behavior of submerged-arc welds. A few of our own composition modifications have been studied and others who are working with submerged-arc welding have sent samples of wires which they have developed for us to try. So far, results are not sufficient to draw conclusions.

In the future, it is hoped that some large batches of the best experimental fluxes will be made. If this is done, samples will be furnished to various people so that they can try them out under shipyard welding conditions. It is considered that this will be the final step in the development of methods of making acceptable submerged-arc welds in HY-80 steel.

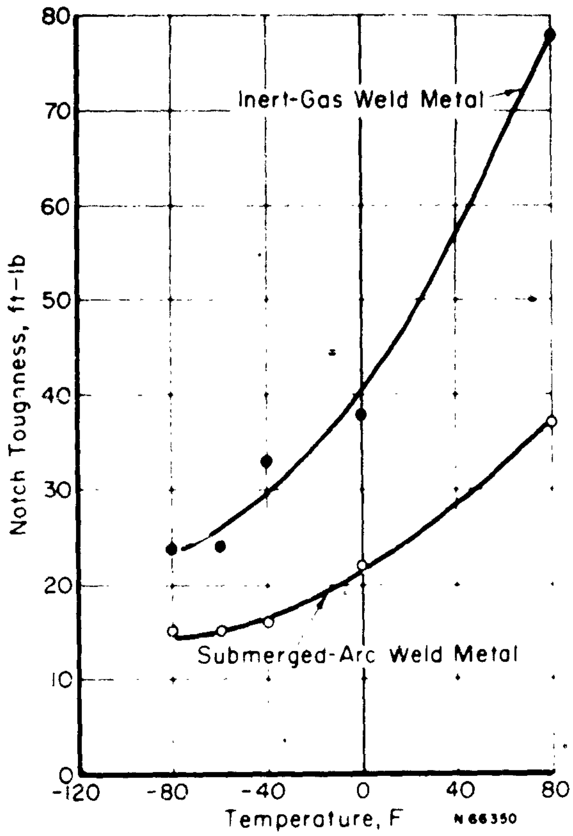


Figure 3. Effect Of Additons Of Calcium Fluoride To Standard Flux On Notched-Bar Properties Of Submerged-Arc Weld Metal

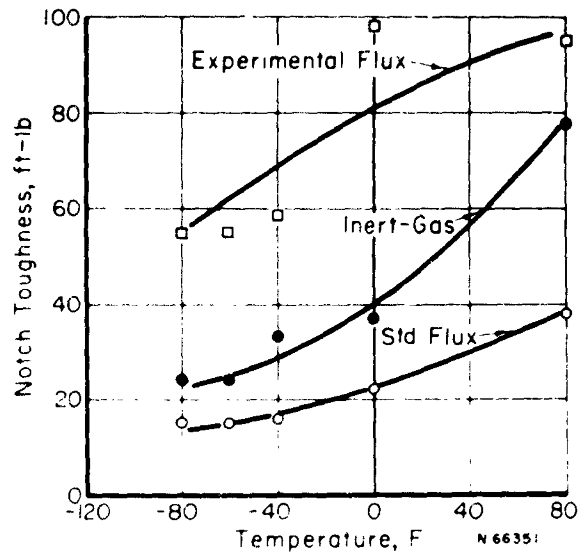


Figure 4. Effect Of Titanium Dioxide Addition To Standard Flux On Notched-Bar Properties of Submerged-Arc Weld Metal

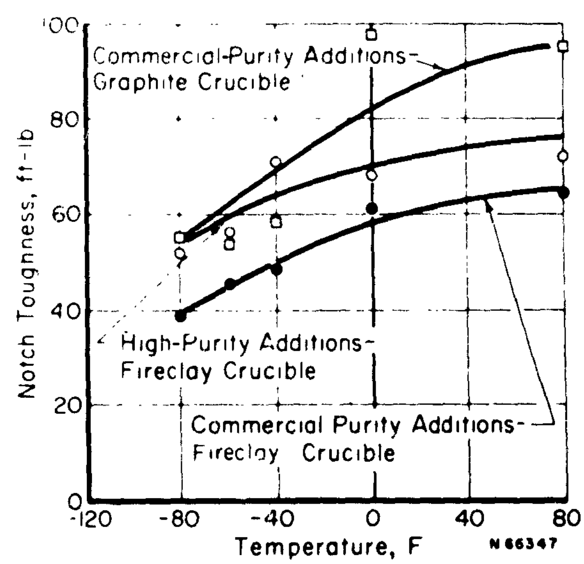
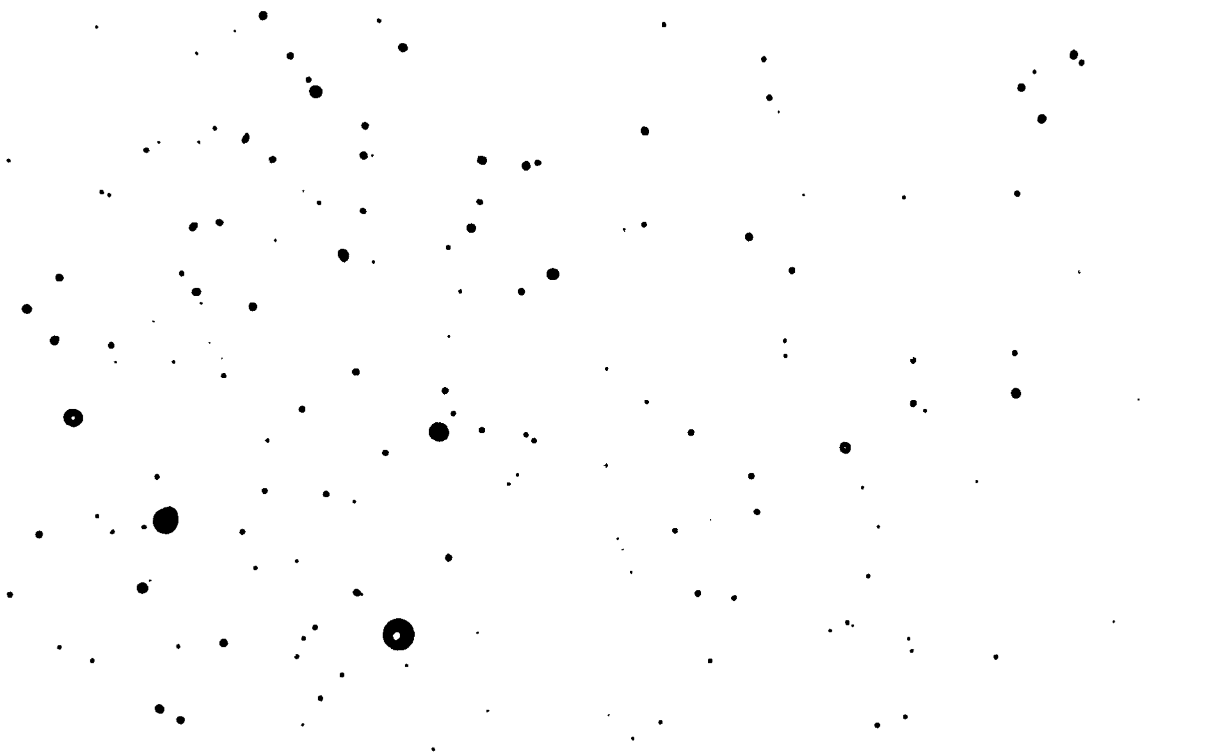


Figure 5. Titanium, Fluoride, Silica Compositions Of Experimental Fused Fluxes



N53372 N64873

(a) Standard Flux

(b) Experimental Flux

Figure 6. Comparison Of Cleanliness Of Welds Made With Standard Flux And Experimental Flux

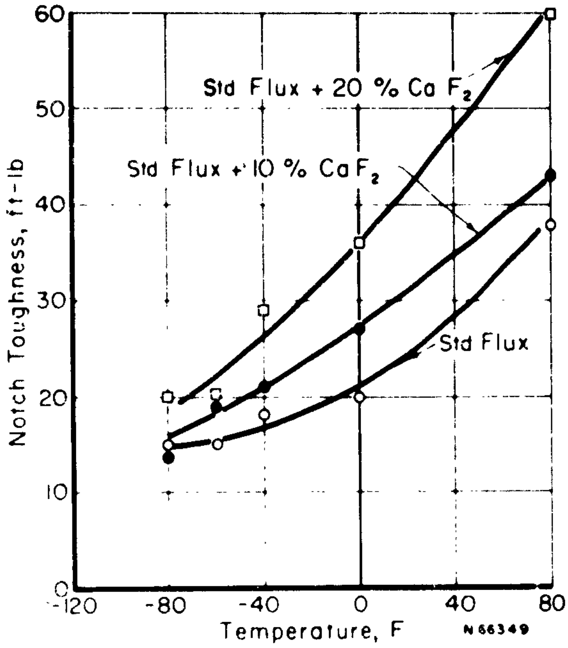


Figure 7. Comparison Of Impact Properties Of Welds Made With Standard Submerged-Arc Flux, Inert-Gas-Shielded Arc Welds, And Welds Made With Experimental Flux

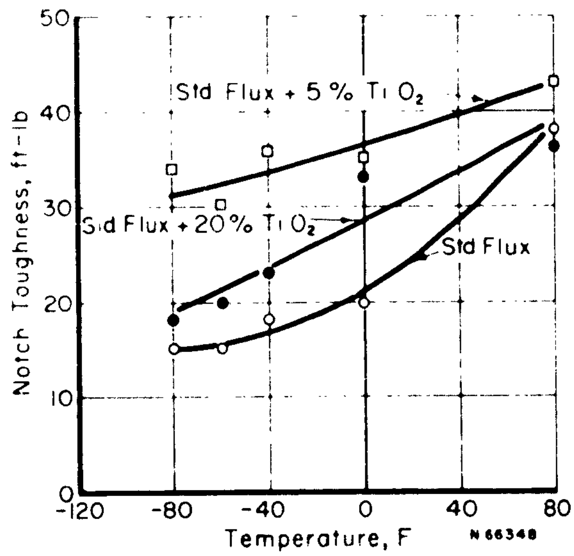


Figure 8. Comparison Of Impact Properties Of Welds Made With Experimental Fluxes Made In Various Types Of Crucibles

NOTES ON
DEVELOPMENT OF "CRACK FREE"
ELECTRODES FOR WELDING HY80 STEEL .

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BUSHIPS CONFERENCE
March 21-22 1960
Washington, D.C.

NOTES ON DEVELOPMENT OF "CRACK FREE" ELECTRODES FOR HY-80 STEEL

About two years ago we had a meeting at the Naval Research Laboratory to discuss the fabricating of HY-80 steel in submarine construction. At that meeting several pros and cons were brought out relative to the problems involved in such fabrication. The various elements entering into the proper use of Grade 11018 electrodes for welding HY-80 were thoroughly discussed and the required precautions spelled out at this meeting and in subsequent Bureau of Ships Notice 9110.

Since that time it has become evident that the 11018 type has proven to be the best electrode available for the welding of grooves in HY-80. It is superior to the Grade 260 in low temperature impact strength. The existing specifications MIL-E-19322 appear to be adequate for purchase requirements and this type electrode is being used currently in several locations with very good success.

However some of the building yards feel that more latitude in preheat application would be desirable in the welding of HY-80. The ultimate objective of course would be an electrode which could be used under any and all conditions without preheating or babying in any way. This UTOPIA will never be attained particularly in heavy sections of tempered and quenched steels welded under shipyard conditions but we can strive towards this goal and possibly reach a plateau closer to the utopian objective than where we now are. In this effort to arrive at such a point it is essential that we advance one step at a time and not try to take too big a jump suddenly lest we find that the "cure is worse than the disease". We therefore proposed to the electrode manufacturers that they try to develop an electrode for use in making temporary attachments to HY-80 with no preheat. These kind of welds are prevalent in all shipbuilding and despite all efforts by BuShips and others to eliminate them we must live with them in our building work. It is not possible to construct vessels by welding without having some of these temporary attachments.

In all cases where such attachments are welded with Grade 260 or 401B electrodes with no preheat some cracking is evident after removal of the attachment and subsequent grinding. Repairs to such cracked areas must be made because such cracks being in the outside fibres are bound to propagate under loading. This repair can be very expensive because of the great number of areas encountered. It is therefore of the utmost interest that, if possible, an electrode be developed for making such welds. Strength or impact level requirements are not as rigid as those required for the 11018 type. As a matter of fact it is generally felt that the yield strength of this "crack free" electrode might well be considerably lower than that of the 11018 type.

Obviously the stipulation as to preheat cannot be observed in fillet welding and as in the case of special treatment steel, a different type of electrode is required for such work performed with no preheat. The type 310 electrode used for STS fillets also is applicable on HY-80 with no preheat but the Bureau has not sanctioned its use. Therefore it was necessary to set up a "crash" program with the electrode manufacturers to find out what they could provide at once in the way of a suitable electrode for use in making attachment welds with no preheat. It was felt that a lower yield strength weld metal would shift the load from the heat affected zone to be distributed and carried partly by the weld metal thus avoiding or minimizing cracking in the heat affected zone. The test noted in this first slide was set up to simulate actual service requirements as a basis of weeding out the crack sensitive electrodes from those less apt to show such cracks. Note the remarks on this sketch as to ambient temperature as well as the provisions for magnetic particle inspection after grinding off the weld deposit. False impressions may be obtained because the HY-80 retains magnetization. This is extremely important in interpretation of results and experience is probably the only teacher in such interpretation.

This next slide shows data on the HY-80 test plate used in these tests. Note that it is of the high chemistry type. In order to check the impact properties at 120 F Charpy Vees were made in both directions, that is parallel to the rolling direction. These tests were repeated after stress relieving at 1150° F for 2 hours followed by furnace cooling. Please note that effect of the direction of rolling on the impact strength at low temperatures. Also note that the stress relieving treatment did not materially affect the impact properties.

We obtained data on the various types of electrodes forwarded by the different manufacturers as shown in this next slide. Four out of eleven types did not crack on this clip test. A few hundred pounds of each type were obtained and sent to the submarine building yards and, in the case of two of them, the yards had good luck. The other two types have just been forwarded to the yards and it is still too early to have any data on their performance out in the field. It is to be stressed that these electrodes are not necessarily commercially available electrodes but have been developed basically to meet the requirements set up in our meetings with the electrode manufacturers.

It must be understood that this original series of tests was conducted in order to try to get an electrode out into the yards as quickly as possible so that they would be enabled to keep on working with a minimum of cracking troubles. The rather good reports from the first two electrodes sent out prompted a second look as to why this "crack free" electrode was less susceptible to cracking than the 11018 electrodes. From our tests, chemistry, yield, impact strengths do not follow any pattern.

It was then decided to try out modifications of some of these electrodes in an effort to ascertain, if possible, the effect of various elements on this "crack free" property of weld metal of this class. This next slide shows some of the variations in the electrodes tested. For example No. 15 is the same as No. 14 except for the slightly higher manganese content of the latter. Likewise No. 18 is the same as No. 15 except that the latter has no molybdenum. By changing one variant at a time we hope to be able to come up with the reason for the difference in susceptibility to cracking between various analyses of welding deposits. The effect of manganese, nickel, and molybdenum variations is being studied. At the same time the limitations of the clip test itself are also being examined. For instance the impact loading in the removal of clips is a factor in the evaluation of the clip test. We are just completing a series of tests in which some clips were removed by hammering with the weld in compression instead of in tension. It is proposed to try a series in which loading to break off the clips will be accomplished by means of a constant hydraulic pressure rather than by impact loading. I personally prefer the impact loading as that is more nearly what happens in service when clips are removed. Other types of tests are being considered so that we may wind up with a specification requirement for "check free" electrodes.

It is recognized that this clip test employed in the testing of these electrodes differs somewhat from the more conventional methods used for other types of electrodes. However it is our belief that the tests described herein served a very useful purpose by providing electrodes which were less crack sensitive in making attachment welds with no preheat than were the 11018 type. As noted above we are continuing with this program as we feel that even better electrodes can be provided by the electrode manufacturers if we tell them what our targets are. In a few short years we have progressed from weld metal with little or no low temperature impact strength (as compared with those of the base metal) to weld metal having many times more impact strength. Our basic target of course is to get weld metal equal to the base metal in low temperature impact strength by use of fabrications procedures involving use of little or no preheat and I, for one, feel extremely confident of the ability of our suppliers to furnish such material.

TESTS OF HY-80 PLATE USED

1-3/8" Thick (Lukens Steel Co.)

Chemistry

.16	Carbon
.56	Moly
3.08	Nickel
1.63	Chrome

Impact at -120°F (As received)

Direction Rolling.	Trans. Direction Rolling.
114	62
114	62
114	62
113	62
113	61

Impact at -120 F (After Stress Relief at 1150°F ± 25°F for 2 hours F.C.)

111	50
111	47
103	47
99	45
90	44

Defect in specimen. Failed near gage marks

TABLE I
COMPARISON OF 9018 TYPE ELECTRODES (5/32" SIZE)

TYPE	CLIP Test	IMPACT STRENGTH (-60 F) AW.	IMPACT STRENGTH (-60 F) SR.	Y. P.	AW. T.S	Elong	C	MN	P	S	Si	Ni	Cr	Mo	V
Spec. MIL-E-19322	-	20	20	80000	-	20	-.10	.50 1.00	-.09	-.03	-.80	1.40 1.80	-.15	-.35	-.05
1	OK	61-61-59 60	66-54-52 57	82750	91000	20	.07	1.34	-	-	.40	2.17	.09	.33	
2	OK	61-55-48 55	28-24-24 25	86000	96000	24.5	.05	.63	.017	.03	.26	1.49	.04	.30	.02
3	Failed	87-75-74 79	58-35-32 42	87250	94750	16*	.04	1.24	.023	.015	.43	1.61	.04	.30	.00
4	Failed	82-81-75 79	42-23-21 29	82500	89500	27	.04	1.13	.017	.022	.28	1.71	-	.34	-
5	Failed	72-72-71 72	57-56-52 55	79000	86750	26	.04	.58	.020	.019	.19	2.93	.29	-	-
6	OK	66-65-61 64	38-34-33 35	87880	98360	19	.06	1.57	.013	.015	.34	1.87	.05	.00	.04
7	OK	58-51-4[illegible] 52	37-26-21 28	98660	105700	24	.06	1.57	.013	.015	.35	2.72	.05	.00	.00
8	Failed	36-36-25 32	28-28-22 26	91450	99250	25	.06	1.57	.013	.010	.34	.06	.24	.30	.01
9	Failed	72-55-47 58	26-22-15 21	92210	101000	22	.07	1.56	.012	.010	.33	1.22	.07	.31	.01
10	Failed	62-51-34 52	17-17-13 16	82710	91360	20	.06	1.53	.013	.015	.33	.07	.24	.00	.01
11	Failed	31-28-23 27	19-19-15 18	86360	94700	28	.06	1.51	.013	.015	.32	.05	.05	.30	.01

TABLE II

COMPARISON OF 2nd BATCH - "CRACK FREE" ELECTRODES (5/32 Size)

TYPE	CLIP TEST	C	MN	SI	NI	CR	MO	REMARKS
12		.04	1.03	.24	1.75	.29	.32	
13		.05	1.31	.30	2.23	-	.37	
14		.05	1.00	.30	2.00	-	.40	
15		.05	1.20	.30	2.00	-	.40	Modification of 14
16		.05	1.40	.30	2.00	-	.40	" " "
17		.05	1.00	.30	2.00	-	.00	
18		.05	1.20	.30	2.00	-	.00	Modification of 17
19		.05	1.40	.30	2.00	-	.00	" " "
20		.05	1.20	.30	1.80	-	.00	
21		.05	1.20	.30	2.50	-	.00	Modification of 20 Higher Nickel
22		.05	1.40	.30	1.80	-	.00	Modification of 20 Higher Mn
23		.05	1.40	.30	2.50	-	.00	Modification of 22 Higher Nickel
24		.06	1.50	.50	1.85	-	.00	
25		.03	1.50	.50	1.85	-	.00	
26		.06	1.50	.50	1.85	-	.00	Same as 24 with different coating
27		.06	1.35	.50	1.85	-	.30	
28		.06	.97	.37	1.58	-	.22	Modification of 3
29		.05	1.08	.33	1.66	-	.35	" " "
30		.05	1.24	.41	1.99	-	.27	" " "
31		.05	1.32	.23	1.92	-	.05	" " "
32		.05	1.20	.28	3.01	-	.05	" " "

SOME OBSERVATIONS ON THE WELDABILITY OF QUENCHED AND TEMPERED HIGH-YIELD-STRENGTH ALLOY STEELS

By W. D. Doty and G. E. Grotke

(Prepared for presentation at a Navy Department Welding Conference to be held in Washington, D. C., on March 21, 1960, and for publication by the Navy Department.)

Abstract

Navy HY-80 steel and USS "T-1" constructional alloy steel have opened the door to new opportunities in the design of engineering structures. However, as in the introduction of many other new engineering materials, the use of HY-80 steel and USS "T-1" constructional alloy steel has required designers and fabricators to depart from conventional practices for structural carbon steels.

In the spring of 1958, several shipyards encountered weld-cracking difficulties in the fabrication of HY-80 steel for the pressure hull of submarines, and for nearly two years U. S. Steel has been collaborating with the Navy Department and submarine yards in seeking a solution to the problem. This report points out some observations from studies on cracked welds removed from a submarine, from studies to produce toe cracking in fillet-welded specimens of HY-80 steel and "T-1" steel, and from studies of the microstructure of welds in these steels.

Metallographic studies on specimens from a frame-to-hull tee joint and from an auxiliary-ballast-tank tee joint showed extensive evidence that intergranular weld-metal cracking and intergranular heat-affected-zone cracking had occurred in heavy-gage-composition HY-80 steel and in light-gage-composition HY-80 steel, particularly at the toes of fillet welds. The type of cracking appeared to be consistent with the theory of "underbead" cracking in welds. It is suggested that a preheat to insure plate dryness, the use of adequately dried low-hydrogen electrodes, and proper contouring of fillet welds would assist in eliminating the welding difficulties.

Fillet-welded test specimens made using dry low-hydrogen electrodes showed that heavy-gage-composition HY-80 steel was very susceptible to heat-affected-zone root cracking in contrast to light-gage-composition HY-80 steel, which was not susceptible. "T-1" steel was moderately susceptible to this type of cracking in stress-relieved joints. Studies indicated that root cracking might be minimized or eliminated in double-fillet-welded tee joints by depositing the fillet welds in a manner which would provide a uniform and simultaneously equal input for each fillet.

The microstructure of the maximum-grain-coarsened heat-affected zone in 1/2-inch-thick heavy-gage-composition HY-80 steel welded at 70 F consisted essentially of untempered and self-tempered martensite, whereas the microstructure at a similar location in "T-1" steel consisted essentially of untempered and self-tempered martensite and bainite. Both steels had, at the prior austenite grain boundaries, a constituent believed to be high-carbon, alloy-enriched martensite. Further metallographic studies are in progress.

Introduction

In 1945 U. S. Steel joined a Navy Department, Bureau of Ships program to develop an improved submarine hull steel possessing high yield strength and good notch toughness, together with good formability and weldability. One of the results of this program was a low-carbon quenched and tempered alloy steel of 80,000 psi minimum yield strength. This steel was accepted in 1951 by the Navy Department as HY-80 under the Navy Specification MIL-S-16216.

Concurrent with this undertaking, U. S. Steel developed a high-yield-strength constructional alloy steel to meet the needs of industry. This steel-USS "T-1" constructional alloy steel-was designed to have a yield strength of 90,000 to 100,000 psi, together with the desirable characteristics of good low-temperature notch toughness, good weldability, and sufficient ductility to undergo bending to reasonable radii.

These two quenched and tempered high-yield-strength alloy steels have opened the door to new opportunities in the design of engineering structures, both military and industrial. The steels have met with outstanding success. Testimony to this fact may be found in the many military applications in which HY-80 steel has been used, and in the earth-moving equipment, pressure vessels, bridges, penstocks, scroll cases, and steel mill equipment in which "T-1" steel has been used.

As in the introduction of many other new engineering materials, the use of HY-80 steel and "T-1" steel has required designers and fabricators to depart from conventional practices used with structural carbon steels. Thus, it is not surprising that some fabrication difficulties have been encountered. In most, if not all these cases, it was possible to minimize or eliminate the difficulties when recognition was given to the importance of using fabrication practices tailored to meet the needs of high-yield-strength alloy steels rather than patterned after procedures acceptable only for steels which have moderate strength.

In the spring of 1958, several shipyards involved in the Navy submarine program encountered weld-cracking difficulties in the fabrication of HY-80 steel. These cracking difficulties were encountered during fillet welding of the frame members to the hull plates. Transverse cracks formed in the weld metal and toe cracks formed in the heat-affected zone adjacent to the weld metal. These observations prompted much investigation, and for nearly two years U. S. Steel has been collaborating with the Navy Department and submarine yards in seeking a full solution to the problem. Significant to U. S. Steel's approach to the problem is the fact that weld-metal and heat-affected-zone cracking had been observed in some highly restrained joints in "T-1" steel. For example, Arnold[1]* has described experiences in the welding of "T-1" steel spheres in Japan. Although weld-metal-cracking difficulties were encountered in the early stages of fabrication, these difficulties were eliminated when care was taken to insure that the steel was dry (obtained by 150 F preheat) and to insure that the low-hydrogen electrodes were essentially moisture free. Arnold's experiences were with welded joints not subsequently stress-relieved. In a few other cases, cracking has been observed in the heat-affected zone of welded joints in "T-1" steel, primarily only after the joints had been stress-relieved. Such difficulties at the toes of welds have been overcome by properly contouring the welds to minimize points of stress concentration, by peening at the toes of the welds, or by depositing weld metal having strength lower than that of the steel being welded and having sufficient ductility to adjust locally and relieve the stress.

Since the introduction of quenched and tempered high-yield-strength steels nearly ten years ago, much has been published on the welding of these steels. The purpose of this report is to point out some additional observations on their weldability. The observations stem from studies on cracked welds removed from the pressure hull of a submarine, from studies to develop a weld-test specimen that will reproduce the type of cracking encountered by fabricators, and from metallographic studies of welds.

Materials and Experimental Work

Samples of Welds From a Submarine

Two samples, each cut from a different multiple-pass-welded tee joint made from plates of HY-80 steel were supplied by a submarine shipyard to the United States Steel Applied Research Laborabory. One sample, Figure 1, had been part of a frame-to-hull tee joint, Figure 2, removed from the pressure hull. The hull plate was 2-1/4-inch-thick HY-80 steel (heavy-gage composition) and the frame plate was 1-3/8-inch-thick HY-80 steel (light-gage composition). The root passes in the joint reportedly had been deposited by the twin-arc, inert-gas-shielded metal-arc welding process using Ni-Mo-V steel wire (A632). The remaining passes in the joint reportedly had been deposited by the manual metal-arc welding process using either E11018 (Mn-Ni-Cr-Mo) electrodes or E10015 (Ni-Mo-V) electrodes. The shipyard conditions prevailing at the time the joint was welded suggest the possibility that the joint and the electrodes were not adequately dry. The second sample

* See References.

supplied by the shipyard, Figure 3, had been part of an auxiliary ballast tank. In this sample, heavy-gage-composition HY-80 steel (1-1/2 inch) was welded to light-gage-composition HY-80 steel (1-3/8 inch), reportedly by the same procedure described for the frame-to-hull joint.

The chemical composition was determined for each of the plates and weld metals in the two samples. However, tensile properties were determined only for the plates in the frame-to-hull tee joint. Both of the welded joints were examined by magnetic-particle inspection and then sectioned and examined metallographically at many locations to determine the nature and extent of cracking.

Restraint-Cracking Studies

Soon after U. S. Steel was informed by the Navy Department in 1958 that weld-cracking difficulties had been encountered in the fabrication of HY-80 steel, preliminary studies were undertaken to reproduce in a laboratory-size welded specimen the fillet-weld toe cracking reportedly encountered. Figure 4 shows two views of a multiple-pass-welded tee-shaped specimen used for these preliminary studies and Figure 5 gives the details of the specimen. It may be noted that a "stem" plate of 1-inch-thick HY-80 steel (light-gage composition) was fillet-welded to a "base" plate of 1-1/2-inch-thick HY-80 steel (heavy-gage composition) previously stiffened by another plate of 1-1/2-inch-thick HY-80 steel.

Three multiple-pass-welded tee-shaped specimens were prepared using the HY-80 steels described in Table I and the welding procedures described in Table II. Dry low-hydrogen electrodes were used in all cases. It may be noted in Table II that two different preheat temperatures (70 and 200 F) and two different welding sequences were used. These different conditions were employed in order to determine the effect of such changes in welding procedure on crack susceptibility. After the specimens were prepared, all the welds in the specimens (including the welds in the large stiffener plate) were carefully inspected by magnetic-particle methods to determine whether cracks were present at or near the weld surfaces. The large stiffener plate was then removed and the remaining tee-shaped portion of the specimen was sectioned to provide three tee-bend specimens, two metallographic specimens, and three "underbead" cracking specimens, all as shown in Figure 6. The tee-bend specimens were tested as simple beams with a concentrated load at the center opposite the stem so that maximum stress occurred at the toe of the fillet welds. Bend performance was judged qualitatively rather than quantitatively. The "underbead" cracking specimens were examined by magnetic-particle-inspection methods and the extent of cracking was expressed as a percentage of the length of the specimen.

Figure 7 gives the details of a multiple-pass-welded cruciform-shaped specimen also used for preliminary studies undertaken in an attempt to reproduce the fillet-weld toe cracking reported by fabricators of HY-80 steel. One such specimen was prepared as described in Table II, and with the HY-80 steel identified as "B" in Table I. The specimen was examined by magnetic-particle inspection to determine whether cracks were present at or near the weld surfaces.

After the above-described preliminary studies were made with multiple-pass-welded tee-shaped specimens and with a multiple-pass-welded cruciform-shaped specimen, extensive work was undertaken using a single-pass-welded cruciform-shaped specimen, Figure 8, similar to that developed by Watertown Arsenal to evaluate the weldability of armor steels. The details of the specimen are given in Figure 9. Specimens in groups of approximately eight were prepared from the following 1/2-inch-thick plate materials described in Table III: one light-gage-composition HY-80 steel plate, two heavy-gage-composition HY-80 steel plates*, and three "T-1" steel plates. Each group contained approximately eight specimens because the preliminary studies with the multiple-pass-welded specimens had raised doubts concerning the reproducibility of cracking encountered in tee-shaped and cruciform-shaped specimens. The welding procedure for the preparation of the single-pass-welded cruciform-shaped specimen is given in Table IV. Dry low-hydrogen electrodes were used in all cases. It will be noted that a preheat was not used. The selected welding conditions provided a heat input of 69,000 joules per inch, a value near the suggested maximum heat input (70,000 joules per inch) for welds made in 1/2-inch-thick "T-1" steel plate at 70 F. It will also be noted that specimens, stress-relieved after welding, were prepared from all the plate steels described in Table III, whereas as-welded specimens were prepared only from one heavy-gage-composition HY-80 steel plate. As-welded specimens of light-gage-composition HY-80 steel and of "T-1" steel were not included in the present study because previous experience with laboratory-size fillet-welded specimens prepared from these steels and not stress-relieved after welding had indicated that these steels when welded with dry low-hydrogen electrodes were not susceptible to heat-affected-zone cracking.

* Although heavy-gage-composition HY-80 steel is not normally produced in thicknesses less than 1-1/4 inches, the Laboratory arranged to have 1/2-inch-thick plates (Items D and E in Table III) of this material produced for welding tests.

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150 F when plate dryness is not certain and the use of adequately dried low-hydrogen electrodes would assist greatly in reducing the weld-metal and heat-affected-zone cracking difficulties by eliminating the sources of hydrogen.

Another observation made from examination of the two tee-joint samples from a submarine concerns the geometry of the fillet welds. The contour of the face of each of the fillet welds, Figures 14 and 17, was such that an abrupt change occurred at the toes of the fillets, particularly at the toes adjacent to each through plate (or hull plate). These abrupt changes in contour provided points of stress concentration when the weld was stressed during contraction on cooling or during the fabrication of adjacent members. Therefore, any plastic deformation resulting from high stress was concentrated at the toes of such poorly contoured fillet welds. Good fillet-weld contouring in which the fillets are faired into the adjacent plates has long been recognized to be a desirable welding practice, regardless of the type of material being joined. In the welding of high-yield-strength materials, refinements in design, including weld contour, are a must if advantage is to be taken of the high strength of these materials. Figure 19 shows a view of the auxiliary-ballast-tank tee-joint sample at a section about 2 inches away from that shown in Figure 17. Note the very abrupt change in contour at the toe of one of the fillet welds and the suggested desirable contour.

Results of Restraint-Cracking Studies

It may be recalled that studies were undertaken with multiple-pass-welded tee-shaped specimens of HY-80 steel in an attempt to reproduce the fillet-weld toe cracking encountered by shipyards. It is significant that all the welding was done with dry electrodes. From the results summarized in Table VIII, it may be noted that no toe cracks or weld-metal cracks were found in any of the specimens. However, root cracks were detected in the two specimens (No. 1 and 2) in which the first fillet weld was completed before the second fillet weld was started. The extent of root cracking was lower (16% vs 43%) in the specimen welded after a 200 F preheat rather than after no preheat. A typical root crack is shown in Figure 20. No cracks were found in the specimen (No. 3) made by alternately depositing beads on each side of the stem plate. The results of the bend tests on specimens from each of the multiple-pass-welded tee joints indicated that toe cracking occurred when each of the specimens was bent a moderate amount-approximately 20 degrees (included angle).

In studies undertaken with a multiple-pass-welded cruciform-shaped HY-80 steel specimen, no toe cracks or weld-metal cracks were detected. Therefore, no further studies were made with this specimen and consideration was given to a single-pass-welded cruciform-shaped specimen since such a specimen was less time consuming to prepare and, therefore, more suited for extensive studies to determine the reproducibility of heat-affected-zone cracking.

Magnetic-particle inspection of the weld surfaces of single-pass-welded cruciform-shaped specimens in both the as-welded and the stress-relieved conditions revealed no toe cracks or weld-metal cracks. However, inspection of the "underbead" cracking specimens prepared from the fillet-welded specimen revealed extensive amounts of root cracking for some of the steels studied. The results are given in Tables IX, X, and XI. It may be noted from the data in Table IX that heavy-gage-composition HY-80 steel was very susceptible to heat-affected-zone root cracking in contrast to light-gage-composition HY-80 steel which showed no susceptibility. The amount of root cracking in the welded and stress-relieved specimens of heavy-gage-composition HY-80 steel was about the same as that in similar specimens in the as-welded condition. In both cases, the cracking was greatest at the root of the "C" fillet. This observation will be discussed later in regard to the effect of welding sequence on the distribution of cracking. Metallographic examination of a typical root crack in an as-welded specimen of heavy-gage-composition HY-80 steel showed that the crack was intergranular, as illustrated in Figure 21.

It may be noted from the data in Table X that "T-1" steel was moderately susceptible to root cracking in contrast to the susceptibility, shown in Table IX, for heavy-gage-composition HY-80 steel. It is also significant that heat-affected-zone root cracks have been observed only in welded specimens of "T-1" steel, stress-relieved after welding. Also, note in Table X the rare occurrence of a toe crack (Steel H-fillet "A" in specimen No. 2). Present indications from studies in progress to determine the cause of cracking in the heat-affected zone of welds in "T-1" steel, when such welds are stress-relieved, suggest that failure occurs by stress rupture in grain-coarsened regions of high residual tensile stress resulting from welding. Failure is believed to occur in the early stage of the stress-relief treatment before the residual stress from welding is significantly reduced.

The results of the tests of the single-pass-welded cruciform-shaped specimens, presented in Tables IX and X, showed that the extent of root cracking was greatest at the root of the "C" fillet and was least at the "D" fillet. The effect of welding sequence on the distribution of the root cracks is illustrated by the data in Table XI, the upper half of which gives the results for fillet welds deposited progressively in a clockwise sequence (standard for this report), and the lower half of which gives the results for fillet welds deposited progressively in a counterclockwise sequence. It may be noted in Table XI that cracking, when the welding sequence was counterclockwise, was greatest at the "A" fillet, instead of the "C" fillet, and was least at the "B" fillet, instead of the "D" fillet. Since it was observed that cracking occurred only in the through plate at the root of the first fillet weld in double-fillet-welded tee joints (see Table VIII) and that the cracks were present only after the second fillet weld was deposited, it is believed that cracking was greatest at "C" fillet (clockwise sequence) and at "A" fillet (counterclockwise sequence) because each of these fillets was the first of a pair of fillet welds at a joint in which the second weld was made only after the through plate had been stiffened by the welds on the opposite side. The results suggest that root cracking might be minimized or eliminated in double-fillet-welded tee joints by depositing the fillet welds uniformly in a manner which would provide a simultaneously equal heat input for each fillet. It is known that this technique has been effective in the past in avoiding cracking in joints in structural carbon steel welded under conditions of high restraint.

In summary, the results of the restraint-cracking studies to develop a laboratory-size welded specimen which would produce fillet-weld toe cracking showed that such cracks were not produced in multiple-pass-welded tee-shaped specimens or in a multiple-pass-welded cruciform-shaped specimen, and were rarely produced in a single-pass-welded cruciform-shaped specimen, all welded with dry low-hydrogen electrodes. However, the studies showed that heavy-gage-composition HY-80 steel was very susceptible to heat-affected-zone root cracking in contrast to light-gage-composition HY-80 steel, which was not susceptible. The amount of cracking in welded and stress-relieved joints in heavy-gage-composition HY-80 steel was about the same as that in as-welded joints. Therefore, stress relieving did not contribute to crack susceptibility. The "T-1" constructional alloy steel was moderately susceptible to heat-affected-zone root cracking in welded and stress-relieved joints. The results of a study of the distribution of the root cracks indicated that the root cracking might be minimized or eliminated in double-fillet-welded tee joints by depositing the fillet welds in a manner which would provide a uniform and simultaneously equal heat input for each fillet.

Results of Metallographic Studies

A comparative study of the microstructures of bead welds in heavy-gage-composition HY-80 steel and "T-1" steel was undertaken to see whether the microstructures, particularly those in the heat-affected zone, would provide information on the cause of cracking in these high-yield-strength alloy steels. Bead welds rather than fillet welds were used for this comparative study, since it was desired to use the simplest weld configuration. The specimens were welded with a heat input of 47,000 joules per inch and at initial plate temperatures of 70, 300, and 500 F. To date, the comparative metallographic study has been completed only for the specimens welded without a preheat (70 F). Therefore, only a limited number of observations can be reported at this time.

Figure 22 is a photomacrograph of a bead weld in "T-1" steel. It is also typical of the appearance, at a magnification of X7, of a similar type of weld in heavy-gage-composition HY-80 steel. The numbered circles in Figure 22 indicate the locations in the specimen that have been given detailed metallographic examination. Typical photomicrographs of the structure revealed at X1500 by the light microscope and at X10,000 by the electron microscope for selected zones in the HY-80 steel specimens (heavy-gage-composition) and in the "T-1" steel specimen are shown in Figures 23 through 25. Photomicrographs of the structures for comparable zones in the "T-1" steel specimens are shown in Figures 26 through 28. The base-metal microstructures for HY-80 steel (heavy-gage composition) and for "T-1" steel are illustrated in Figures 23 and 26, respectively. The microstructure of the HY-80 steel and the "T-1" steel consisted of tempered martensite and tempered bainite.

The microstructures of the maximum-grain-coarsened heat-affected zone in the as-welded HY-80 steel specimen, Figure 24, consisted essentially of untempered and self-tempered martensite, the constituent at the prior grain boundaries probably being alloy-enriched areas. Tempering of the alloy-enriched areas during a stress-relief treatment resulted in the formation of agglomerated carbides, Figure 25.

The microstructure of the maximum-grain-coarsened heat-affected zone in the as-welded "T-1" steel specimen, Figure 27, consisted essentially of untempered and self-tempered martensite and bainite. Alloy-enriched areas are believed to be present at the prior austenite grain boundaries and also adjacent to the bainite needles. Tempering of these alloy-enriched regions during a stress-relief treatment resulted in the formation of many agglomerated carbides, Figure 28.

Though the metallographic studies have provided much information on the microstructural changes that occur in the weld heat-affected zone of both HY-80 steel and "T-1" steel, these studies have not, as yet, clarified the mechanism of crack susceptibility. Further metallographic studies are in progress on specimens welded at 300 F and at 500 F, and it is hoped that the information from these studies, together with that from the specimens welded at 70 F, will be valuable in determining the cause of cracking in the high-yield-strength alloy steels.

Summary

The results of studies on samples of welds from a submarine, of studies to produce toe cracking in fillet-welded specimens of HY-80 steel and "T-1" steel, and of studies of the microstructure of welds in these steels are summarized as follows:

1. Metallographic studies of a specimen from a welded frame-to-hull tee joint and of a specimen from a welded auxiliary-ballast-tank tee joint, both removed from a submarine, showed extensive evidence that intergranular weld-metal cracking and intergranular heat-affected-zone cracking had occurred, particularly at the toes of the fillet welds. The heat-affected-zone cracking was observed in heavy-gage-composition HY-80 steel and in light-gage-composition HY-80 steel.

2. The type of cracking appeared to be consistent with the theory of "underbead" cracking in welds. Thus, the use of a preheat to a temperature of approximately 150 F, when plate dryness is not certain, and the use of adequately dried low-hydrogen electrodes would assist greatly in eliminating the weld-metal and the heat-affected-zone cracking difficulties with HY-80 steel plates.

3. Abrupt changes in fillet-weld contour provided points of stress concentration in the frame-to-hull tee joint and in the auxiliary-ballast-tank tee joint. This condition probably contributed to the cause of the toe cracking in the tee joints removed from the submarine. Good weld contouring is a necessity if full advantage is to be taken of the properties of welded high-yield-strength alloy steels.

4. Studies to develop a laboratory-size welded specimen which would produce fillet-weld toe cracking showed that such cracks were not produced in a multiple-pass-welded tee-shaped specimen and in a multiple-pass welded cruciform-shaped specimen and were rarely produced in a single-pass-welded cruciform-shaped specimen, all welded with dry low-hydrogen electrodes.

5. Fillet-welded test specimens made using dry low-hydrogen electrodes showed that heavy-gage-composition HY-80 steel was very susceptible to heat-affected-zone root cracking in contrast to light-gage-composition HY-80 steel, which was not susceptible. "T-1" constructional alloy steel was moderately susceptible to heat-affected-zone root cracking. The root cracking in "T-1" steel occurred in welded and stress-relieved joints, whereas the root cracking in heavy-gage-composition HY-80 steel occurred on welding.

6. A study of the distribution of the root cracks indicated that the root cracking might be minimized or eliminated in double-fillet-welded tee joints by depositing the fillet welds in a manner which would provide a uniform and simultaneously equal heat input for each fillet.

7. Metallographic studies on bead welds made in 1 2-inch-thick plate at 70 F and with a heat input of 47,000 joules per inch showed that the microstructure of the maximum-grain-coarsened heat-affected zone in heavy-gage-composition HY-80 steel and "T-1" steel consisted essentially of untempered and self-tempered martensite. Both steels had, at the prior austenite grain boundaries, a constituent believed to be high-carbon alloy-enriched martensite. Further metallographic studies are in progress.

References

1. Arnold, P. C., "Problems Associated With the Welding of 'T-1' Material," The Welding Journal, 36 (8), Research Supplement 373-s to 381-s, August, 1957.

2. R. D. Stout and W. D. Doty, "Weldability of Steels," Welding Research Council, 1953.

Table I

Chemical Composition of the HY-80 Steel Plates Used for Multiple-Pass-Welded Tee-Shaped Specimens and Multiple-Pass-Welded Cruciform-Shaped Specimen

Item	Composition Type*	Heat No.	Plate Thickness, in.	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Ti	Al (Sol)
				Chemical Composition (Check Analysis), per cent											
A	Heavy-gage	69L320	1-1/2	0.13	0.24	0.007	0.014	0.17	0.05	3.08	1.43	0.27	<0.005	<0.005	0.038
B	Heavy-gage	71L252	1-1/2	0.15	0.24	0.014	0.023	0.18	0.03	2.87	1.68	0.49	0.004	0.007	0.039
C	Light-gage	72L324	1	0.14	0.25	0.011	0.018	0.22	0.04	2.60	1.10	0.27	~0.005	0.005	0.030

Chemical Composition Requirements for HY-80 Steel Plates [Military Specification—Steel Plate, Alloy, Structural, High Yield Strength, MIL-S-16216D (NAVY) 12 February 1959]

Nominal Thickness, pounds per square foot	C	Mn	P	S	Si	Ni	Cr	Mo
	Chemical Composition (Ladle Analysis), per cent**							
Over 51.0 (1-1/4 inch)	0.23 max	0.10/0.40	0.035 max	0.040 max	0.15/0.35	2.50/3.25	1.35/1.85	0.30/0.60
To 56.1 incl***(1-3/8 inch)	0.22 max	0.10/0.40	0.035 max	0.040 max	0.15/0.35	2.00/2.75	0.90/1.40	0.23/0.35

* HY-80 steel water-quenched from 1650 F and tempered at 1200 F.

** For certain elements, the check analysis is permitted to be over the maximum limit of the ladle analysis or under the minimum limit of the ladle analysis by the following amounts:

0.05% Mn, 0.03% Si, 0.07% Ni, 0.06% Cr, 0.03% Mo.

*** For thicknesses between 51.0 and 56.1 pounds per square foot, either composition may be supplied.

TABLE II

Summary of Welding Conditions Used in the Preparation of Multiple-Pass-Welded Tee-Shaped Specimens and Multiple-Pass-Welded Cruciform-Shaped Specimens

Specimen Type	Specimen Number	Stem Material*	Base or Through-Plate Material*	Electrode**	Initial Plate Temperature, F	Maximum Interpass Temperature, F	Type of Weld	Welding Procedure
Tee	1	C	A	E12015	70	125	Full-penetration fillet	The first fillet weld was completed before the opposite fillet was made.
Tee	2	C	A	E12015	200	250	Full-penetration fillet	The first fillet weld was completed before the opposite fillet was made.
Tee	3	C	B	E12015	70	125	Full-penetration fillet	Fillet welds were made by alternately depositing beads on each side of the stem plate.
Cruciform	1	B	B	E12015	70	125	Fillet	See Figure 7.

* See Table I for identity of materials A, B and C.

** All electrodes immediately upon removal from hermetically sealed containers were stored in a drying oven at 225 F. The electrodes were used within 30 minutes after removal from the oven. The first pass in each fillet was made with 5/32-inch-diameter electrodes employing 23 volts, 160 amperes, and a travel speed of approximately 5.5 inches per minute (energy input about 40,000 joules per inch). Subsequent passes were deposited with 3/16-inch-diameter electrodes using 22 volts, 200 amperes, and a travel speed of approximately 6 inches per minute (energy input about 42,500 joules per inch).

TABLE III

Chemical Composition of 1/2-Inch-Thick Steel Plates Used for Single-Pass-Welded Cruciform-Shaped Specimens

Item	Steel*	Heat No.	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	B	Ti	Al (Sol)	N
			Chemical Composition (Check Analysis), per cent													
D	HY-80 (Heavy-gage composition)	72P305**	0.18	0.30	0.018	0.013	0.20	0.05	2.99	1.68	0.41	--	--	--	0.022	0.007
E	HY-80 (Heavy-gage composition)	68U695	0.15	0.26	0.011	0.021	0.25	--	2.95	1.83	0.48	--	--	--	0.040	0.010
F	HY-80 (Light-gage composition)	69L090	0.12	0.22	0.009	0.016	0.18	--	2.24	1.16	0.20	--	--	--	0.038	0.007
G	USS "T-1"	74L236	0.14	0.94	0.013	0.018	0.25	0.30	0.89	0.49	0.47	0.03	0.0039	<0.001	0.049	0.006
H	USS "T-1"	65M100	0.14	0.77	0.016	0.028	0.17	0.32	0.91	0.50	0.40	0.06	0.003	0.018	0.048	0.006
J	USS "T-1"	65M074**	0.15	0.85	0.017	0.014	0.21	0.29	0.75	0.60	0.45	0.045	0.003	0.008	0.025	0.005

* HY-80 steel water-quenched from 1650 F and tempered at 1200 F
"T-1" steel water-quenched from 1650/1750 F and tempered at 1150/1275 F.

** The indicated materials were also used for the preparation of bead-welded specimens for metallographic studies.

TABLE IV

Summary of Welding Conditions and Stress-Relief Treatment Used in Preparation of Single-Pass-Welded Cruciform-Shaped Specimens

Welding Process:	Manual Shielded-Metal-Arc Welding
Initial Plate Temperature:	70 F
Interpass Temperature:	70 F
Electrode*:	AWS Class E11018, 5/32-inch diameter
Arc Voltage, volts	23
Current, amperes:	180
Travel Speed, ipm:	6
Energy Input, joules per inch:	69,000
Fillet Size, inch:	1/4
Stress-Relief Treatment**:	The specimens were charged into a furnace heated to 400 F maximum, heated to 1100 F at a rate of 400 to 500 F per hour, held at 1100 F for one hour, cooled to 400 F at a rate of 50 F per hour followed by air-cooling.

* All electrodes immediately upon removal from hermetically sealed containers were stored in a drying oven at 225 F. The electrodes were used within 30 minutes after removal from the oven.

** As-welded specimens were prepared from one heavy-gage-composition HY-80 steel plate (Item D, Table III) whereas stress-relieved specimens were prepared from all the plate materials described in Table III

TABLE V

Summary of Welding Conditions Used in Preparation of Bead-Welded Specimens

Welding Process:	Automatic Shielded Metal-Arc Welding
Initial Plate Temperatures:	70, 300, and 500 F
Electrode*:	AWS Class E11018, 3/16-inch diameter
Arc Voltage, volts:	22
Current, amperes:	260
Travel Speed, ipm:	7.3
Energy Input, joules per inch:	47,000

*All electrodes immediately upon removal from hermetically sealed containers were stored in a drying oven at 225 F. The electrodes were used within 30 minutes after removal from the oven.

TABLE VI

Chemical Composition of the HY-80 Steel Plates and the Weld Metals for Two Welded Samples From a Submarine

Type of Sample	Location in Sample	Plate Thickness, in.	Chemical Composition, per cent									
			C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V
Frame-to-hull tee joint	Frame	1-3/8	0.15	0.20	0.007	0.018	0.21	0.13	2.33	1.01	0.29	0.005
	Hull	2-1/4	0.17	0.36	0.015	0.024	0.23	0.15	2.85	1.60	0.45	0.005
	Weld Metal (cracked fillet)	-	0.055	1.90	0.014	0.020	0.60	0.05	1.60	0.22	0.46	0.01
Auxiliary-ballast-tank tee joint	Stem	1-1/2	0.17	0.35	0.011	0.021	0.16	0.02	2.94	1.54	0.42	0.003
	Base	1-3/8	0.16	0.20	0.007	0.019	0.18	0.11	2.23	1.24	0.32	0.005
	Weld Metal (cracked fillet)	-	0.07	0.81	0.014	0.021	0.37	0.17	1.68	0.11	0.32	0.13

TABLE VII

Tensile Properties* of Plate Steels in Frame-to-Hull Tee-Joint Sample

Location in Sample	Plate Thickness, in.	Steel	Yield Strength (0.2% Offset), psi	Tensile Strength, psi	Elongation in 1 Inch, %	Reduction of Area, %
Frame	1-3/8	HY-80 (Light-gage)	81,400	98,900	26	76
Hull	2-1/4	HY-80 (Heavy-gage)	89,400	106,600	26	72

* The tension-test values are the average of three tests using 0.252-inch-diameter specimens oriented parallel to the joint.

TABLE VIII

Results of Tests of Multiple-Pass-Welded Tee-Shaped Specimens

Specimen Number	Stem Material*	Base Material*	Welding Conditions: Initial Plate Temperature, F	Welding Conditions: Maximum Interpass Temperature, F	Welding Procedure	Magnetic-Particle Inspection of Weld Surfaces: Toe Cracks	Magnetic-Particle Inspection of Weld Surfaces: Weld-Metal Cracks	"Underbead" Cracking, per cent of weld length: Toe Cracks	"Underbead" Cracking, per cent of weld length: Root Cracks
1	C	A	70	125	The first fillet weld was completed before the opposite fillet was made.	None	None	0	43**
2	C	A	200	250	The first fillet weld was completed before the opposite fillet was made.	None.	None	0	16**
3	C	B	70	125	Fillet welds were made by alternately depositing beads on each side of the stem plate.	None	None	0	0

* See Table I for identity of materials A, B and C.

** Cracks were found only at the root of the first fillet weld.

TABLE IX

Results of Tests of Single-Pass-Welded Cruciform-Shaped Specimens of 1, 2-Inch-Thick HY-80 Steel

Steel*			"Underbead" Cracking, per cent of weld length**									
			As-Welded Condition					Stress-Relieved Condition				
Item	Type	Specimen No	Fillet A	Fillet B	Fillet C	Fillet D	Specimen Average	Fillet A	Fillet B	Fillet C	Fillet D	Specimen Average
D	HY-80 (Heavy-gage composition)	1	40	0	45	20	26	37	0	50	23	28
		2	39	0	83	0	31	50	10	40	0	25
		3	35	0	83	0	30	0	0	27	0	7
		4	40	0	100	0	35	0	0	55	0	14
		5	0	0	47	0	12	0	0	25	0	6
		6	27	0	70	0	24	60	0	83	0	36
		7	0	0	80	0	20	61	0	87	0	37
		8	50	0	78	0	32	0	0	70	0	18
		9	-	-	-	-	-	15	0	35	0	13
		10	-	-	-	-	-	25	0	30	0	14
E	HY-80 (Heavy-gage composition)	1	-	-	-	-	-	10	49	80	0	35
		2	-	-	-	-	-	0	10	45	25	20
		3	-	-	-	-	-	10	0	100	0	28
		4	-	-	-	-	-	5	25	95	0	31
		5	-	-	-	-	-	95	75	100	15	71
		6	-	-	-	-	-	50	0	100	0	39
		7	-	-	-	-	-	0	0	95	0	24
		8	-	-	-	-	-	60	80	100	27	66
F	HY-80 (Light-gage composition)	1	(Previous experience with a different type of fillet-welded specimen of light-gage-composition HY-80 steel welded with dry low-hydrogen electrodes indicated no susceptibility to heat-affected-zone cracking.)					0	0	0	0	0
		2						0	0	0	0	0
		3						0	0	0	0	0
		4						0	0	0	0	0
		5						0	0	0	0	0
		6						0	0	0	0	0
		7						0	0	0	0	0
		8						0	0	0	0	0

* See Table III for complete identity of material.

** Values shown indicate extent of root cracking. No toe cracks were observed.

TABLE X

Results of Tests of Single-Pass-Welded Cruciform-Shaped Specimens of 1, 2-Inch-Thick "T-1" Steel

Steel*		"Underbead" Cracking, per cent of weld length**					
		Stress-Relieved Condition***					
Item	Type	Specimen No.	Fillet A	Fillet B	Fillet C	Fillet D	Specimen Average
G	USS "T-1"	1	0	0	25	0	6
		2	0	0	0	0	0
		3	0	0	0	0	0
		4	0	3	0	0	1
		5	0	0	0	0	0
		6	0	0	1	0	0
		7	0	0	10	0	3
		8	0	0	0	0	0
H	USS "T-1"	1	0	0	45	0	11
		2	0+	0	0	0	0
		3	25	0	0	0	6
		4	0	15	15	0	8
		5	0	0	2	0	1
		6	0	0	23	0	6
		7	0	0	27	0	9
		8	0	0	43	0	11
J	USS "T-1"	1	0	0	15	0	4
		2	0	0	0	0	0
		3	0	0	15	0	4
		4	0	0	90	0	23
		5	0	0	60	0	15
		6	0	0	0	0	0
		7	0	0	20	0	5
		8	0	0	45	0	11

* See Table III for complete identity of material.

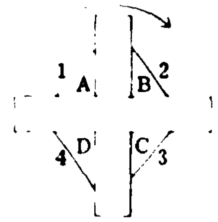
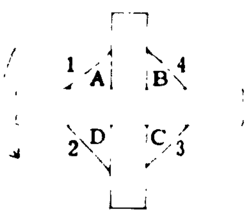
** Values shown indicate extent of root cracking. No toe cracks were observed unless otherwise indicated by note.

*** Previous experience with as-welded specimens (different type of fillet-welded specimen of "T-1" steel welded with dry low-hydrogen electrodes) indicated no susceptibility to heat-affected-zone cracking.

\+ A 0.10-inch-long toe crack was detected.

TABLE XI

Effect of Welding Sequence on the Distribution of Underbead Cracks in Single-Pass-Welded Cruciform-Shaped Specimens

Welding Sequence for Fillet Welds	Specimen No.	"Underbead" Cracking, per cent of weld length* Fillet A	Fillet B	Fillet C	Fillet D	Specimen Average
Clockwise Sequence (As Shown in Fig. 9)	1	37	0	50	23	28
	2	50	10	40	0	25
	3	0	0	27	0	7
	4	0	0	55	0	14
	5	0	0	25	0	6
	6	60	0	83	0	36
	7	61	0	87	0	37
	8	0	0	79	0	18
	9	15	0	35	0	13
	10	25	0	30	0	14
Counter clockwise Sequence	1	100	0	0	50	38
	2	100	0	0	87	47
	3	90	0	0	50	35
	4	90	0	0	30	30
	5	85	0	0	0	21
	6	100	0	0	45	36

* Stress-relieved specimens of 1, 2-inch-thick HY-80 steel (heavy-gage-composition Steel D in Table III). Values shown indicate extent of root cracking. No toe cracks were observed.

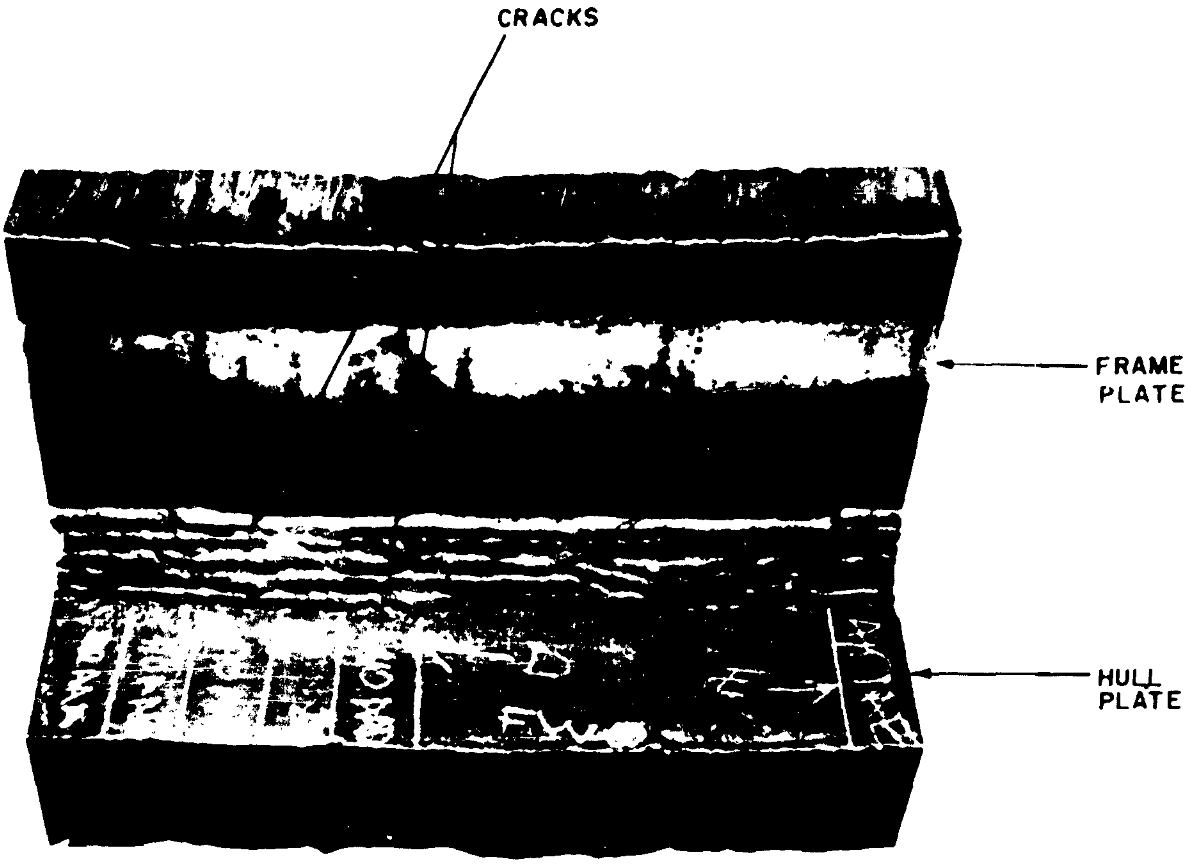


Figure 1. Sample of frame-to-hull tee-joint removed from the pressure hull of a submarine. View shows side of joint where cracks were observed.

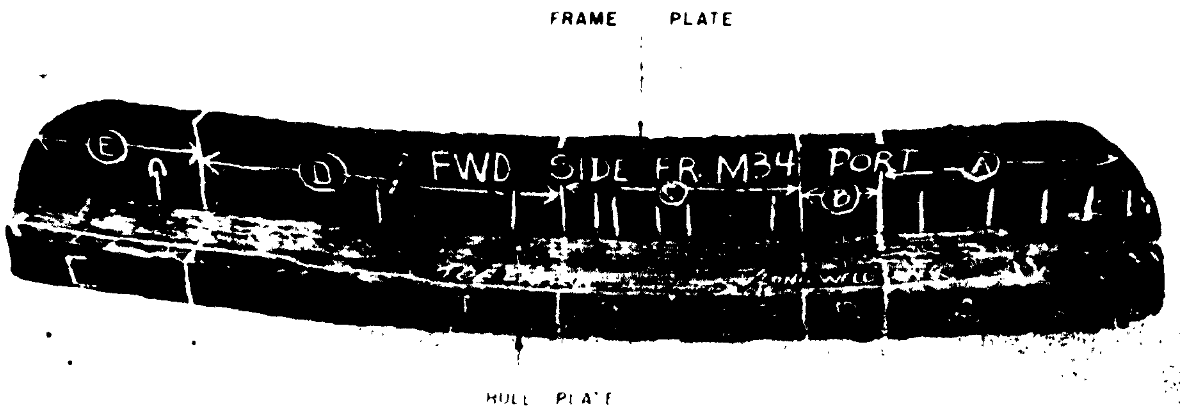


Figure 2. Frame-to-hull tee-joint removed from the pressure hull of a submarine.

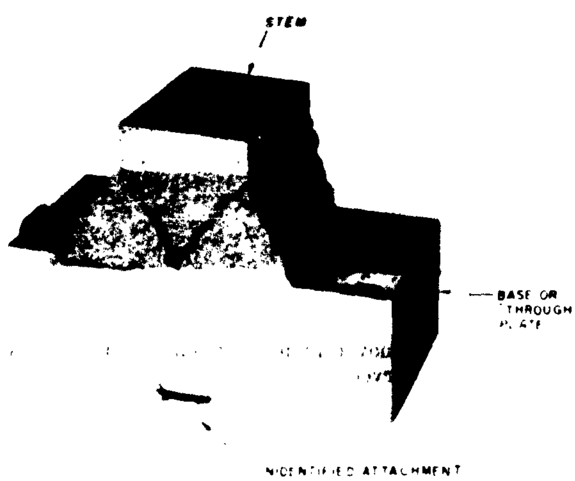
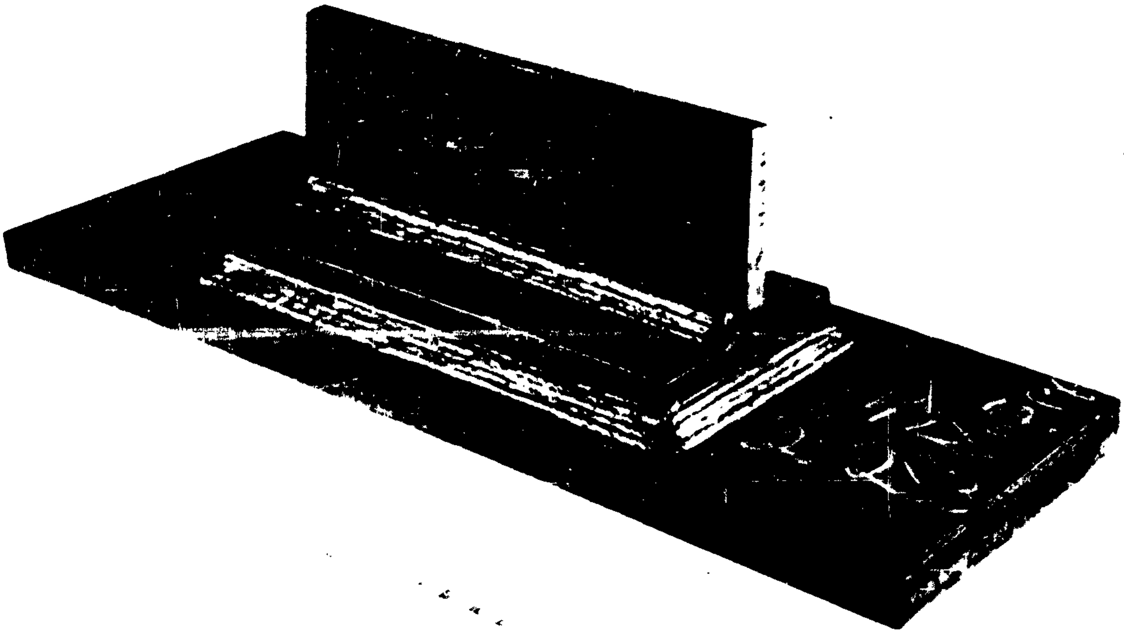
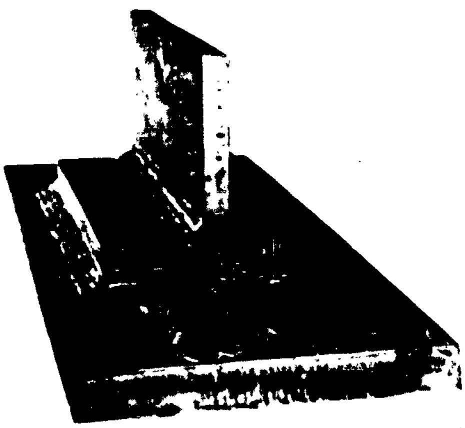


Figure 3. Sample of auxiliary-ballast-tank tee-joint removed from a submarine.



A. Side view



B. End view.

Figure 4. Multiple-pass-welded tee-shaped specimen.

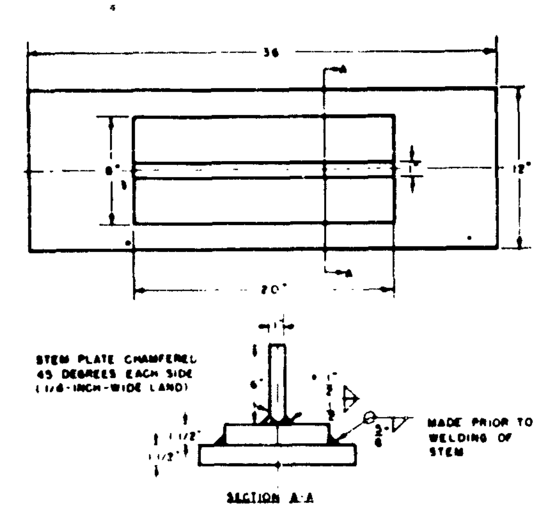


Figure 5. Details of Preparation of Multiple-Pass-Welded Tee-Shaped Specimen

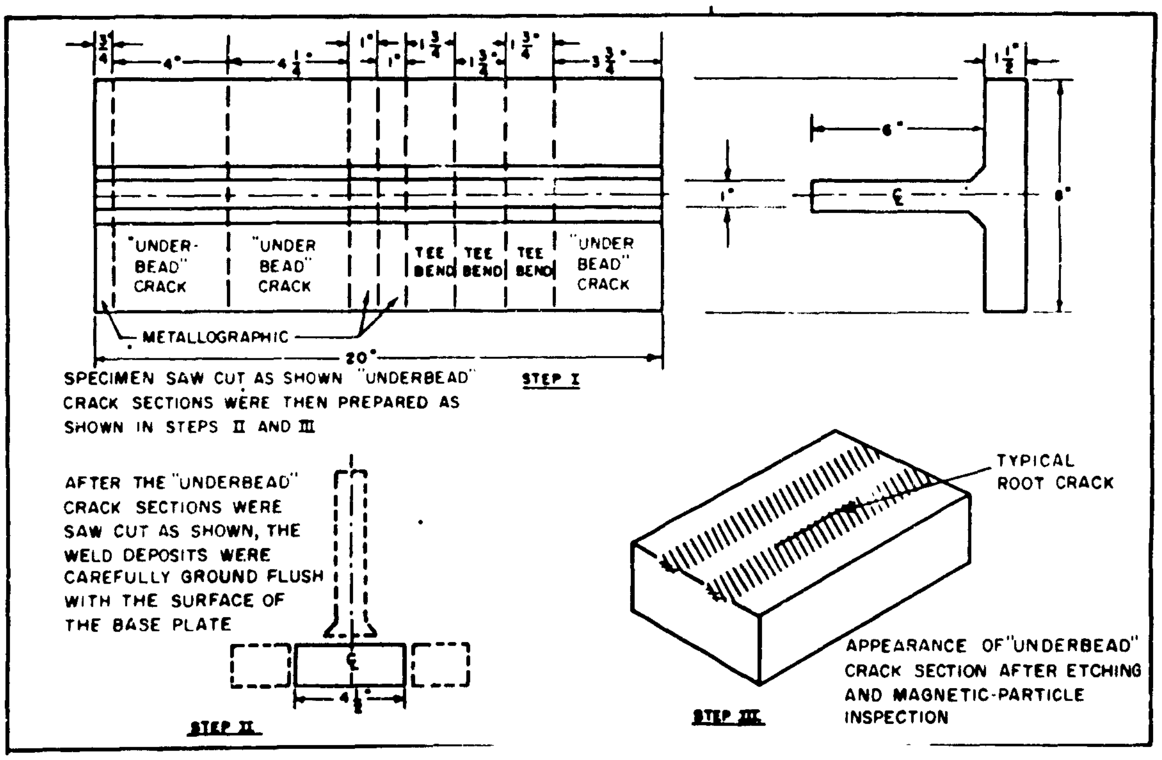


Figure 6. Details of Sectioning and Inspection Procedure for Multiple-Pass-Welded Tee-Shaped Specimens

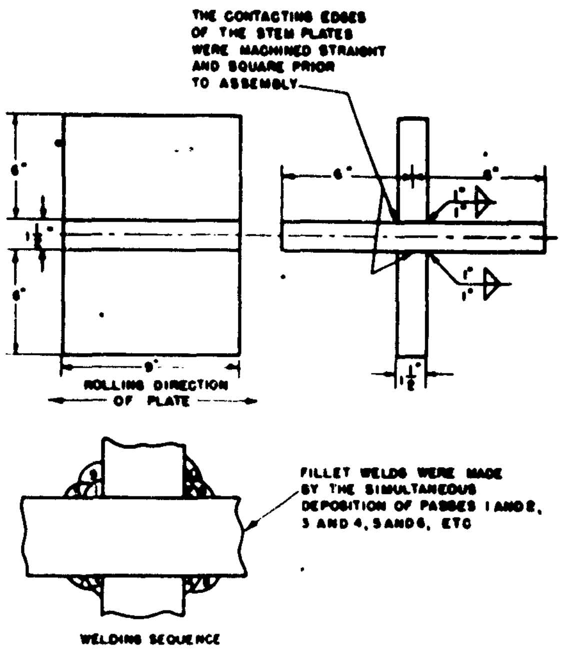


Figure 7. Details of Preparation of Multiple-Pass-Welded Cruciform-Shaped Specimen

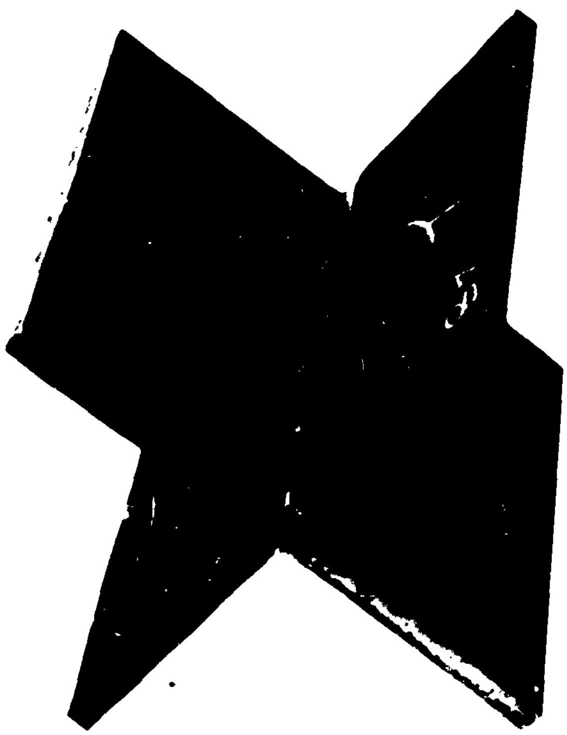


Figure 8. Single-pass-welded cruciform-shaped specimen.

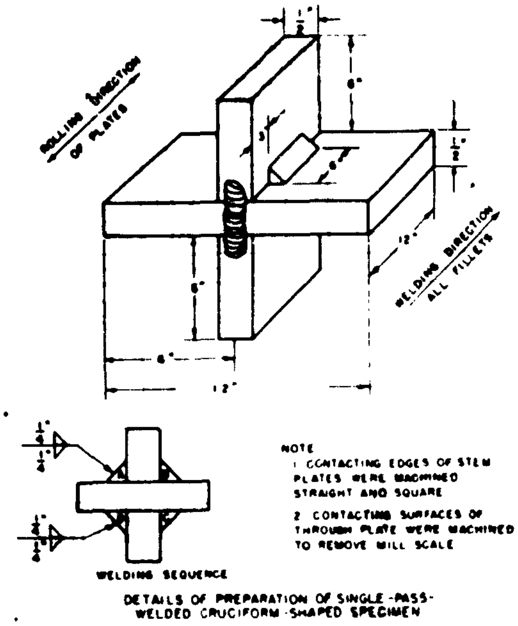


Figure 9. Details of Preparation of Single-Pass Welded Cruciform-Shaped Specimen

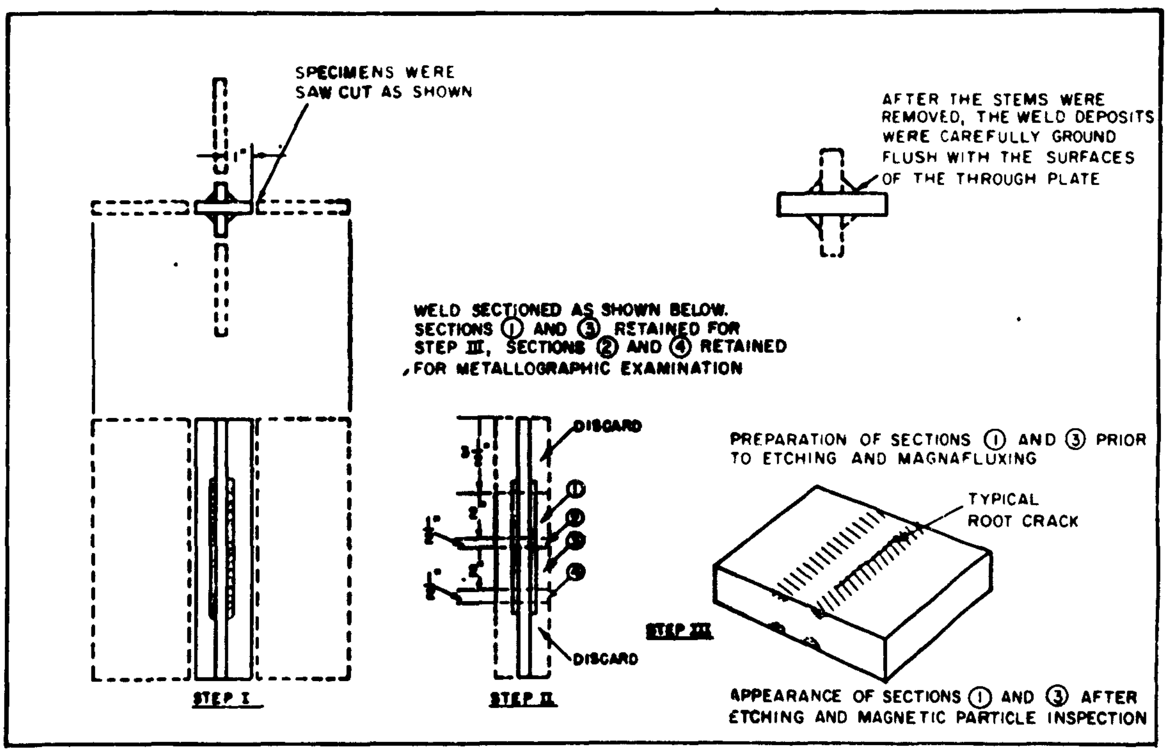


Figure 10. Details of the Sectioning and Inspection Procedure for Single-Pass-Welded Cruciform-Shaped Specimens

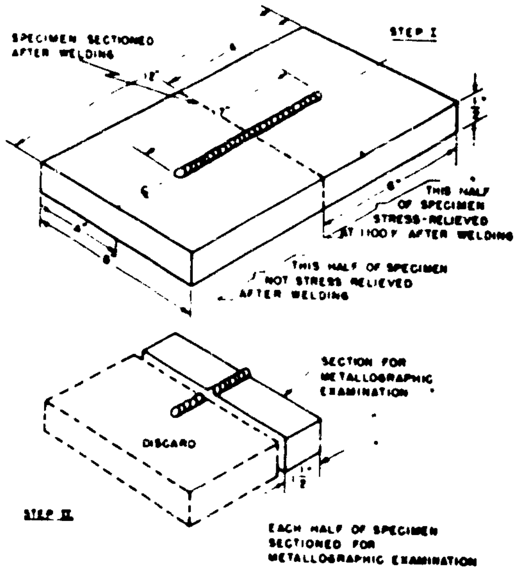


Figure 11. Details of Preparation Bead-Welded Specimen

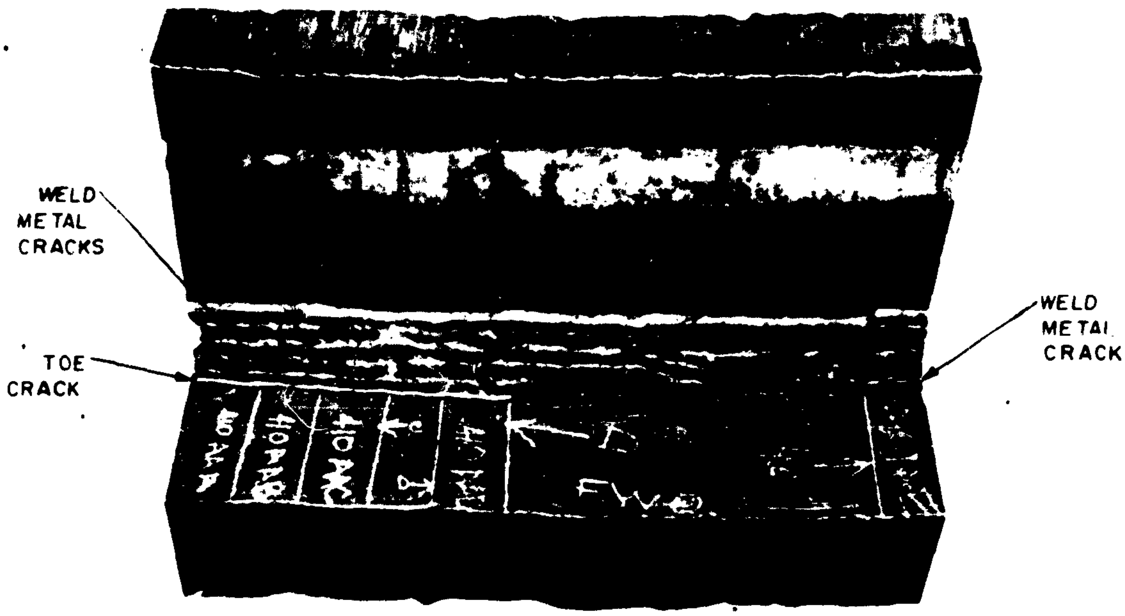
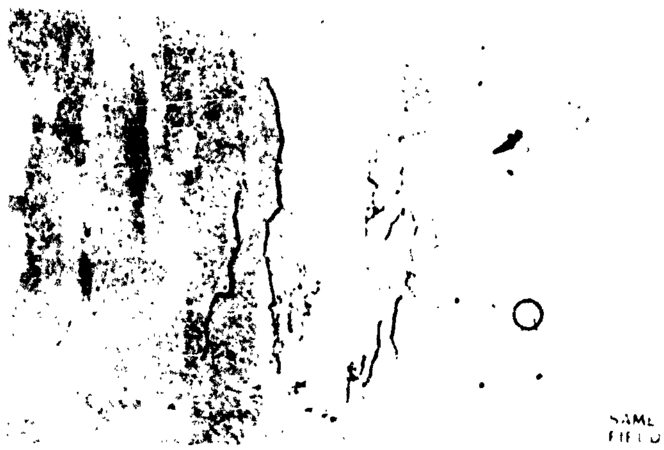
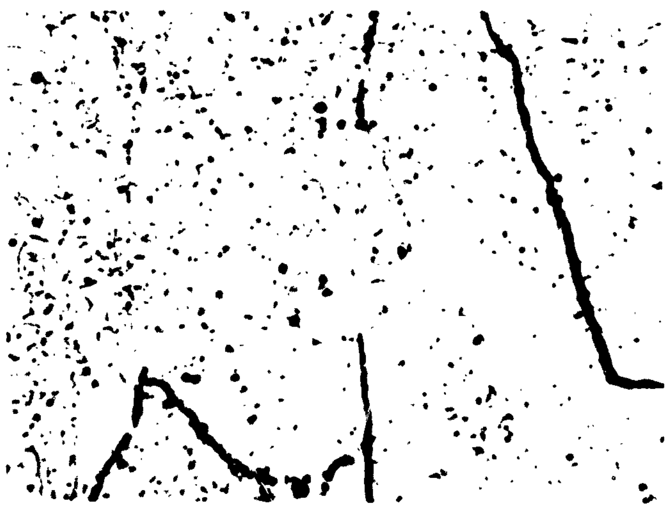


Figure 12. Locations of weld-metal cracks and a toe crack found by magnetic-particle inspection of the frame-to-hull tee-joint sample.



A. X100.



B. X1500.

Figure 13. Typical intergranular weld-metal cracks observed in the frame-to-hull tee-joint sample. Etched in Super Picral

Figure 14. Photomacrograph showing heat-affected-zone cracks in the heavy-gage-composition HY-80 steel hull plate in the frame-to-hull tee-joint sample. Etched in Ammonium Persulfate. X6.

A. Region where crack propagated through weld metal adjacent to the bond. X500.

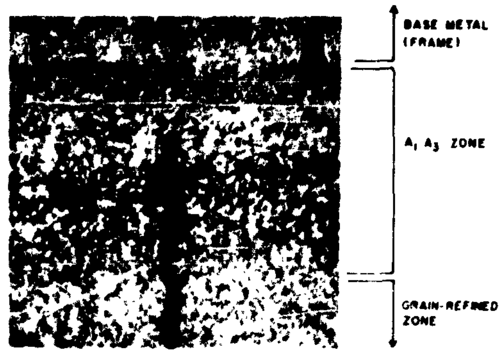


Figure 16. Terminus of a heat-affected-zone crack in the light-gage-composition HY-80 steel frame plate of the frame-to-hull tee-joint sample. Etched in Super Picral. X250.

B. Intergranular crack in the grain-coarsened heat-affected-zone. X1000.

Figure 15. Photomicrographs of a toe crack in heavy-gage-composition HY-80 steel hull plate of frame-to-hull tee-joint sample. Etched in Super Picral.

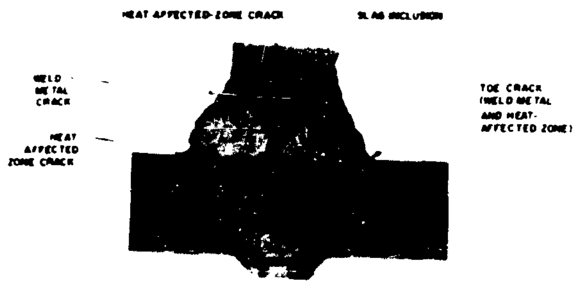


Figure 17. Photomacrograph of the auxiliary-ballast-tank tee-joint sample showing a slag inclusion, a weld-metal crack and several heat-affected zone cracks. Etched in Ammonium Persulfate. XI.

A. Heavy-gage-composition HY-80 steel stem plate. X250.

B. Light-gage-composition HY-80 steel base plate. X500.

Figure 18. Intergranular cracks in the grain-coarsened heat-affected zones of the auxiliary-ballast-tank tee-joint sample. Etched in Super Picral.

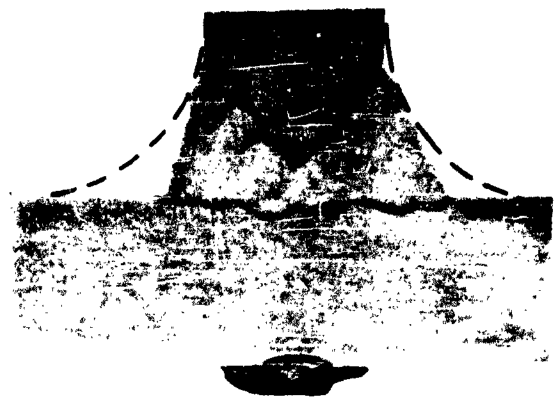


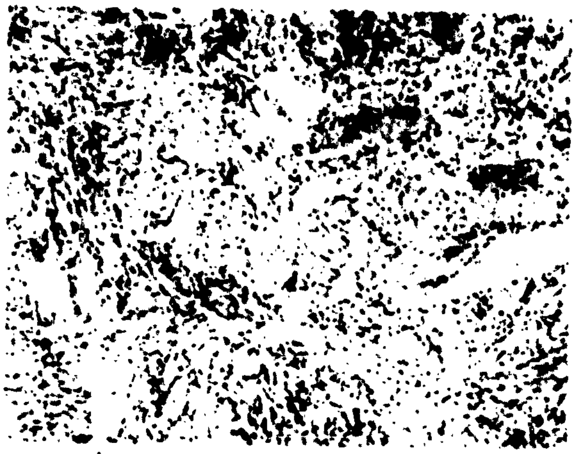
Figure 19. A view of the auxiliary-ballast-tank tee-joint sample showing abrupt change in contour at the toes of the fillet welds and suggested desirable contour. Ammonium Persulfate Etch. X1.

Figure 20. Typical root crack in a multiple-pass-welded tee-shaped specimen. Etched in Ammonium Persulfate. X2.

Figure 21. Typical heat-affected-zone root crack in single-pass-welded cruciform-shaped specimen of heavy-gage-composition HY-80 steel. As-welded condition. Etched in Super Picral. X500.

Figure 22. Photomicrograph of bead weld in USS "T-1" steel plate welded at 70 F. Numbered circles identify the zones described below. Etched in Nital. X7.

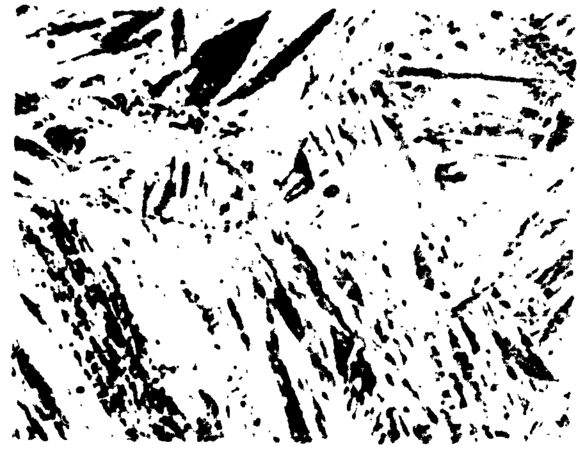
Location	Description
1	Weld Metal
2	Weld Metal and Maximum-Grain-Coarsened Heat-Affected Zone
3	Moderately Grain-Coarsened Heat-Affected Zone
4	Grain-Refined Heat-Affected Zone
5	Grain-Refined Heat-Affected Zone
6	A_1-A_3 Heat-Affected Zone
7	Base Metal



A. Light photomicrograph. X1500.

B. Electron photomicrograph. X10,000.

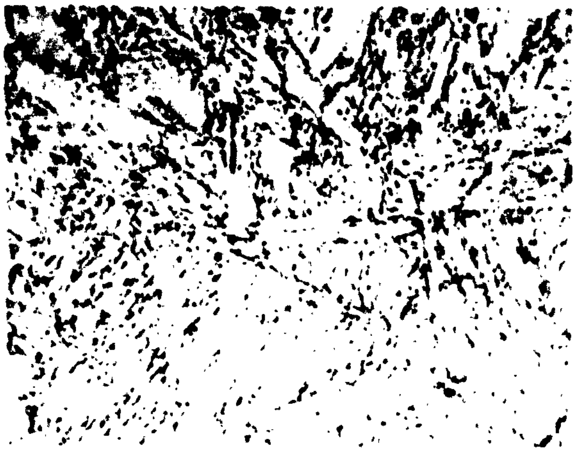
Figure 23. Microstructure of heavy-gage-composition HY-80 steel plate. Unwelded. Etched in Super Picral.



A. Light photomicrograph. X1500.

B. Electron photomicrograph. X10,000.

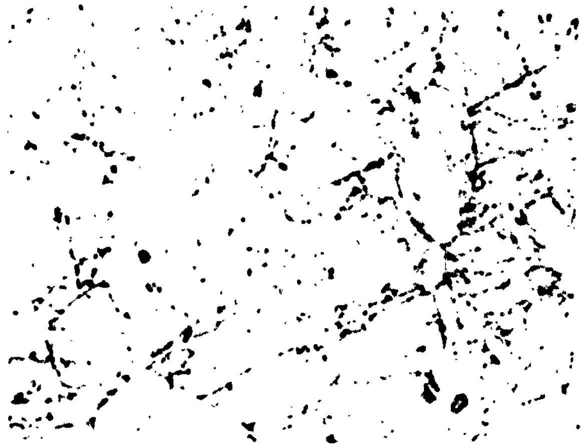
Figure 24. Microstructure of maximum-grain-coarsened heat-affected-zone in heavy-gage-composition HY-80 steel plate welded at 70 F. As-welded condition. Etched in Super Picral.



A. Light photomicrograph. X1500.

B. Electron photomicrograph. X10,000.

Figure 25. Microstructure of maximum-grain-coarsened heat-affected-zone in heavy-gage-composition HY-80 steel plate welded at 70 F. Stress-relieved condition. Etched in Super Picral.

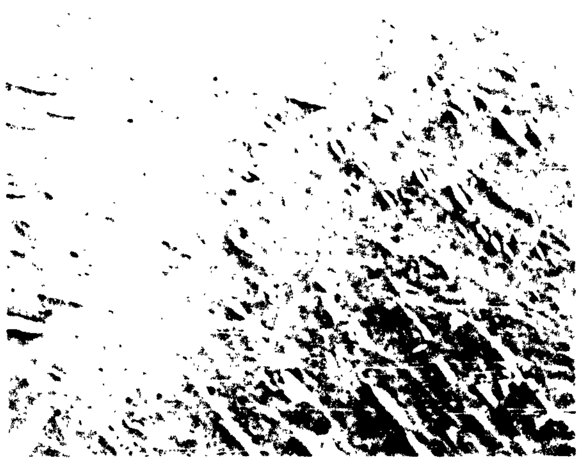


A. Light photomicrograph. X1500.

B. Electron photomicrograph. X10,000.

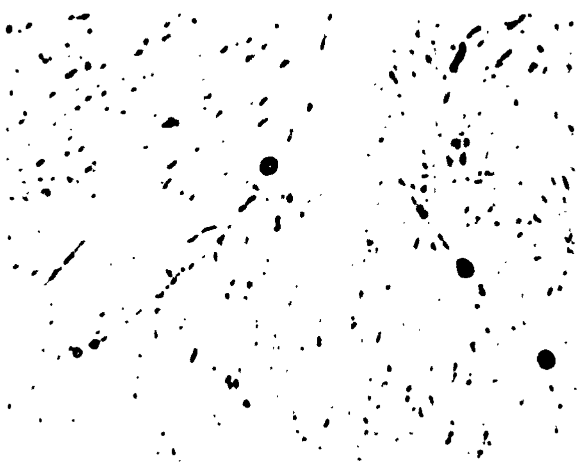
Figure 26. Microstructure of USS "T-1" steel plate. Unwelded. Etched in Super Picral.

A. Light photomicrograph. X1500.



B. Electron photomicrograph. X10,000.

Figure 27. Microstructure of maximum-grain-coarsened heat-affected zone in USS "T-1" steel plate welded at 70 F. As-welded condition. Etched in Super Picral.



A. Light photomicrograph. X1500.

B. Electron photomicrograph. X10,000.

Figure 28. Microstructure of maximum-grain-coarsened heat-affected zone in USS "T-1" steel plate welded at 70 F. Stress-relieved condition. Etched in Super Picral.

FATIGUE PROPERTIES OF WELDS IN HY-80 STEEL

by

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INTRODUCTION

Background

In view of the fact that HY-80 alloy steel is used extensively in the Naval service, information is required for its application as a structural material. One of the more important considerations is the effects of welding on the HY-80 base metal structure and properties. While a background of information has been accumulated for static properties of welds in HY-80 steel, there have been little data available relative to fatigue properties.

In January 1959, the Bureau of Ships authorized the Material Laboratory to obtain data relative to the fatigue properties of welds in rich chemistry HY-80 steel. The immediate need was for information relative to the fatigue lives of fillet assemblies; however, it was indicated that similar data for butt welds would also be required. It was also known that the long range requirements of the program, which could involve other joints and materials would require apparatus which could operate near the yield strength of HY-80 material (approximately 80,000 psi).

The related field problems which had required the development of fatigue data involved complex weldments in comparatively heavy thicknesses. Consequently, small scale tests were not considered suitable because they would not take into account such factors as residual stress, mass effects or variations in contour and quality normally encountered in a weldment. On the other hand, it was realized that an excessively large specimen was objectionable for the following reasons:

a. Fewer specimens would be obtained for a given effort and amount of material. In view of the normal variations encountered in fatigue testing, conclusions based on an insufficient number of samples could be misleading.

b. In very large scale specimens consistency and reproducibility become more difficult to obtain. In some cases failure may be induced by a random flaw in base or weld metal.

In view of the above, it was decided to develop a suitable specimen for the available Material Laboratory beam fatigue testing machine and, in addition to develop a new fatigue machine to apply repeated uniform loading to plate type specimens.

Large Scale Beam Type Fatigue Tests

A sketch of the large scale beam type fatigue specimen developed for this investigation is given in Figure 1. The upper portion of the specimen is made from HY-80 steel and is 5 inches wide by 1 inch thick at the critical section. The specimen is proportioned so as to permit developing the desired high stresses at the weld in the largest welded joint practicable within the capacity of the machine. The lower portion was grade HT plate.

The machine used for dynamically loading the beam type specimens has been described in detail in another paper.* The machine is of the vibratory type and may be classified as a constant-load repeated-bending machine. The repeated bending moment which is generated by rotating eccentric discs is impressed on the specimen in such a manner as to be uniform along the span. The cross section of the specimen is so designed that the maximum stress occurs in the outer fibers at the weld. The machine applies completely reversed stresses to the specimen at a frequency depending on the stiffness of the assembly. This frequency which is approximately 430 cycles per minute is maintained constant by the machine until failure occurs, at which time the safety cut-off switch is automatically actuated. The impressed repeated bending moment is readily calculated from the weight, eccentricity, speed of rotation and shaft spacing of the eccentric discs, thereby permitting a simple calculation of stress at the critical section of the specimen. Figure 2 shows a specimen set up in the machine for test.

Large Scale Plate Type Fatigue Tests

A sketch of the large scale plate type fatigue specimen developed for uniform loading under pneumatic pressure is given in Figure 3. This plate type specimen, which was used in most plate tests

*A Unique Machine for Large Scale Fatigue Testing, ASTM STP 216, 1957 conducted to date, was designed to have a thickness of one inch, so that tests could be conducted with the available building compressed air supply of 100 psi. However, compressed air at higher pressures has since become available in sufficient quantity, and current tests are being conducted on full thickness (1-1/2") assemblies.

The apparatus for applying repeated uniform loading to these plate type specimens was specifically designed and constructed for this work. A photograph of the complete assembly is given in Figure 4. The apparatus consists of an air supply, a reservoir to minimize pressure drop in the supply line, a loading frame, a system of solenoid valves and pressure switches, a deflection recorder, a pressure recorder, and other incidental pieces of equipment. The strain gage indicator and recorder employed for stress measurement are not shown in the photo. The plate type specimen is simply supported at the two edges parallel to the weld at a span of 28 inches, nominal, and is free at the other two edges. A sheet of neoprene gasket material is cemented to the top edge-surfaces of the lower frame to seal the loading chamber. The system was originally designed for operation with water but more rapid cyclical loading, approximately 20 cycles per minute, was obtained by operating with compressed air. The cyclical stresses obtained are not reversed but range from zero to a maximum. Since two edges of the plate are free, stresses may be calculated by means of the simple beam formula. A pressure recorder and deflection recorder are connected to the test equipment in order to provide continuous records of pressure and deflection throughout the test. In addition, two dial indicators are fixed to the stationary frame so as to indicate deflections of the plate at two points along the web symmetrically located with respect to the center. An electrical cycle counter is also included in the solenoid valve control circuit to indicate the total number of loading cycles at any time.

Observations made during the course of the tests reveal that failure of the plate type specimens starts long before ultimate failure occurs. This failure parallels the increase in deflection recorded during the test. In the case of tests of welds from 0 to maximum tension, the increase in deflection starts before the first indication of a crack has been observed. It appears therefore that in these cases, the increase in deflection may be taken as a measure of the overall structural damage of the plate. In order to arrive at some rational basis for determining the fatigue life of the plate type specimen, an increase in deflection of 10 percent over the initial deflection has been tentatively chosen as the criterion of fatigue failure. This value has been chosen because it has represented substantial failure of the specimen and the start of rapid increase in deflection accompanying the increase in crack propagation near ultimate failure.

PROCEDURE

All HY-80 material used ranged from 1-7/16" to 1-3/4" in thickness and was in conformity with the requirements of specification MIL-S-16216D whose chemical and mechanical requirements are shown in Table 1. Details of typical welding procedures, joint designs and pass sequences used are shown in figures 5 through 8 and table 2. In the case of fillet assemblies, web and flange were of equal thickness. While it was realized that in actual application the web member is usually thinner than the flange, the relatively heavier web thickness was used to emphasize the effects of the weldability factor.

For the dynamically loaded beam tests, a 24" x 8" (Min.) web was welded to a 66" x 24" flange (See Figure 9). As indicated therein, the welds were made parallel to the final direction of rolling of the flange and opposite in direction to each other. The welded assembly was machined into 4 specimens as shown. The start of weld and the finishing weld crater were not included in the fatigue specimens. Each machined specimen was then welded to the high tensile (Grade HT, MIL-S-16113B) bottom plate.

For the plate fatigue fillet specimens, a 35" x 8" (Min.) web was welded to a 35" x 30" flange, and then machined as was shown in Figure 3. A procedure was developed to minimize the distortion resulting from the extensive welding and machining involved. In this test, the stress imposed at a given pressure varies with the thickness of the plate. A uniform thickness adjacent to the length of the weld is required in order to yield a uniform stress distribution in the heat affected zone. Maximum thickness at the edges would tend to produce initial failure where edge effects are present, thereby complicating the interpretation of results. Since a plate of absolute uniformity is not possible, it was decided to utilize an assembly wherein the maximum thickness was at the center and the thickness variation in the weld area did not exceed 0.032". The method described in Figure 6 resulted in a surface with a longitudinal convexity approximating 1/32". This degree of flatness was maintained throughout the subsequent machining operations.

The increased plate thickness at the center, which represents an area of slightly greater stress under the conditions of test, is not considered objectionable and may even be considered desirable for the following reasons:

a. The effect of thickness variation of this magnitude is small compared to variations due to other effects introduced in the course of fabrication of the assembly.

b. The fracture tends to be initiated away from the edges, thereby minimizing any complications which might be introduced due to edge effects.

c. Since the approximate zone of fracture can be localized, this area can be explored fully in the course of test.

The welding procedure for plate fatigue butt samples is shown in Figure 8. As indicated therein, all assemblies were restrained by welding two 30" x 6" x 1" bars to the assembly. In addition, all layers prior to the last two on each side were welded in the horizontal position (plate vertical). This procedure provided the following advantages:

a. The moderate degree of restraint employed more closely approximated field conditions than unrestrained assemblies.

b. Welding in the horizontal position (plate vertical) enabled two operators to work simultaneously. This shortened the time of fabrication and equalized heat input and thermal stresses imposed.

c. The restraining bars maintained flatness throughout the welding operation.

d. The equalization of heat input in turn resulted in specimens which were essentially flat (within 1/16") after the restraining side bars had been removed.

The distortion encountered (approximately 3/8") in the course of machining the butt assemblies from 1-11/16" to the desired 1" thickness was appreciably greater than that observed with the fillet assemblies. This was due to the fact that, in the case of the fillet assemblies, the 2" web section stiffened the assembly and minimized movement longitudinal to the weld during machining. The last three of the eight butt welded specimens did not require reduction to a 1" thickness, since the available air supply and apparatus were able to accommodate specimens of full plate thickness.

Beam fatigue and plate fatigue specimens were then subjected to fatigue loading in their respective types of testing machines.

After test, each assembly was examined by magnetic particle inspection to determine the extent and location of the fatigue cracks produced. A hardness survey was made on representative assemblies. Several specimens which had been tested were fractured to study the fracture pattern. Representative sections of welds were examined metallographically at 100X magnification.

Using the techniques and tests described above, the following information relative to fatigue loading in HY-80 weldments was developed:

Assembly	Type Test	Stress	Objective
Fillet	Beam	Alternating	S-N Curve
Fillet	Plate	0 to tension	S-N Curve
Fillet	Beam	Alternating	Investigation effects of grinding and shot peening
Butt	Beam	Alternating	Comparison Butt vs. Fillet assemblies; ultimately to develop S-N curve
Butt	Plate	0 to tension	S-N curve
Fillet	Plate	0 to compression	S-N curve (currently underway)
	Beam	0 to compression	S-N curve (currently underway)

In addition a total of eight beam type specimens of fillet welds (Mil-8016 weld deposits) in HTS base metal were tested at 32,000 and 37,000 psi to compare the properties of fillet welds in HTS and HY-80.

Fillet Welds - Beam Type Specimens - Alternating Stress

Eight beam type specimens (PB series) were subjected to cyclical stress on the dynamic vibratory machine. Stress levels required to give a life in the range of 10,000 to 100,000 cycles were estimated for the first few specimens and these results used as a guide to select stresses for the remaining specimens so as to provide S-N data over the desired range of lives. The preliminary results obtained in the above manner were used as a guide in selecting the desired stresses for the conduct of fatigue tests on the major series of specimens (LB series).

Fillet Welds - Plate Type Specimens - 0 to maximum tension

Prior to testing, six SR-4 type strain gages were applied to each specimen in order to measure strains in the base plate at the toe of the fillet weld on each side of the web. Three gages were cemented on each side, one at the center and one near each edge of the base plate. The first step in the testing of each plate was to obtain static load (uniform pressure) versus deflection and static load versus strain data for equal increments of load from zero to the maximum to be applied during the cyclical loading. The plate was then subjected to cyclical loading until ultimate failure occurred. Continuous records of cyclical pressure and cyclical deflection were obtained for the entire test of each plate. During the course of the test, minimum and maximum dial indicator readings were recorded at intervals of approximately

500 loading cycles. In addition, observations were made to determine the approximate number of loading cycles at which a crack started and progressed to various lengths throughout the test.

Fillet Welds - Comparison of the Effects of Grinding and Shot Peening - Beam Type Specimens

All weld assemblies for these tests were derived from a single 1.427" thick plate in accordance with Figure 10. Shot peening was done under contract in accordance with laboratory specifications. The apparatus employed is shown diagrammatically in Figure 11 along with details of the peening procedure. A macro representing adjacent section was shot peened simultaneously with each specimen. The peened surface and macrosection are shown in Figure 12. Intensity of shot peening was verified by using an individual Almen strip for each specimen and by inspecting each peened surface at 10X magnification. The method of measurement of intensity of shot peening by means of Almen strips is shown in Figure 13. In brief, the principle involved is that shot peening depresses the metal on the surface, and in the case of the Almen strip, results in an elongated surface. This in turn produces the curvature shown, the curvature being proportional to the amount of cold work or intensity of shot peening. An example of the extent to which shot peening deforms the surface of metal is shown in Figure 14. Examples of shot peened surfaces, viewed at 10X magnification, are shown in Figure 15. Figures 16 through 18, which show sections at 250X, indicate the extent of cold work induced. As indicated therein, the observable deformed metal appears to be less than .008" deep. Shot peening was accomplished on each specimen as a final operation prior to testing.

Grinding operations were conducted with an AR 6020, 600 taper cup wheel on a full 24 inch width of assembly prior to sectioning. This eliminated end effects. Photographs of welds in the "as ground", and ground and shot peened conditions, are shown in Figures 19 and 20. As indicated therein, the desired contour is readily obtainable. While initial undercutting of the flange was encountered, this difficulty was overcome by intentionally clogging the lower face of the wheel by running it over an asphalt tile. (See Figure 21.)

All assemblies were tested in the beam type machine in the manner previously described.

Butt Welds - Beam Type Specimens

Butt weld assemblies were sectioned and tested in a manner similar to the fillet welds described above. In the course of reducing the area under test to the required 1" thickness, it was found that some distortion was encountered as a result of welding. However, machining the convex side of the assembly to reduce the thickness from 1-1/2" to 1" resulted in a specimen with a straightness deviation of less than 1/16".

Butt Welds - Plate Type Specimens

As was indicated above, the first five specimens were tested with thickness reduced from 1-11/16" to 1". With the subsequent availability of sufficient high pressure compressed-air, it was possible to test the last three specimens in full plate thickness.

Fillet Welds - Compression - Plate Type Specimens

Plate type specimens are being tested in a manner similar to that previously described for the plate type 0 to maximum tension tests, except the pressure is imposed on the welded side of the assembly. Full plate thickness (1-1/2") specimens are being used. Since the weld is inside the pressurized chamber, it is not possible to observe the formation of cracks. Therefore, it became necessary to develop a system of inspection from the unwelded side for detecting cracks at the toe of a fillet. This was accomplished by ultrasonic methods using a shear type crystal on the exposed face, at a distance approximating the plate thickness under test. The application of this technique is shown in Figure 22.

RESULTS

Fillet Welds - Beam Type Tests

Results of fatigue tests of fillet welds on beam type specimens are shown plotted on semi-logarithmic paper in Figure 23. The curve is fitted by eye through the median points, the intermediate point of each set of three, at the six stress levels. The straight line representing the S-N data for a preliminary (PB) series is also shown for comparison.

With due consideration for the scatter of results, the S-N curve for the LB series of beam type specimens, Figure 23, indicates approximate fatigue strengths for various lives as follows:

Fatigue Life, Cycles to Failure	Approximate Fatigue Strength psi
10,000	52,000
100,000	20,000
1,000,000	11,000

The results represent ultimate failure of the specimens, or the point at which the deflection, or amplitude of vibration, increased sufficiently to actuate the cut-off switch. In most cases the crack at the toe of the fillet was found to have progressed across the full 5 inches of width of the specimen but not through the depth. The failures started anywhere along the toe of the fillet weld and did not favor the edges of the specimen or any other location. The beginning of failure was observed to start shortly before ultimate failure occurred. In general, failures occurred on only one side, but in a number of instances a crack had also started on the opposite side.

Typical macrospecimens before and after testing, as well as typical paths of fracture, are indicated in Figures 24 and 25. Photomicrographs of a failed section, and the adjacent section which had not been subjected to fatigue tests are shown in Figures 26 and 27. A hardness survey on typical macrospecimens is shown in Figure 24. It should be noted that the hardness results on the web member were influenced by flame cutting, as well as subsequent welding. Accordingly, these results have not been included in the summary shown below. A summary of the results of Rockwell C hardness tests showed the following:

Weld Metal		Heat Affected Zone (Flange)		Base Metal	
Range	Average	Range	Average	Range	Average
24-34	29	28-41	36	17-21	19

The particular side of the tee weld where failure originated did not appear to be influenced by the variations of range in fillet contour or welder technique associated with fabrication. Each fracture originated at the toe of the weld.

Figure 23 also indicates the results of the comparative tests conducted with HTS assemblies. As indicated therein, at the levels investigated, the results for HY-80 and HTS were similar.

Fillet Welds - Plate Tests - 0-Tension

Figure 28 shows an S-N curve for plate type specimens using the 10 percent increase in deflection criterion of failure. The curve was fitted by the method of least squares. The 95 percent confidence envelope is also shown. On the basis of these results, the fatigue strength of the fillet welds is 60,000 psi for a life of 10,000 cycles. This result should be taken with caution since the life represents almost complete failure of the plate and start of failure actually occurs much earlier. Based on the data therein, the 10,000 and 100,000 cycle lives of these assemblies approximate 60,000 psi and 30,000 psi, respectively.

In general failures started in the heat affected zone away from the edges of the plate. In many cases, cracks opened at more than one location and progressed until they met or reached the edge.

A typical deflection record for a plate subjected to cyclical stress is shown in Figure 29 on a reduced abscissa scale. This curve shows a rapid increase in deflection as ultimate failure is reached. The numbers along the deflection curve indicate the total number of inches of crack on one side of the web corresponding to the indicated deflection.

Measurements of stress by means of SR-4 strain gages reveal that the stress developed is not uniform across the plate near the toe of the weld. The measured stresses are highest near the center of the plate where the thickness is greatest. In addition, the calculated stress appears to be representative of the average of the measured stresses.

The fatigue results for plate type specimens cannot be compared directly with the results shown for beam type specimens for the following reasons:

a. The stress cycle for a plate type specimen is 0 to maximum tension whereas for a beam type specimen it is a completely reversed stress cycle. This condition alone should result in a higher fatigue strength for the plate type specimen.

b. The fatigue cracks in a plate specimen must traverse a larger section and as a result the specimen will probably show a longer life.

c. When failure starts at any point, the stress level in the undamaged portion of the plate is not raised as high on the plate type specimen as on the beam type specimen.

Failure of the plate type specimens start long before ultimate failure occurs. Figure 29, which indicates the total length of crack on one side of the web corresponding to various deflections, shows that the cracks are quite extensive much before ultimate failure occurs. It appears, therefore, that some criterion of fatigue failure for the plate type specimen is required, before a fatigue strength for a given life can be established and before a comparison can be made with the fatigue results on beam type specimens.

The curves of deflection versus number of cycles, similar to Figure 29 provide a means for establishing the fatigue life under a given stress. Each curve rises very slowly at first during initiation and propagation of a crack, then rises more rapidly as the crack becomes more extensive, and finally rises very rapidly as impending ultimate failure is approached. The complete curve to failure represents an increase in deflection of approximately 100 percent over the initial deflection. It may be observed from Figure 29 where the numbers on the curve indicate length of crack, that an increase in deflection of 10 percent corresponds to a length of crack of over 16 inches or 50 percent of the full width of specimen. The increase of deflection, which reflects the depth of crack as well as length, is considered to be a better measure of fatigue failure than size of crack which is not completely visible, especially the depth. Although an increase in deflection of 10 percent appears to be a reasonable basis for discussion of fatigue failure, other criteria based on different degrees of deflection or on length of crack might also be used.

Fillet Welds - Comparison of Effects of Grinding and Shot Peening - Beam Type Specimens

Results of beam tests comparing as welded, ground, shot peened and the combination of ground and shot peened fillet welds are shown in Figure 30. Figures 31 and 32 indicate sample macrosections of the fatigue failures. Since study of most of the failures has not as yet been accomplished, the photographs are being offered for information purposes without comment at this time.

A review of the summary data of Figure 30 in the light of the information contained herein will permit us to draw various conclusions and implications. Considering the lines representing the as welded condition, we see that weld quality is reproducible. This was achieved through close control of the welding operation. In view of the above, it is reasonable to assume that the welds under discussion represent a quality which is better than the average obtained in the field. Any deficiencies, such as undercut, porosity at the fillet toe, overheating of the heat affected zone, etc. which are conditions occasionally encountered in the field, could very likely have produced poorer results.

The improvement as a result of grinding is significant and readily explainable on the basis of the reduction of the acuity of notch effect at the toe of the fillet, with some possible added benefit derived from the removal of weld metal containing locked up stresses. It is reasonable to assume that the benefits are permanent and predictable.

The results of shot peening indicate an improvement over the ground condition. However, in assessing shot peening, the process should be considered in relation to the overall application. Shot peening represents a surface effect of imposed compressive stress. Related work on other steels has shown that upon removal of the surface layer of peened material (such as may occur as a result of corrosion), the beneficiating effects are lost and fatigue properties revert to the original condition. In addition, the effects of shot peening on some of the other properties which formed a basis for selection of HY-80 steel, have not as yet been assessed. The preceding statements are not intended to imply that shot peening should be ruled out as a method of improving the fatigue properties of weldments in HY-80 steel. However, the facts are presented so that consideration of the method should be based on its limitations as well as its apparent advantages.

The combination of grinding and shot peening generally yielded the greatest improvement. In some cases failure occurred away from the weld in the HY-80 steel. Figure 33 illustrates a failure of HY-80 base plate near the area of curvature of the specimen. The limitations of this procedure are:

a. Its relatively high cost.

b. The question of permanency of the full effect.

c. The limitation of knowledge in respect to the effects of peening on properties other than fatigue.

The limitation as to permanency of effect is not as critical as that in the case of welds which are only peened, since we may reasonably expect that at the worst, results would revert back to the as ground condition.

Results of the combined grinding and shot peening confirm one important fact. Since the first fatigue results on fillet welds in HY-80 were obtained, their relatively poor fatigue properties has raised a question as to whether incipient submicroscopic discontinuities were present throughout the welds, prior to test. The fact that the fatigue life can be improved to the extent noted, indicates that the welds were sound.

Butt Welds - Beam and Plate Type Tests

Results of tests of beam and plate type butt weld specimens have been included in Figures 23 and 28. As indicated therein, the lives of these welds were much longer than the comparable tee fillet welds.

Some of the beam specimens tested to date failed through the welds. Radiographs illustrating the extent and type of weld cracking encountered are shown in Figure 34. All failures of plate type specimens observed to date, occurred in the heat affected zone adjacent to the weld. Work on this phase is currently underway and a more complete study of the butt weld fatigue fractures will be made.

Compression Tests - Beam and Plate Type Tests

Some results of fatigue tests on beam type specimens in which the stress was always compression are tabulated below. The mean initial compressive stress was applied in setting up the specimen by forcing a shim between the specimen end and specimen holder. The holder consisted of a large base plate in which a recess was cut for the specimen which was held in place by steel straps which permitted the imposition of additional initial compression. Results obtained to date are indicated below:

Initial Mean Stress, psi	Applied Alternating Stress, psi	Stress Range, psi	Cycles to First Indication of Failure	Cycles to Ultimate Failure
20,100c	20,400	300T 40,500c	2,565,000	3,005,200
29,200c	28,500	700c 57,700c	*	790,000
36,700c	33,700	3000c 70,400	-	354,000

*First indication not observed; cut-off switch stopped machine at 790,000 cycles. During the course of these tests the initial compression relaxed from 10 to 15 per cent.

Three results have been obtained on plate type specimens in which the fillet weld was always in compression. For these tests the specimen was mounted with the web on the loaded side of the plate. The full thickness of plate, 1-1/2 inches, was tested with results, as follows:

Stress Range	Cycles to First *** Indication of Failure	Cycles to Ultimate Failure*
0-70,000 c	4850**	8180
0-70,000 c	2000	4660
0-60,000 c	4000	

*There was no clear indication of ultimate failure; crack progressed along full length of fillet.

**Failure was noted at this point but may have started earlier.

***As evidenced by ultrasonic method.

DISCUSSION

It should be noted that the results obtained are readily explainable on the basis of the mechanical and metallurgical characteristics of HY-80 weldments as well as the geometrical effects involved.

The improvement effected by grinding can be attributed to a reduction of the geometrical notch acuity; the improvement by peening, the superimposition of a residual compressive stress in the critical area.

The better fatigue life of butt welds as compared to fillets can be attributed to the reduction of the acuity of the geometrical notch; in addition there is a possibility that the degree of locked in stress at the toe of the butts may have been significantly less than at the toe of the fillets.

SUMMARY

In general, the results obtained for the various assemblies and specimens investigated were as follows:

a. Fillet Welds - Beam Type Tests - To Total Failure - Alternating Stress

10,000 cycle level - 52,000 psi
100,000 cycle level - 20,000 psi
1,000,000 cycle level - 11,000 psi

b. Fillet Welds - Plate Type - to 10% Deflection - 0 to max. tension

10,000 cycle level - 60,000 psi
100,000 cycle level - 30,000 psi

c. Fillet Welds - Beam Type Tests - Effects of grinding and shot peening - Alternating Stress

Both grinding and shot peening improved fatigue properties, grinding being somewhat less effective than shot peening. The combination of grinding and shot peening was the most effective. However, shot peening represents a surface effect which could be destroyed by removal of the surface layers of metal.

d. Fillet Welds - Beam Type Tests - Comparison HTS and HY-80 - Results obtained with HTS assemblies at 37,100 and 32,000 psi were similar to these obtained with comparable welds in HY-80 base metal.

e. Butt Welds - On the basis of both plate and beam type specimens, the fatigue properties of butt welds loaded transverse to the direction of welding appear better than comparable fillet assemblies.

f. Compression - Limited results obtained with the beam type machine indicate that longer life may be expected when the stress range is all compression. Results on plate type specimens also indicate that the life under compression is longer. However, results are too few to draw conclusions at this time.

FUTURE WORK

It is apparent that there are many facets of the overall problem of evaluating the effects of welding on the fatigue characteristics of high strength steels of the HY-80 type. Some aspects relative to fatigue properties of HY-80 weldments which are currently being investigated are:

a. Compression loading

b. Welds containing imperfections commonly encountered in the field (undercut, embrittlement, lack of fusion)

c. Repair welds in HY-80 plate

d. Comparison of welded plate with base metal properties.

In addition to the above, the beam type apparatus is being redesigned to accommodate full thickness (1-1/2") specimens. The modifications will permit imposing any desired proportion of stress ranging from complete compression to complete tension.

ACKNOWLEDGEMENT

The authors wish to acknowledge the advice and effort of Mr. T.J. Griffin of the Bureau of Ships who initiated the program and was present during the overall planning and the participation of their many colleagues in the Material Laboratory, especially Cdr. R. Hall, Project Officer, Messrs. E.A. Imbembo, Metallurgy Branch Head, H. Nagler, V.A. Di Giglio and K. Pon, Welding Engineers, and R. Wolfe, P. Abramov and E. Lewis Mechanical Engineers.

Table 1

Mechanical and Chemical Requirements - Rich Chemistry HY-80 Steel Plate (MIL-S-16216D)

<u>Chemical Analysis</u>

Carbon	0.23 (Max.)
Manganese	0.10-0.40
Phosphorus	0.35 (Max.)
Sulfur	0.040 (Max.)
Silicon	0.15-0.35
Nickel	2.50-3.25
Chromium	1.35-1.85
Molybdenum	0.30-0.60

<u>Mechanical Properties</u>

Yield Strength (psi) (0.2% Offset)	80,000-95,000
Tensile Strength (psi)	Not specified*
Elongation (%) 2" Gage	20 (min.)
Charpy V Notch Impact (-120°F) ft. lbs.	50 (Min. Av.) - 1-1/2" thick 30 (Min. Av.) - 1-3/4" thick

*Tensile strength of plates used ranged from 99,400 psi to 105,800 psi.

Table 2

TYPICAL PROCEDURE FOR WELDING OF HY-80 PLATES

1. All surfaces in area of weld were ground prior to welding.

2. Electrode - Code A Brand - Type MIL-110-18

   a. 5/32" diameter was used for the first three layers on each side; 3/16" diameter for remaining layers.

   b. Electrodes were conditioned prior to welding by baking at 800°F for 2 hours and then stored at 200°F-300°F until used.

3. a. Preheat temperature 150°F

   b. Interpass Temperature 200°F

4. a. String bead technique.

   b. After the optimum operating current and voltage was determined, welding speed was set to maintain heat input below 50,000 joules per inch. Typical conditions used were as follows:

Electrode Dia.	Volts (Av.)	Amperes (Av.)	Polarity	Range*		Joules (In.)
5/32"	23	165	D.C. (Rev.)	31,000	-	48,200
3/16"	24	185	D.C. (Rev.)	25,900	-	45,900

Joules/in. were calculated for each assembly as shown below:

$$\frac{\text{Joules}}{\text{In.}} = \frac{V \times A \times T}{l \times n}$$

V - Volts
A - Amperes
T - Time (sec.) for welding one side
l - Length of weld (In.)
n - Number of beads on one side

   c. Tempering the Heat Affected Zone - The first or outside beads of each layer of weld and particularly of the outside or last layer of weld metal were deposited against and connecting to the base plate with the following beads deposited in such a manner as to overlap the first bead without touching the base plate.

5. Inspection - After the third layer was completed on each side with the 5/32" size electrode, the welds were inspected for cracks by magnetic particle inspection while the assembly was maintained at 150-[illegible]0°F. All assemblies were examined by magnetic particle inspection after completion.

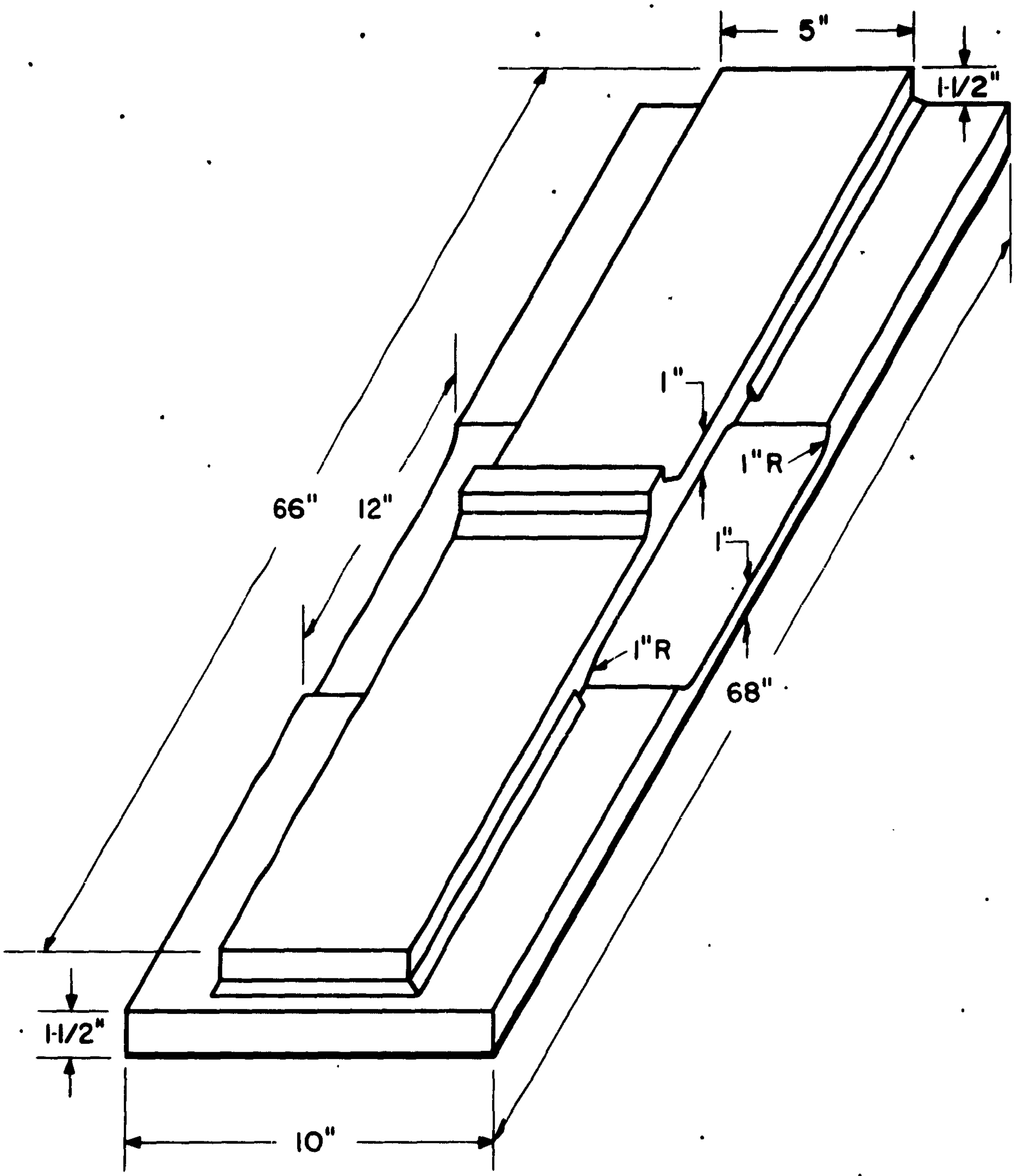


Figure 1 — Large Scale Beam Type Fatigue Specimen

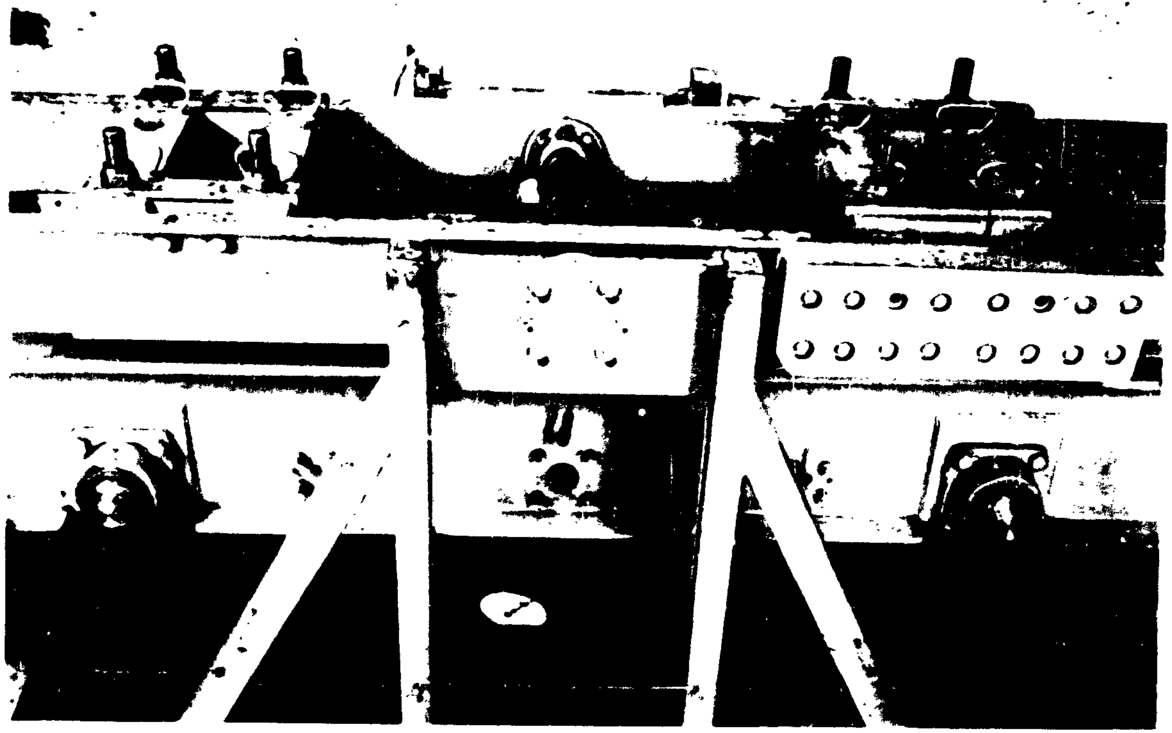


Figure 2 – Set Up Of Specimen For Test In The Dynamic Fatigue Machine

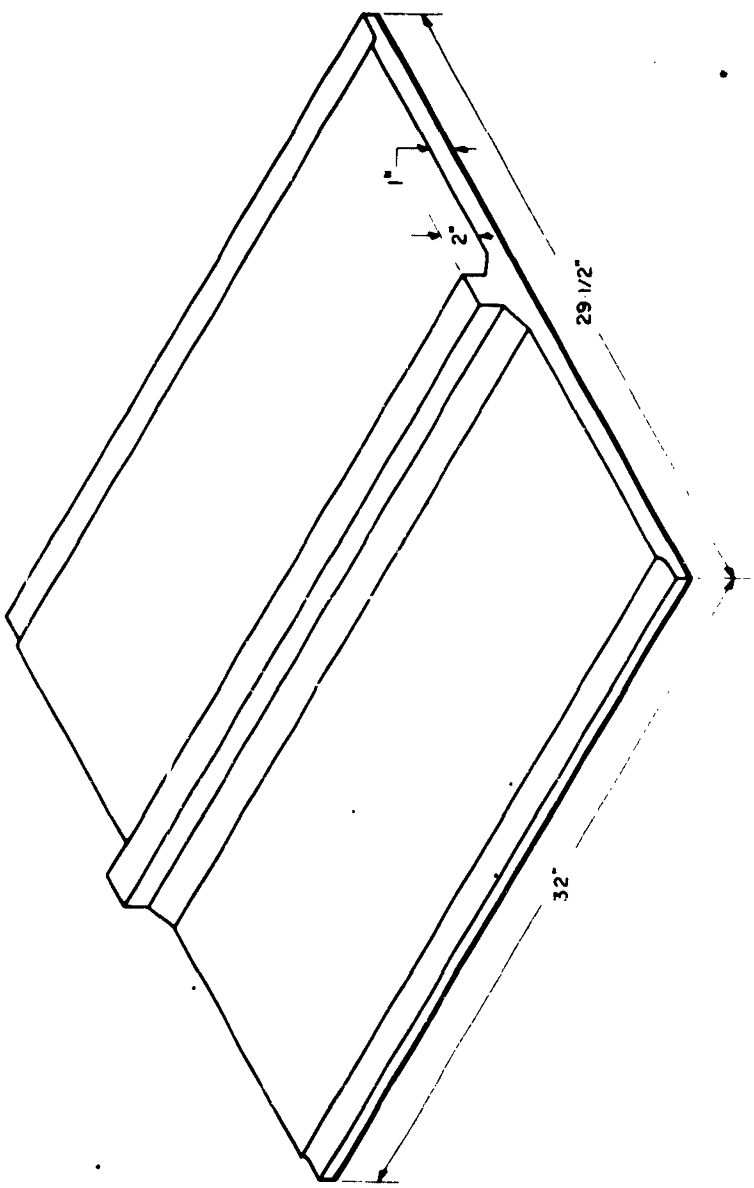


Figure 3 — Large Scale Plate Type Fatigue Specimen

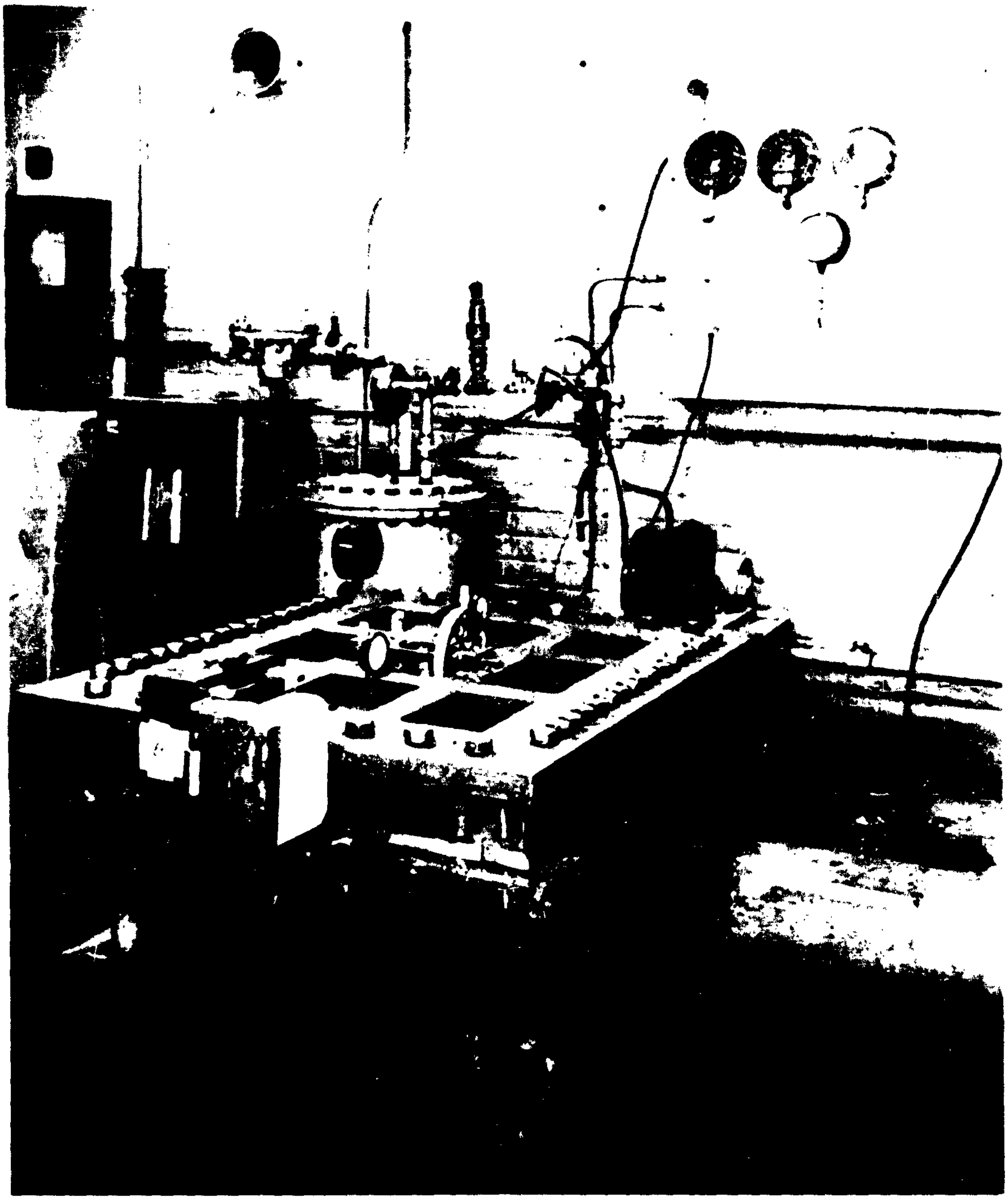
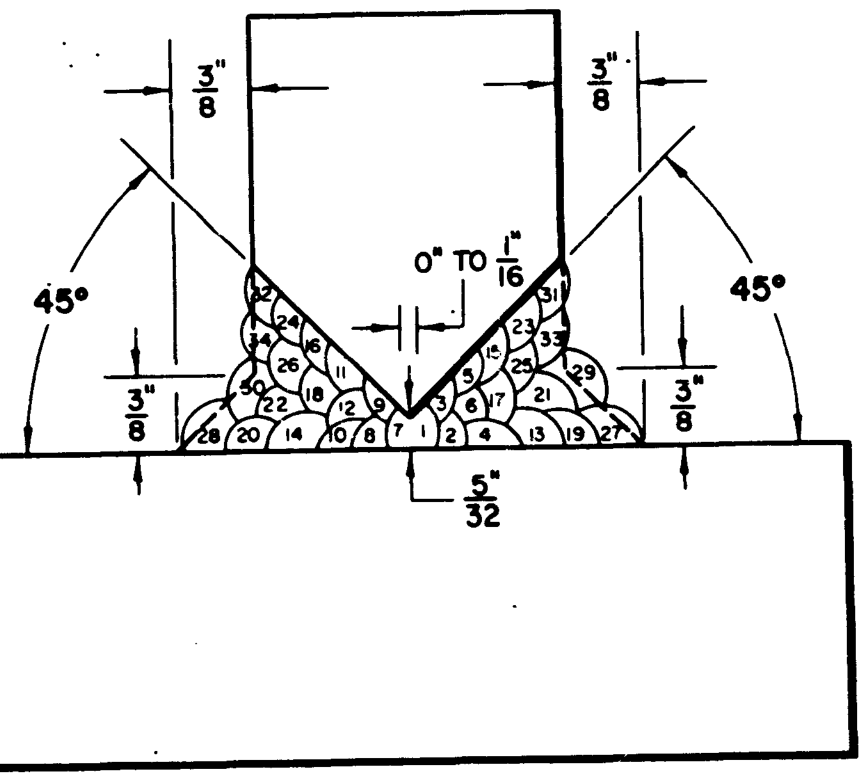


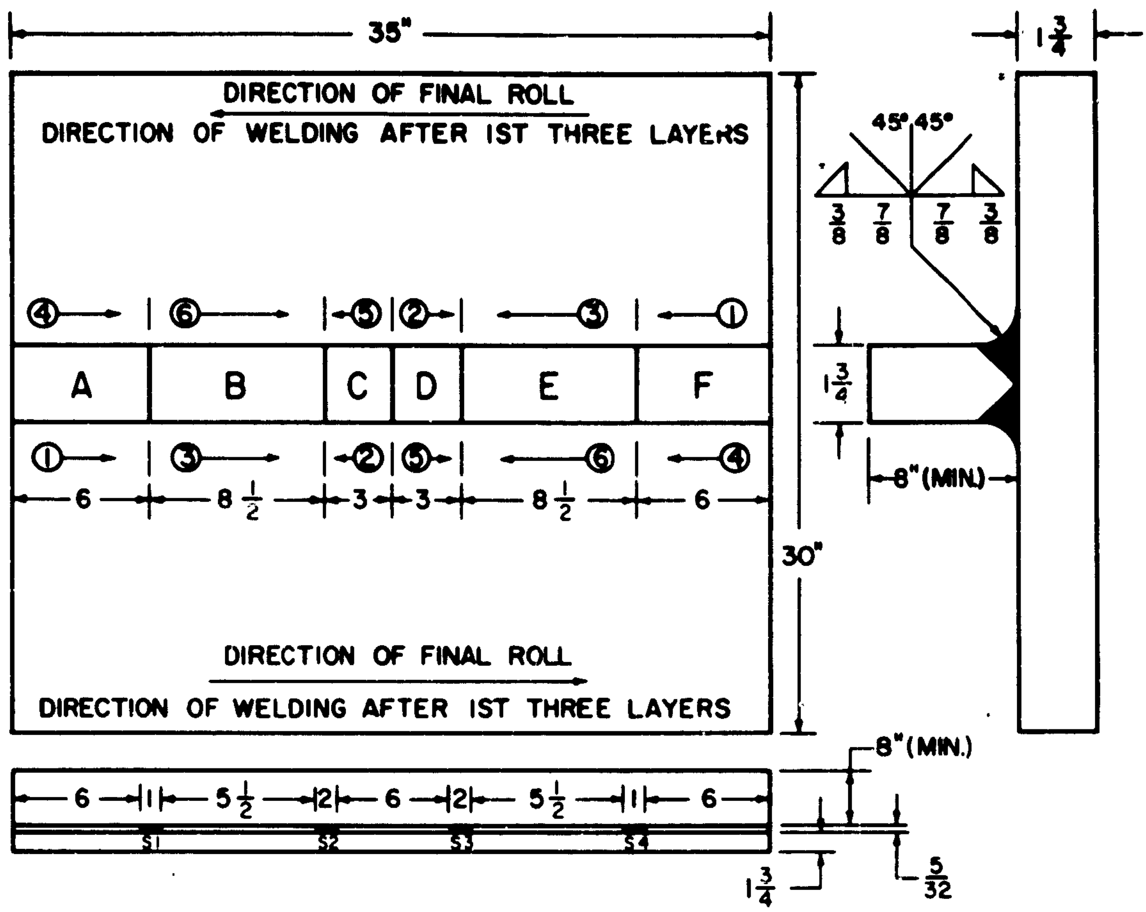
Figure 4 – Hydrostatic Loading Equipment



DOUBLE - BEVELED TEE JOINT
FILLET - REINFORCED

Figure 5 — Joint Design and Weld Sequence

Figure 6 – Final Procedure for Welding Plate Fatigue Assembly

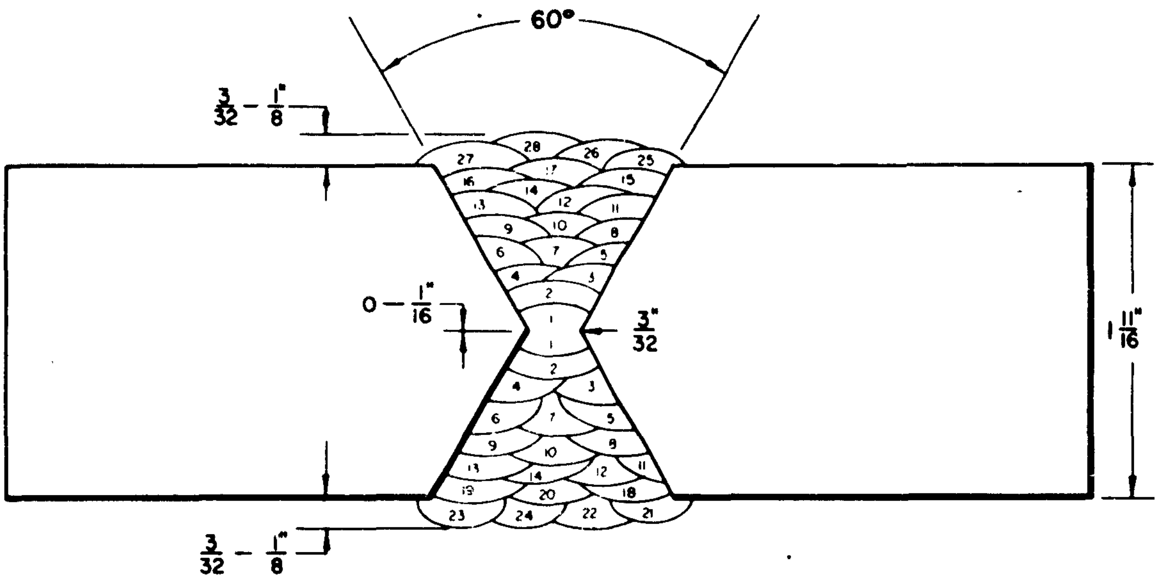


Notes to Figure 6

1. Entire top surface of plate should be ground flat prior to welding and machining.
2. Locate spacers (S1 to S4) as shown. Spacers should be of hardened steel.
3. Deposit the 1st three layers in block sequence as shown using a 5/32" diameter electrode.
4. Retain spacers in position until the respective block is to be welded. Remove prior to welding.
5. Complete as shown with 3/16" dia. electrode using continuous welds.
6. Examine welds by magnetic particle inspection after the third and final layers.
7. See Table 2, Notes 2, 3, 5 and 7.

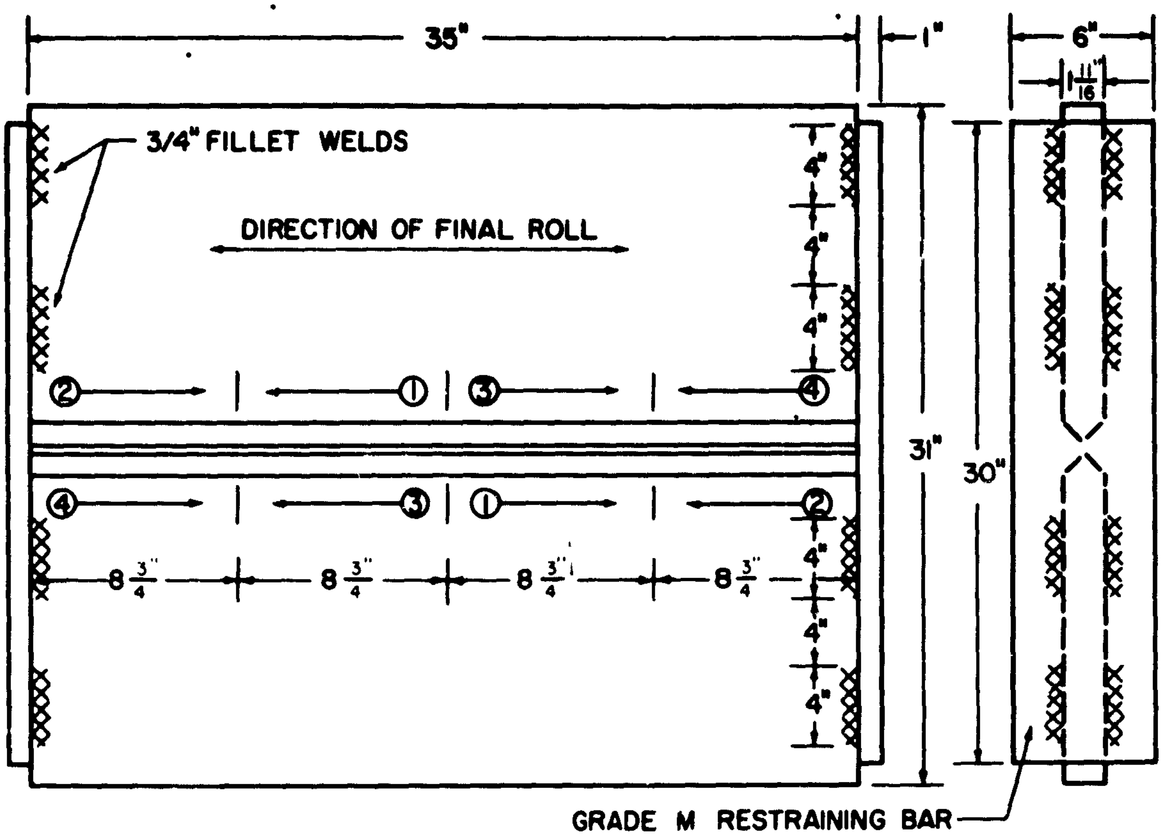
Figure 7 – Typical Procedure For Welding Of HY-80 Plates

Joint Design and Typical Pass Sequence - Double-V Butt Joint



The last two layers on each side were welded in flat position, all other layers were welded in horizontal position.

Figure 8 – Final Procedure For Welding Butt-Joint Plate Fatigue Assembly



Notes

1. The assembly was properly aligned and 3/4" fillet welds were deposited as shown.

2. The first 4 layers were welded in the horizontal position with 5/32" diameter electrodes, in block sequence as follows:

   a. Sections 1 and 2 of both sides of the double-V butt joint were welded simultaneously until the completion of the 4th layer.

   b. The roots on both sides were chipped and inspected for cracks by magnetic particle inspection.

   c. Sections 3 and 4 were welded similarly to Sections 1 and 2.

3. The 5th and 6th layers were welded in the horizontal position using 3/16" diameter electrodes, simultaneously on both sides, in straight progression and reversed layers.

4. The 7th and 8th layers were welded in the flat position in straight progression and reversed layers.

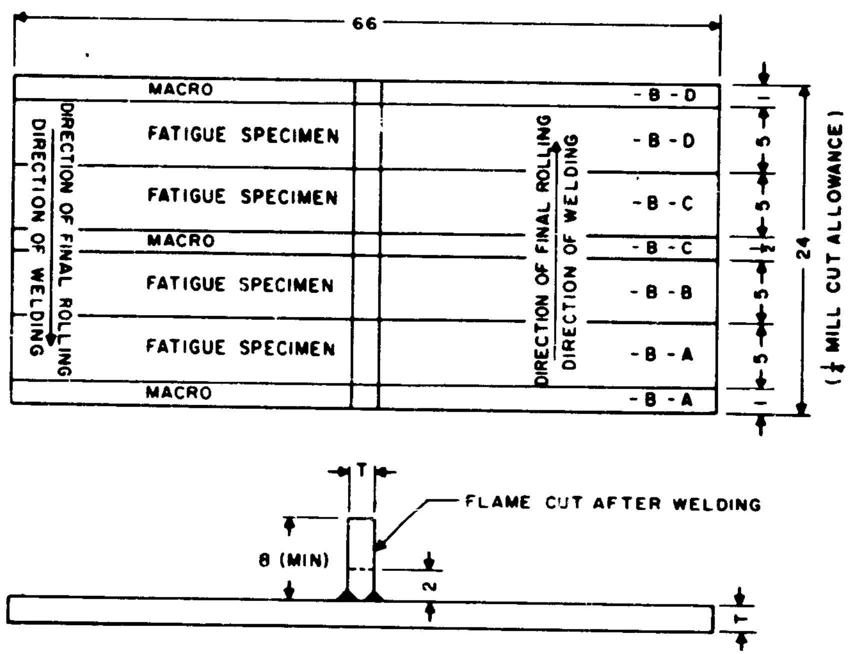


Figure 9 – Metnod of Specimen Preparation

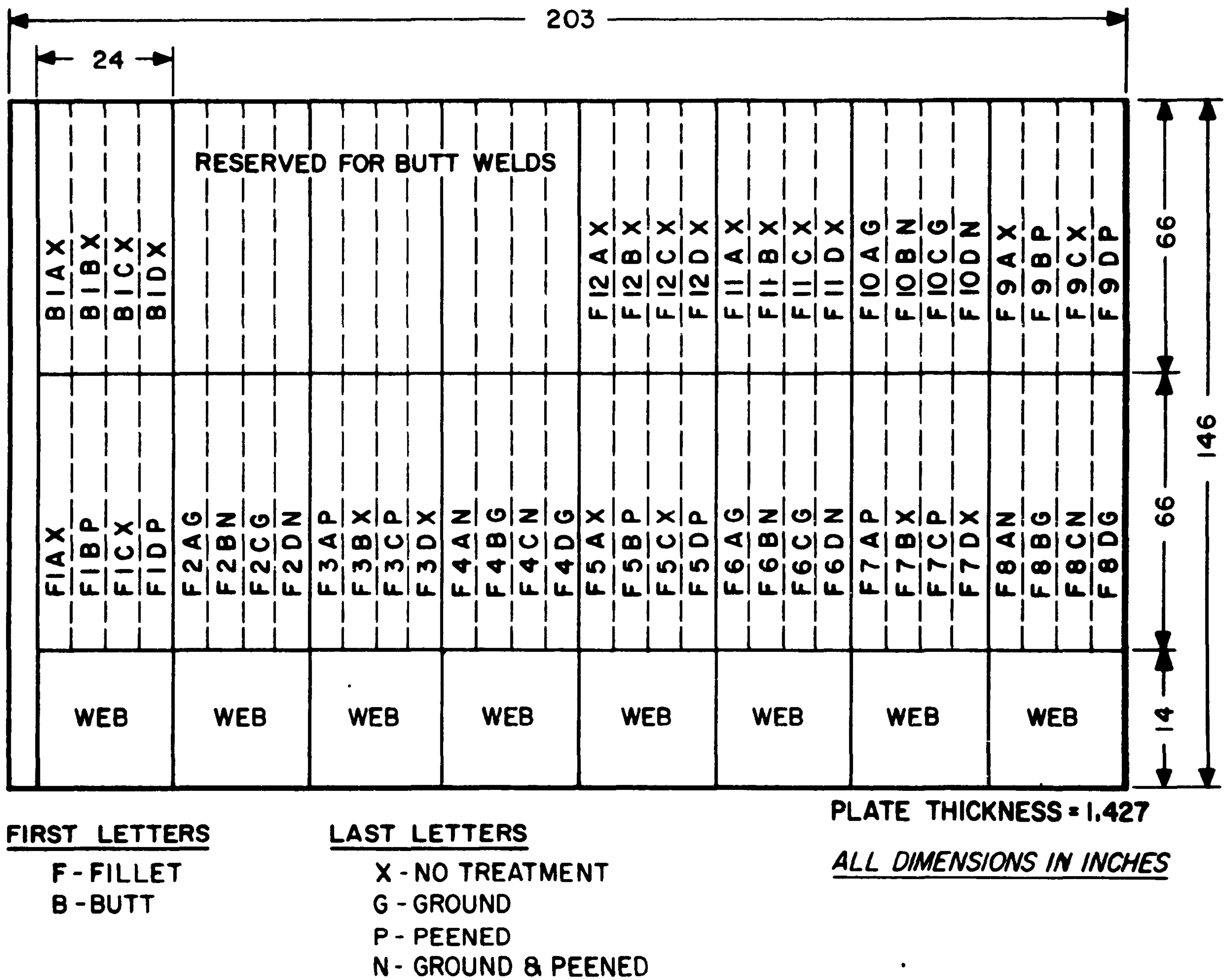
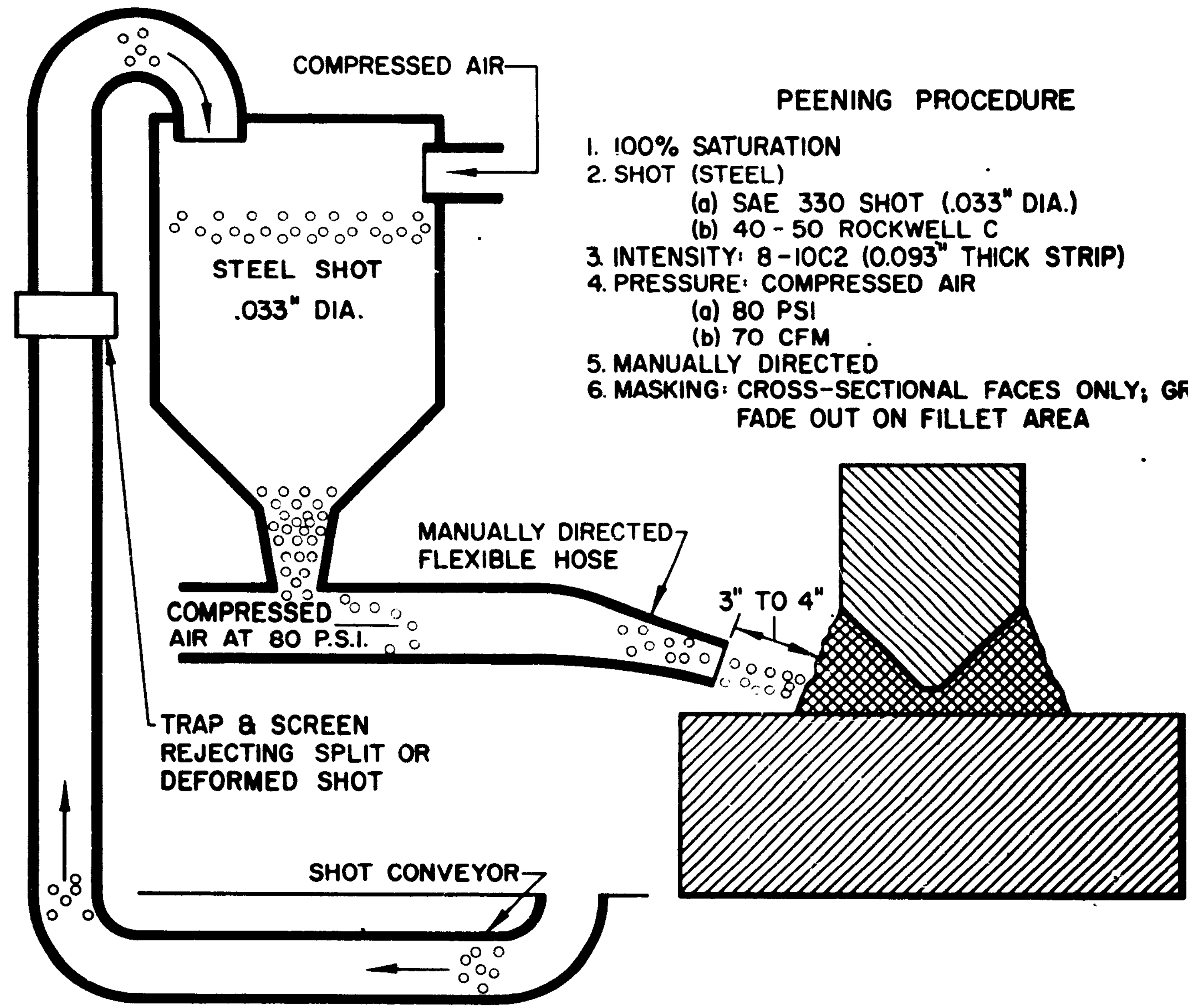


Figure 10 – Assembly and Specimen Distribution


COMPRESSED AIR
PEENING PROCEDURE
1. 100% SATURATION
2. SHOT (STEEL)
(a) SAE 330 SHOT (.033" DIA.)
(b) 40 - 50 ROCKWELL C
3. INTENSITY: 8-10C2 (0.093" THICK STRIP)
4. PRESSURE: COMPRESSED AIR
(a) 80 PSI
(b) 70 CFM
5. MANUALLY DIRECTED
6. MASKING: CROSS-SECTIONAL FACES ONLY; GRADUAL FADE OUT ON FILLET AREA
STEEL SHOT
.033" DIA.
MANUALLY DIRECTED FLEXIBLE HOSE
3" TO 4"
COMPRESSED AIR AT 80 P.S.I.
TRAP & SCREEN REJECTING SPLIT OR DEFORMED SHOT
SHOT CONVEYOR

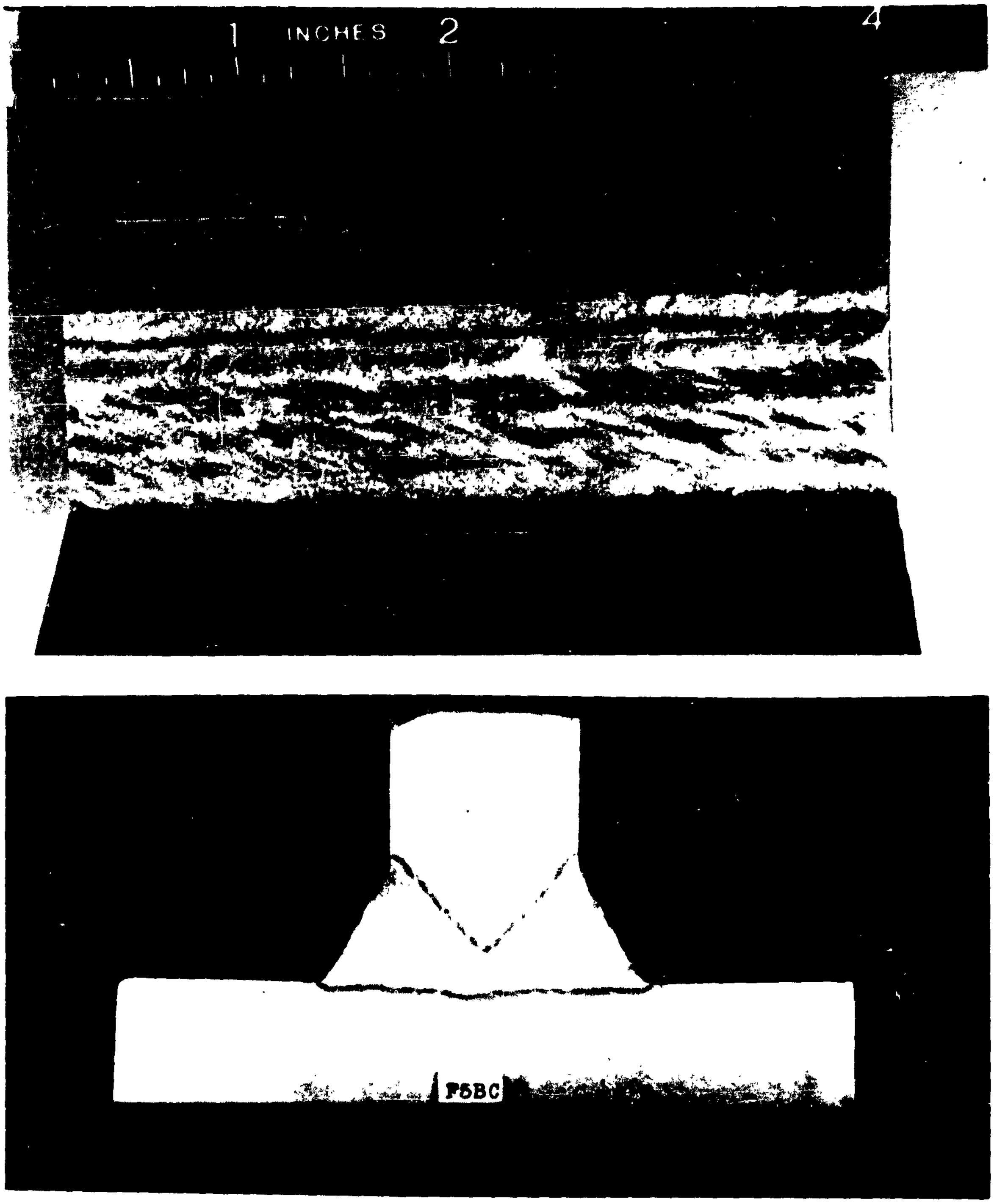


Figure 12 – Peened Specimen

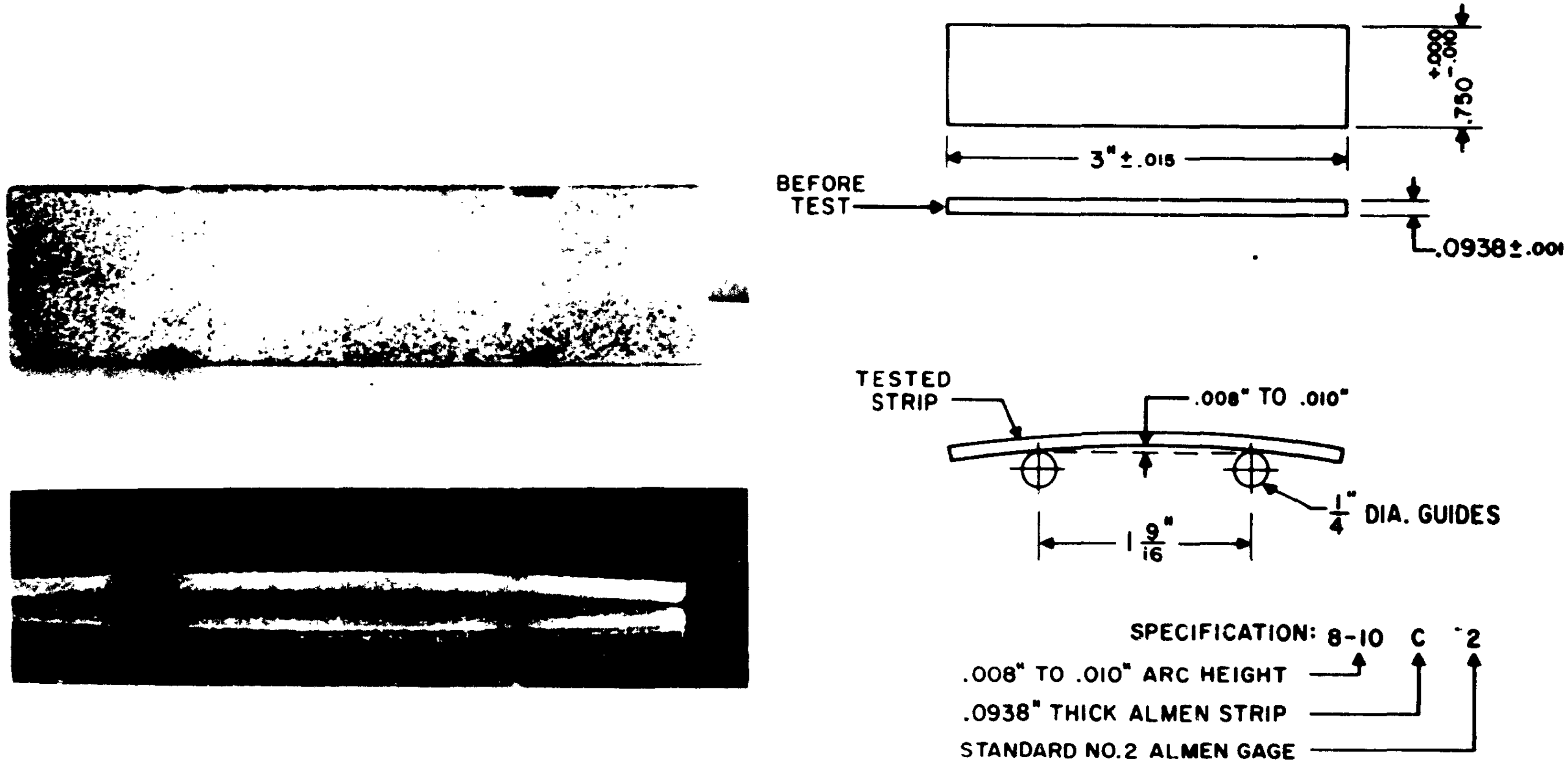


Figure 13 — Almen Strips And Method Of Measurement

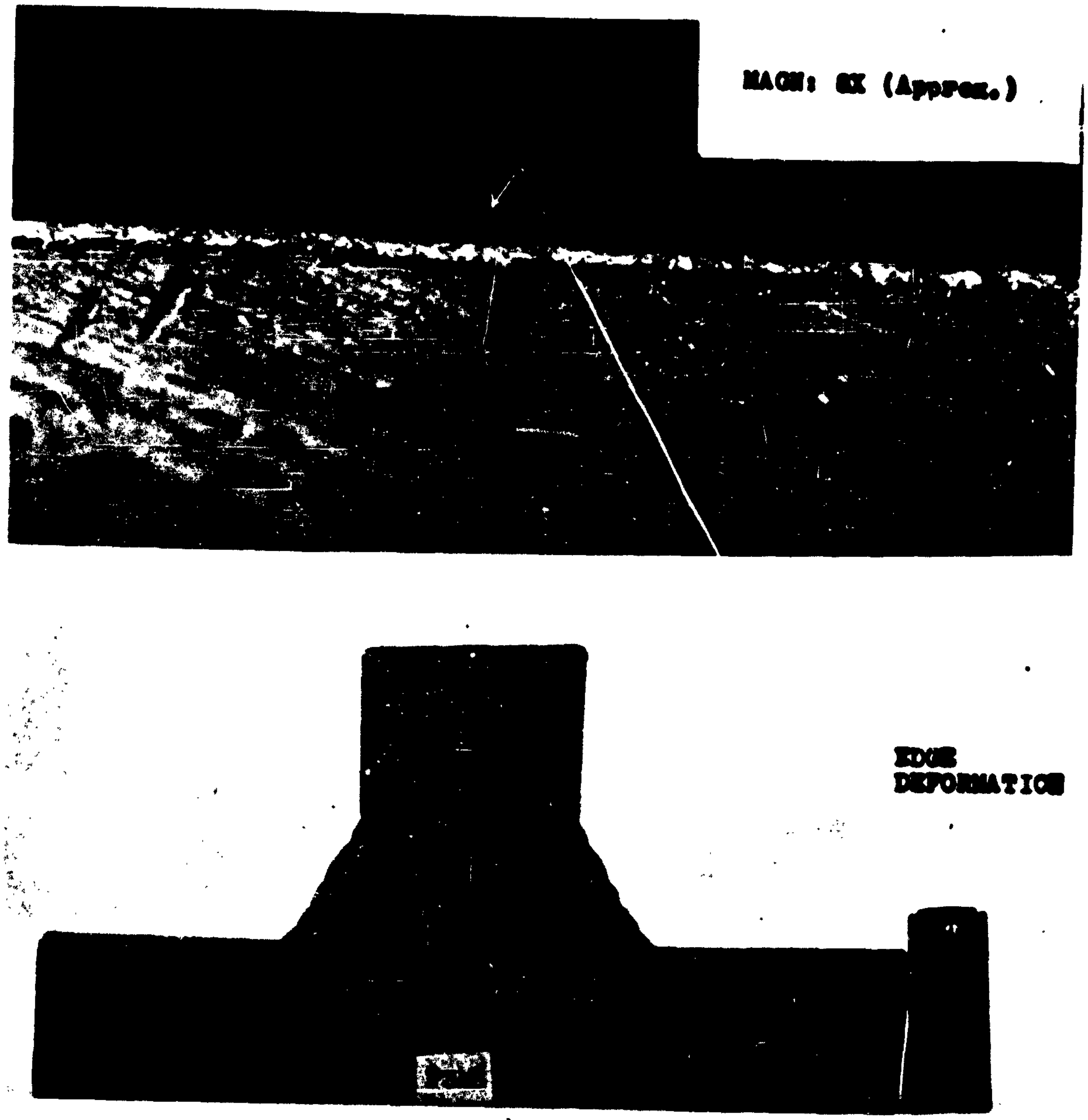


Figure 14 – Deformation Of Surface After Shot Peening

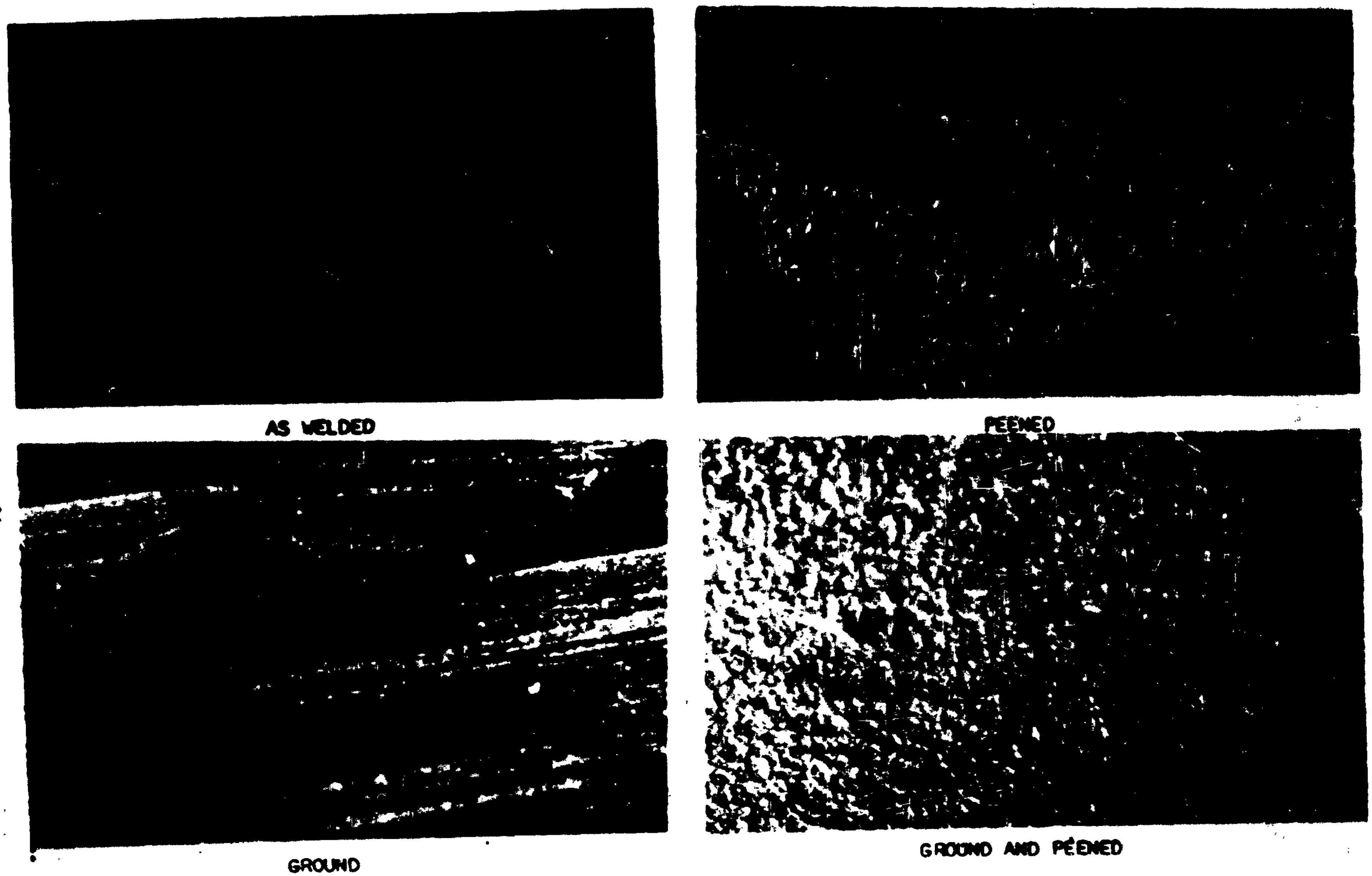


Figure 15 — Peened and Unpeened Surfaces (Weld Deposit - Magn. 10X Approx.)

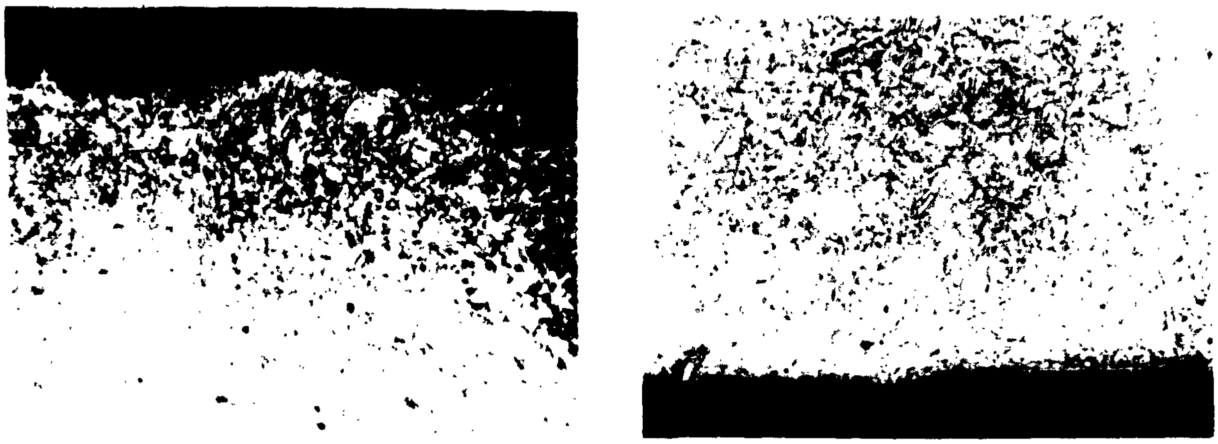


Figure 16 – Photomicrographs of Peened and Unpeened Areas HY-80 Base Metal - 250X

Figure 17 – Photomicrographs of Peened and Unpeened Areas Heat Affected Zones - 250X

Figure 18 — Photomicrographs of Peened and Unpeened Type MIL-100-18 Weld Deposits - 250X

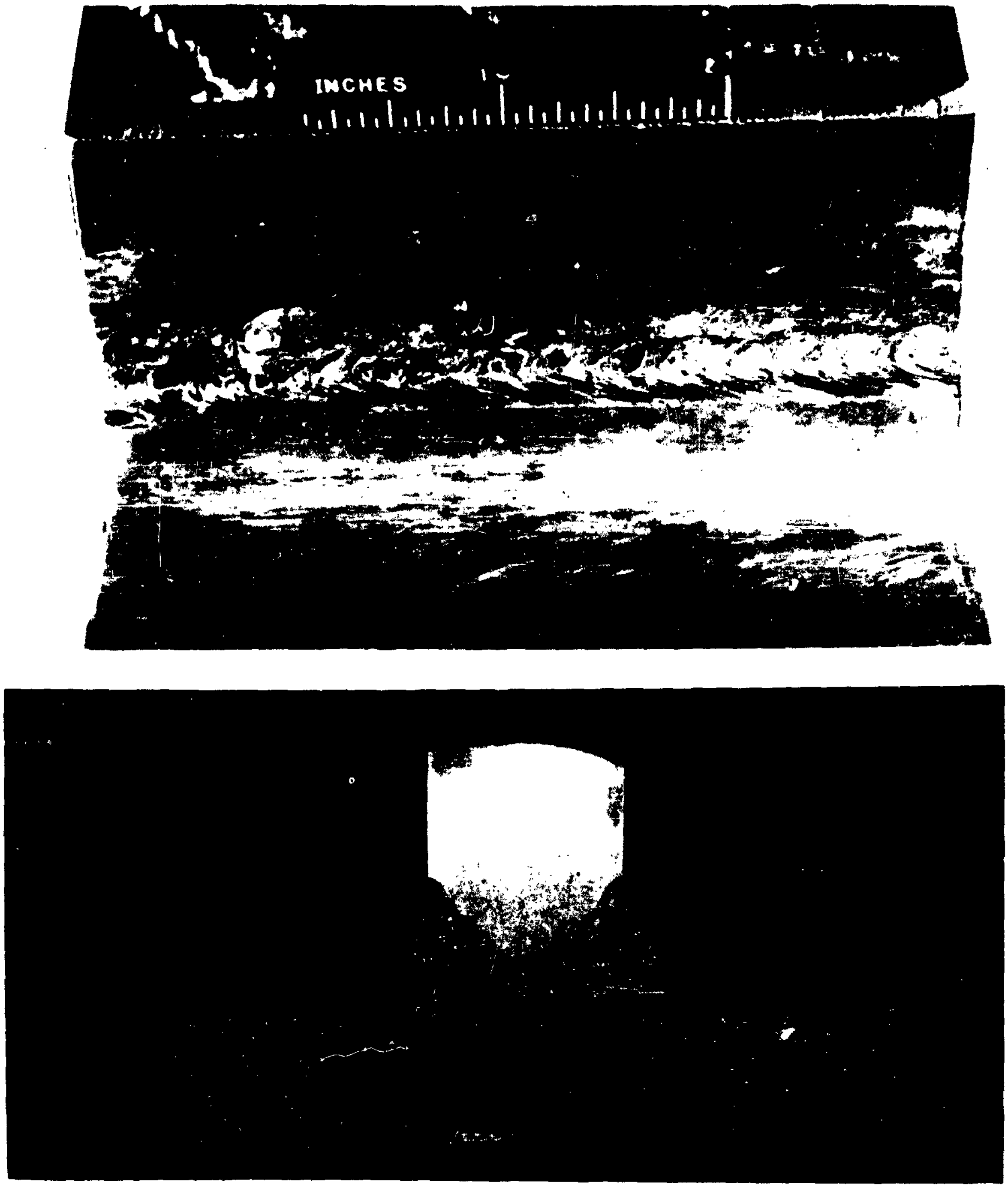


Figure 19 — Ground Specimens

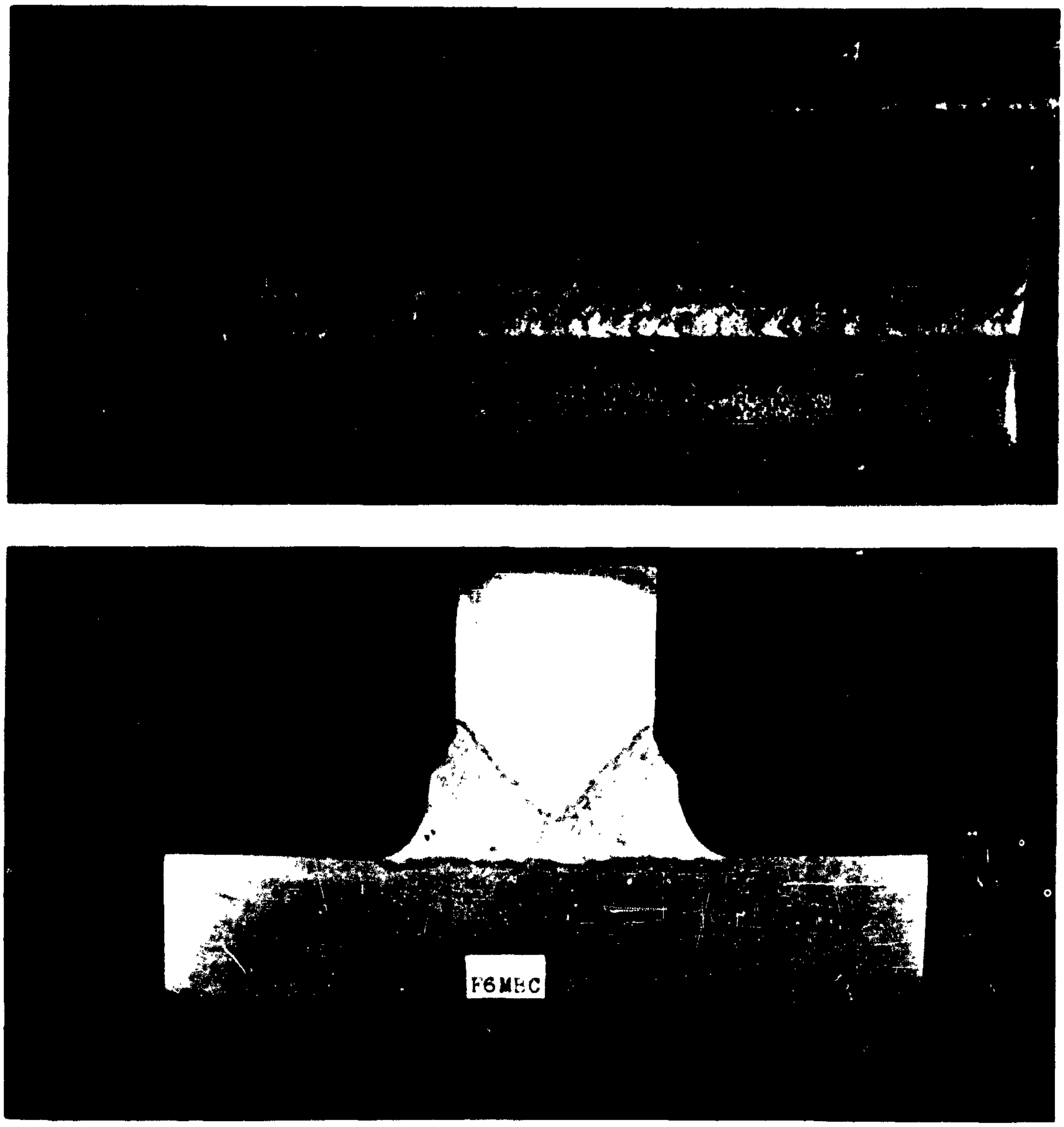


Figure 20 – Ground and Peened Specimens

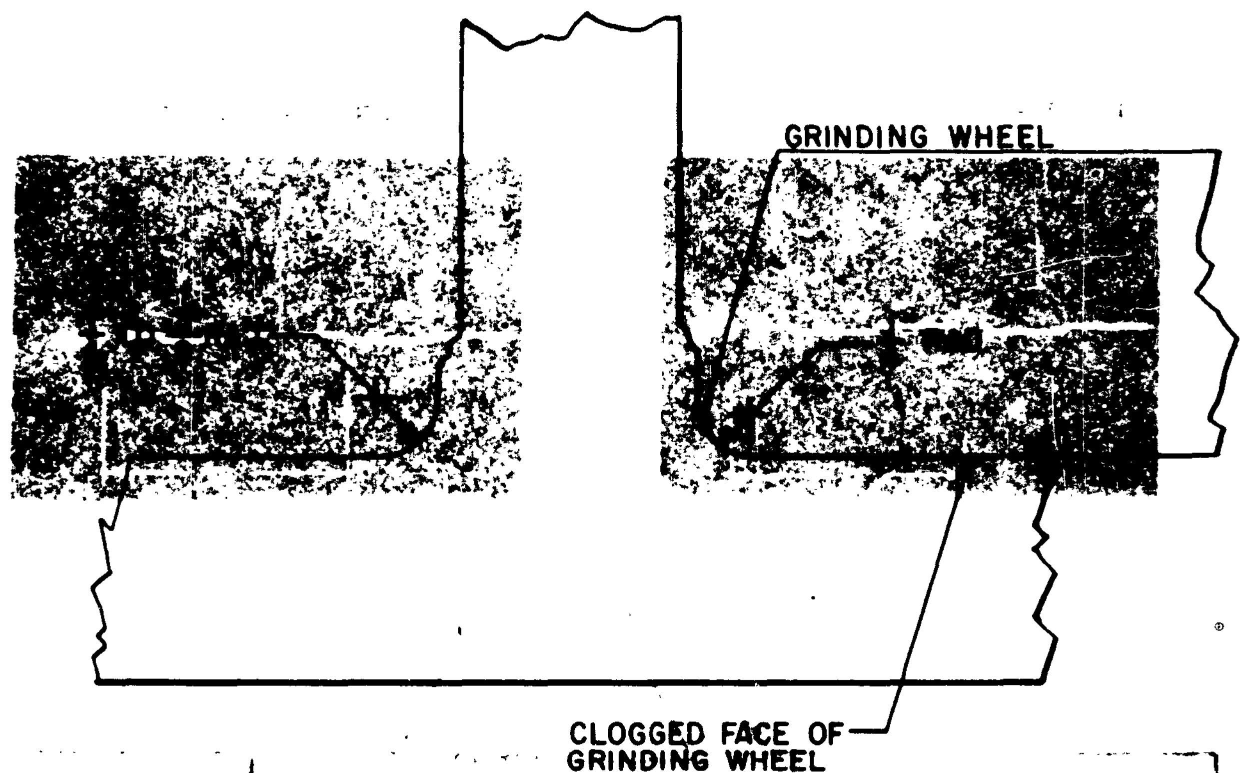


Figure 21 – Metnod Of Application Of Treated Wheel

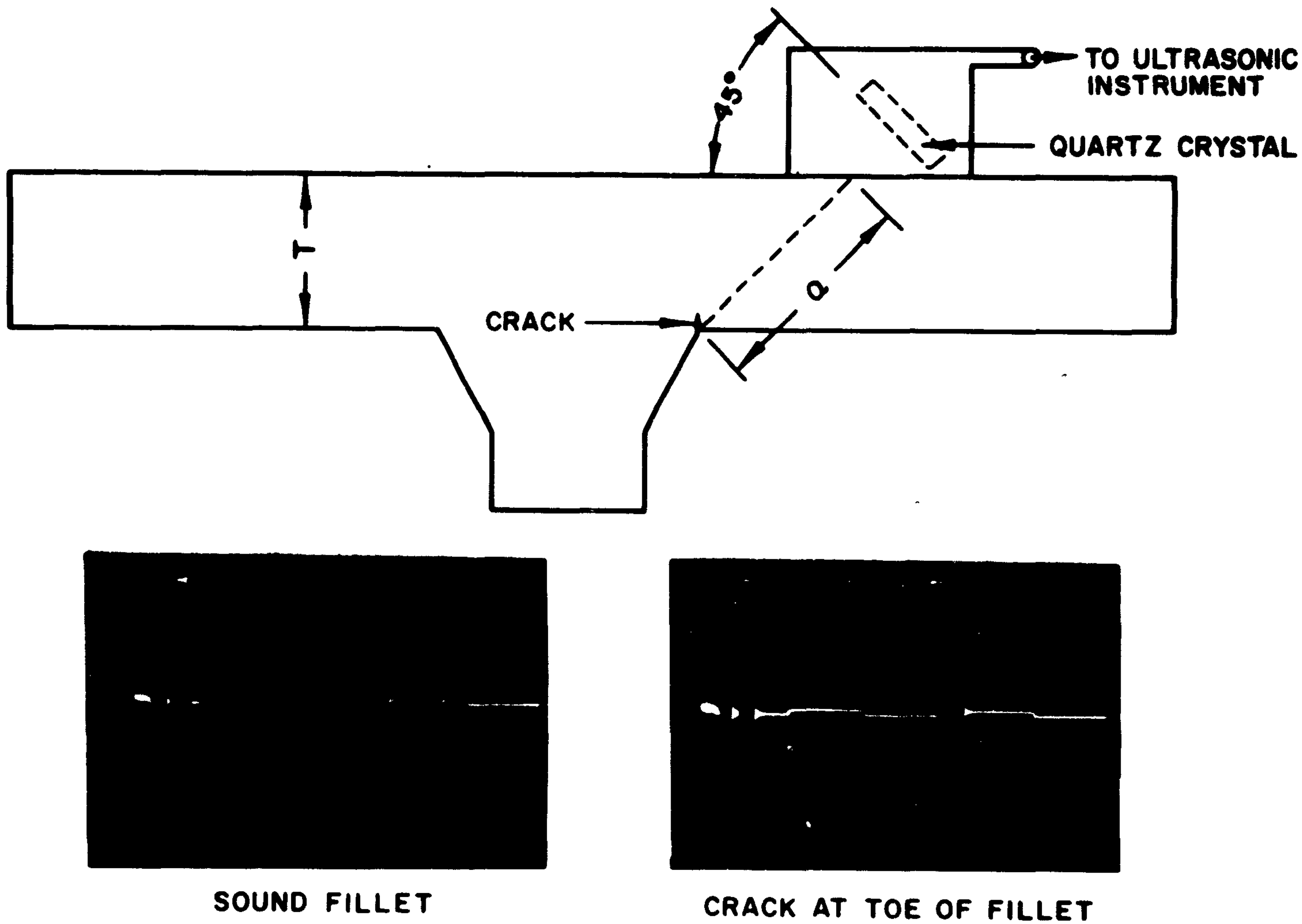


Figure 22 – Ultrasonic Inspection Procedure (Fillet Inaccessible)

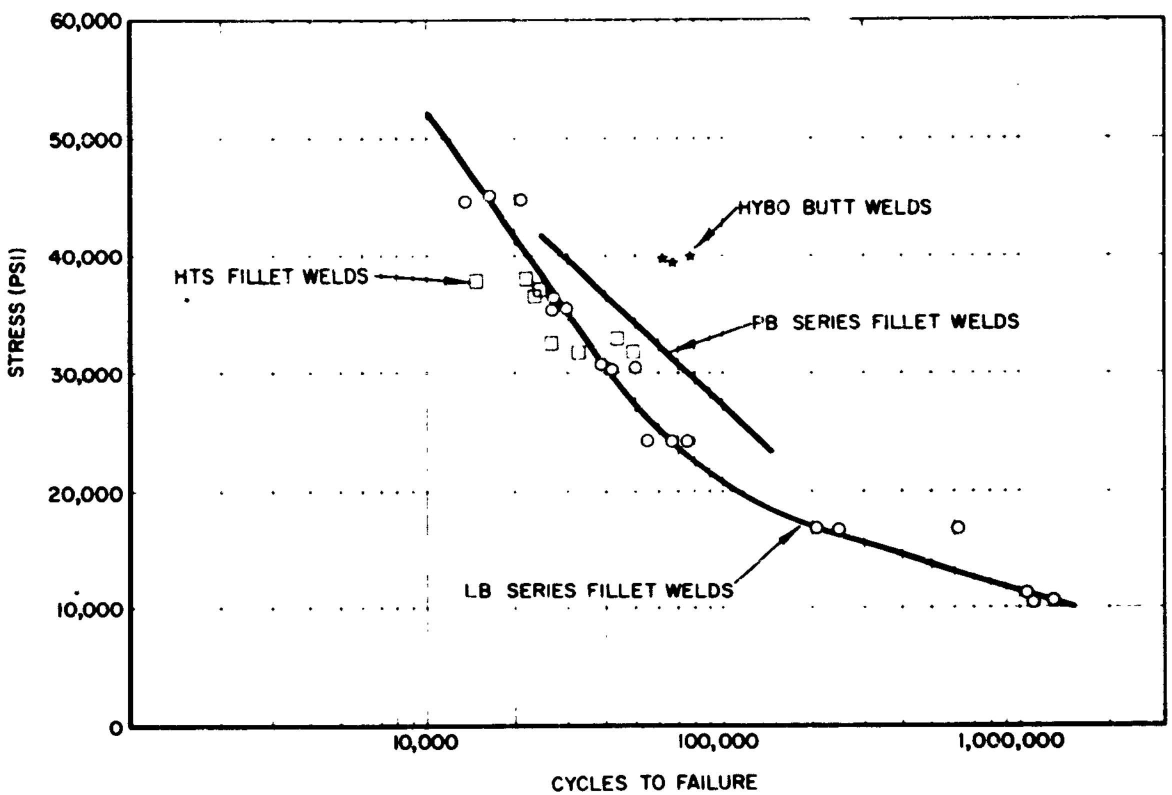


Figure 23 – S-N Curves And Plotted Data For Fillet And Butt Weld Beam Type Fatigue Specimens - Completely Reversed Stresses

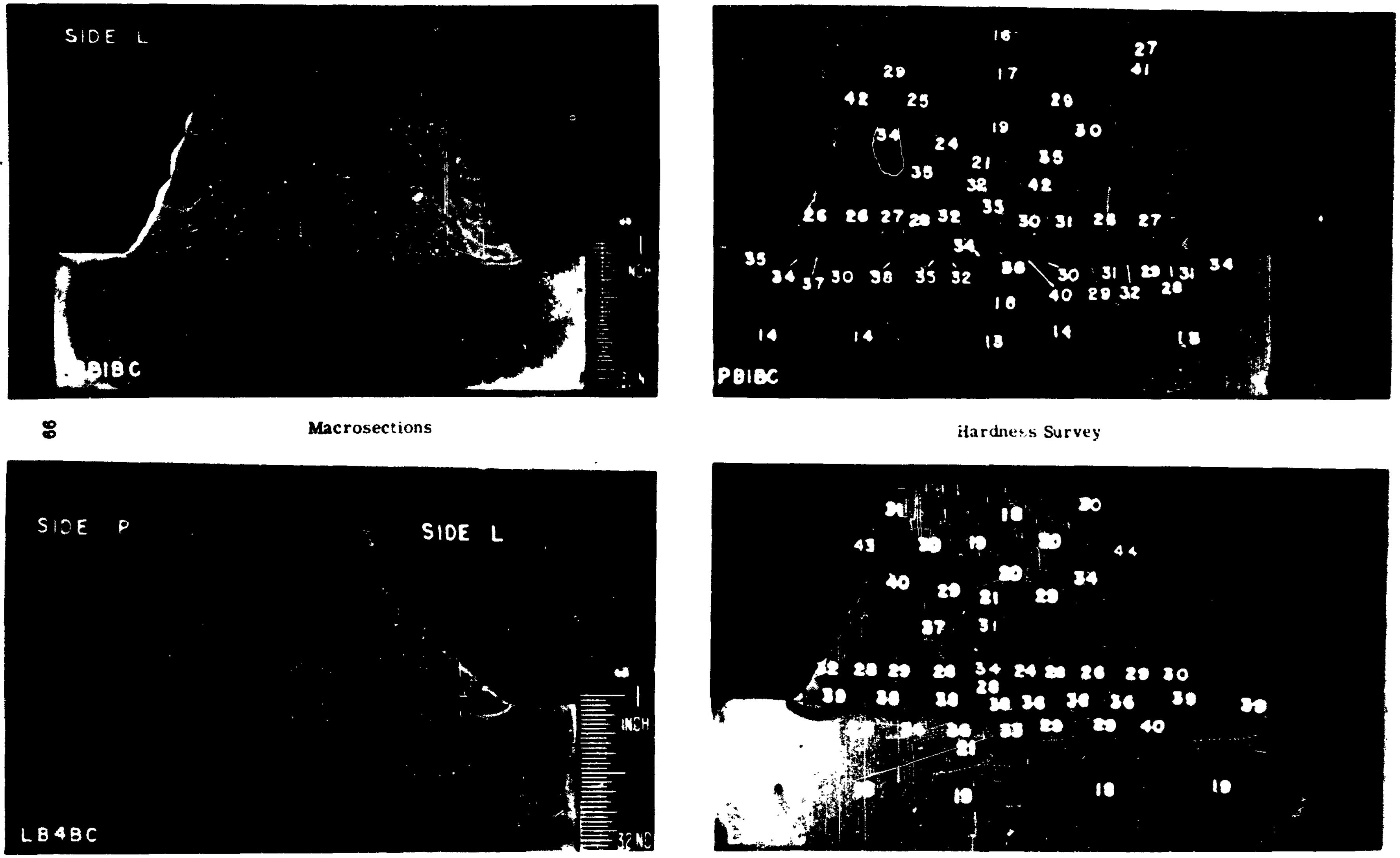
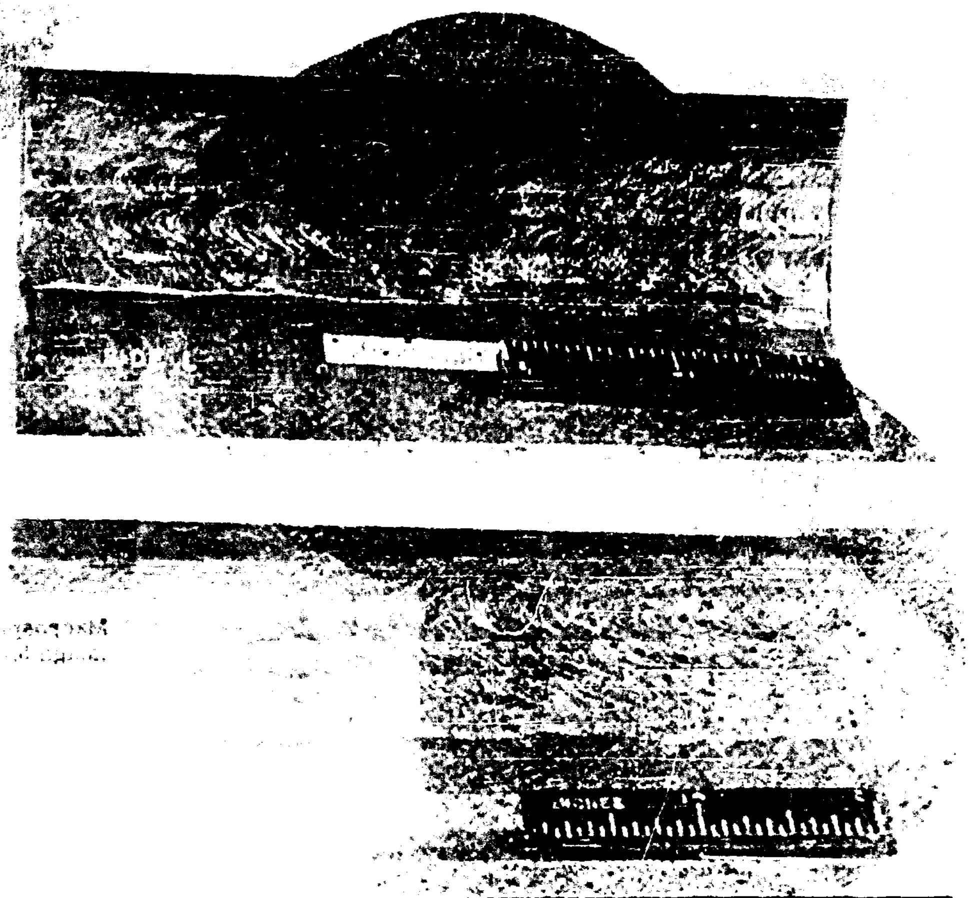


Figure 24 - Macrosections and Hardness Survey Of Typical Beam Fatigue Assemblies

Fracture paths in longitudinal sections shown by magnetic particle indications.



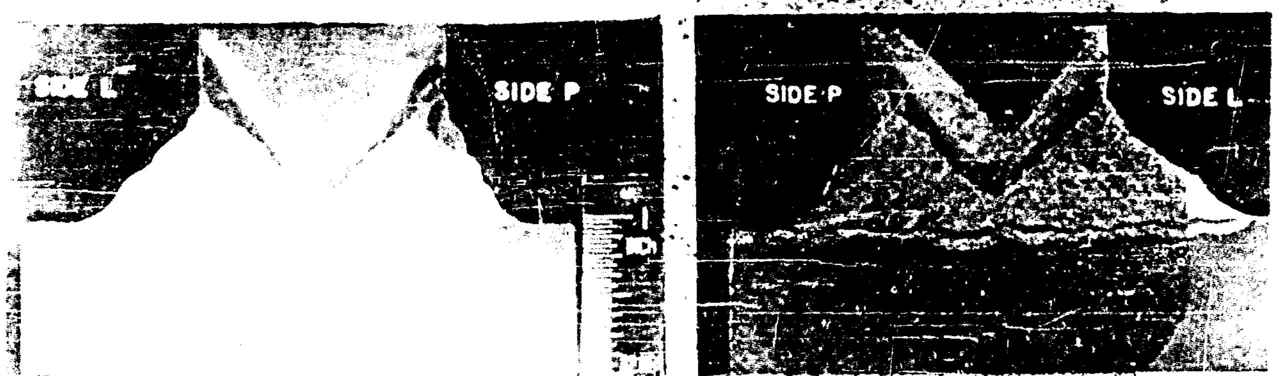


Figure 25 -- Typical Paths Of Fractures After Beam Fatigue Tests

Macrospecimen (LB4MDP)
(Magn 5X)

Magn 100X
Reduced .6X
Etchant: Vilella's Etch

Figure 26 – Microstructure of Area Near Toe of Weld Double Beveled Tee Joint, Fillet Reinforced - 60# HY 80 Plate

Macrospecimen (LB4DP 2)
(Magn 5X)

Magn 100X
(Reduced .65X)
Etchant: Vilella's Etch

Figure 27 — Photomicrograph of Fatigue Fracture - As Welded

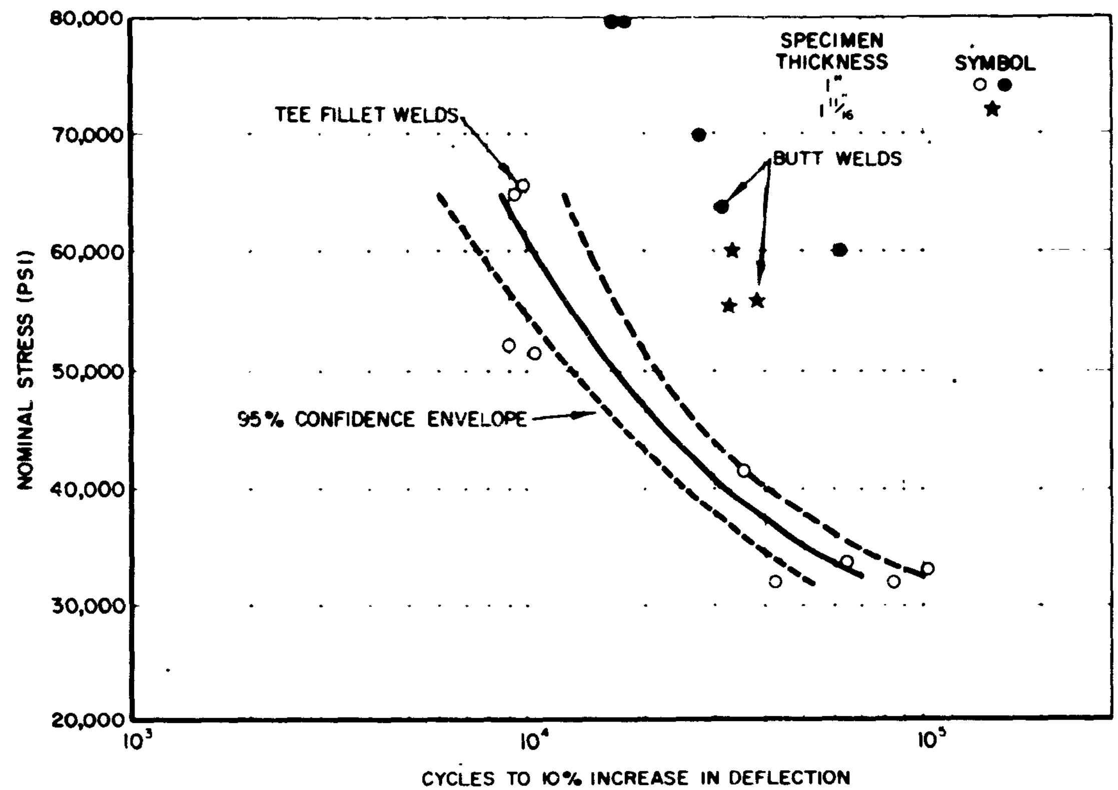


Figure 28 **S-N Curve For Plate Type Specimens Stress Cycle - Zero To Maximum Tension**

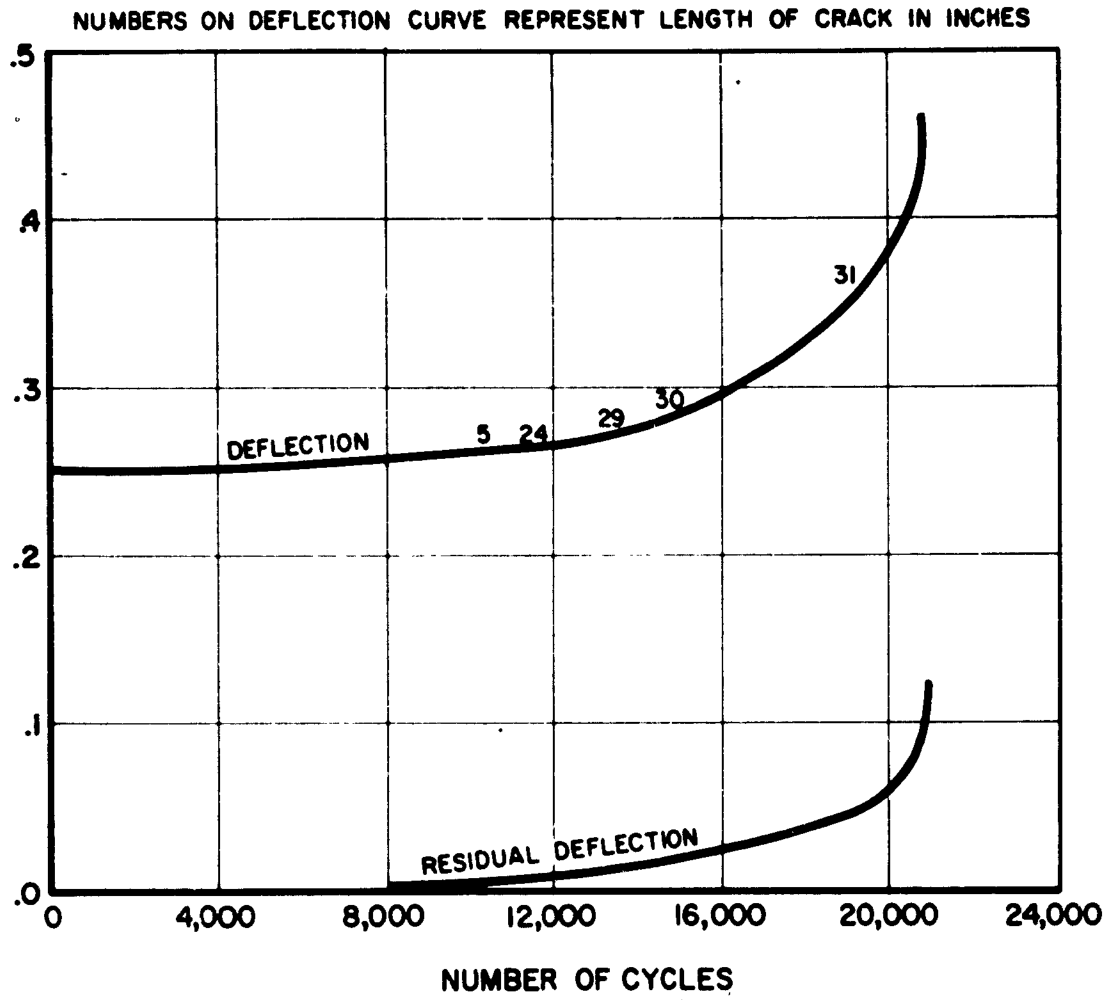


Figure 29 — Curves Showing Progressive Increase In Deflection As Crack Propagated Through Critical Section Of Plate Type Specimen LH-7 Stress Cycle 0-56, 600 PSI

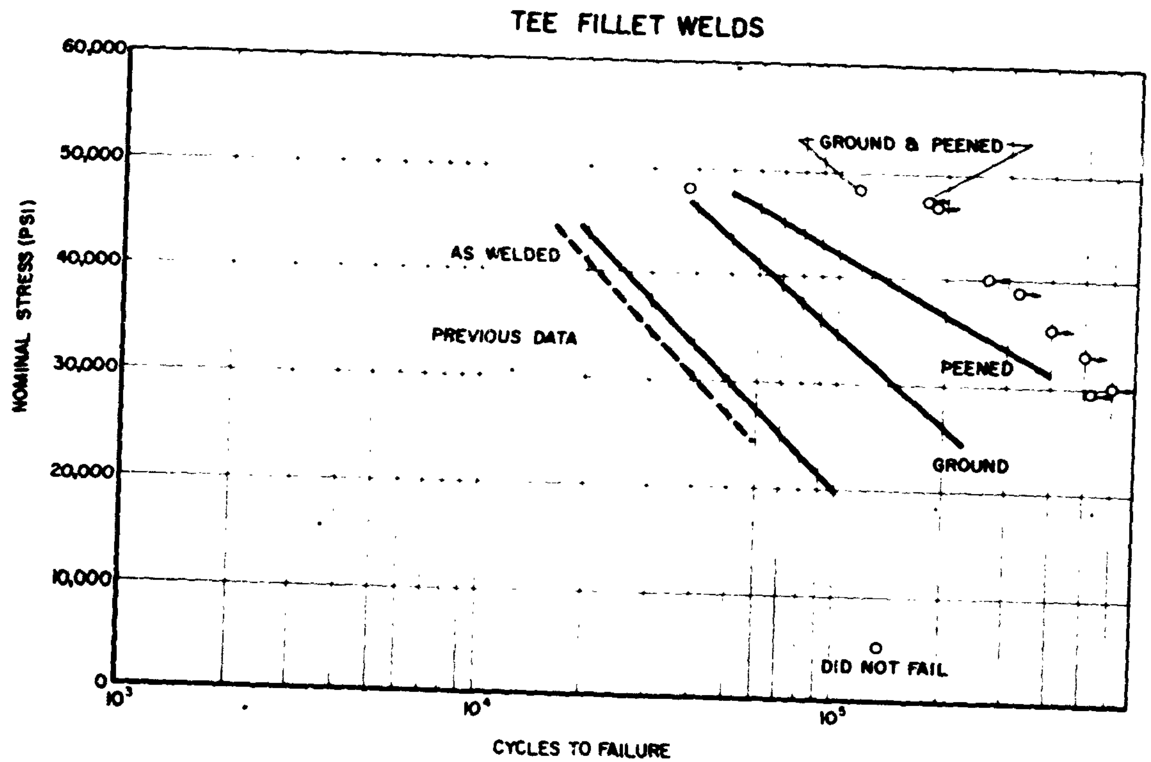


Figure 30 – SN Curves For Beam Type Specimens Completely Reversed Stresses

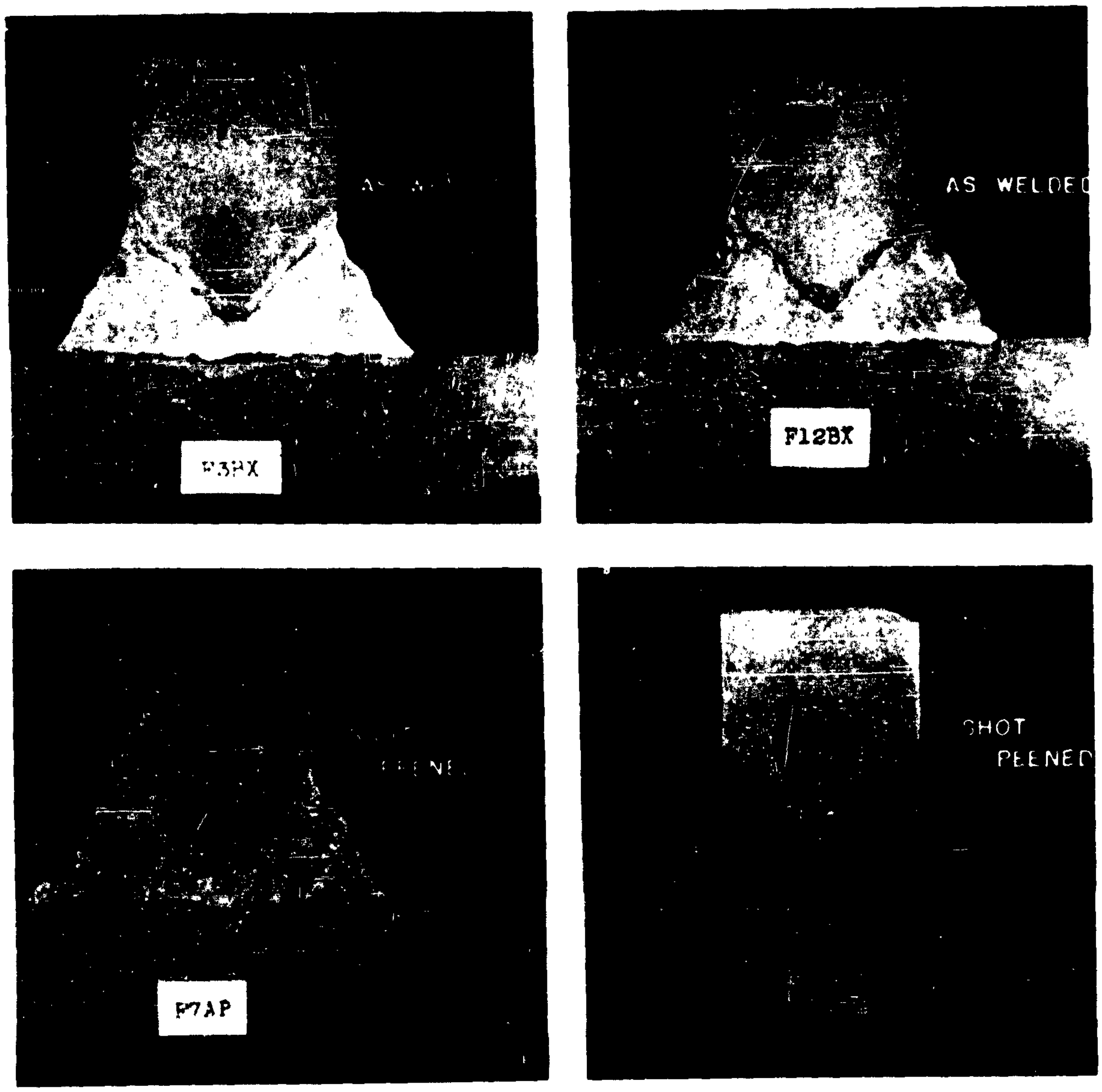


Figure 31 – Macrosections of Unground Fatigue Fractures - As Welded and Shot Peened

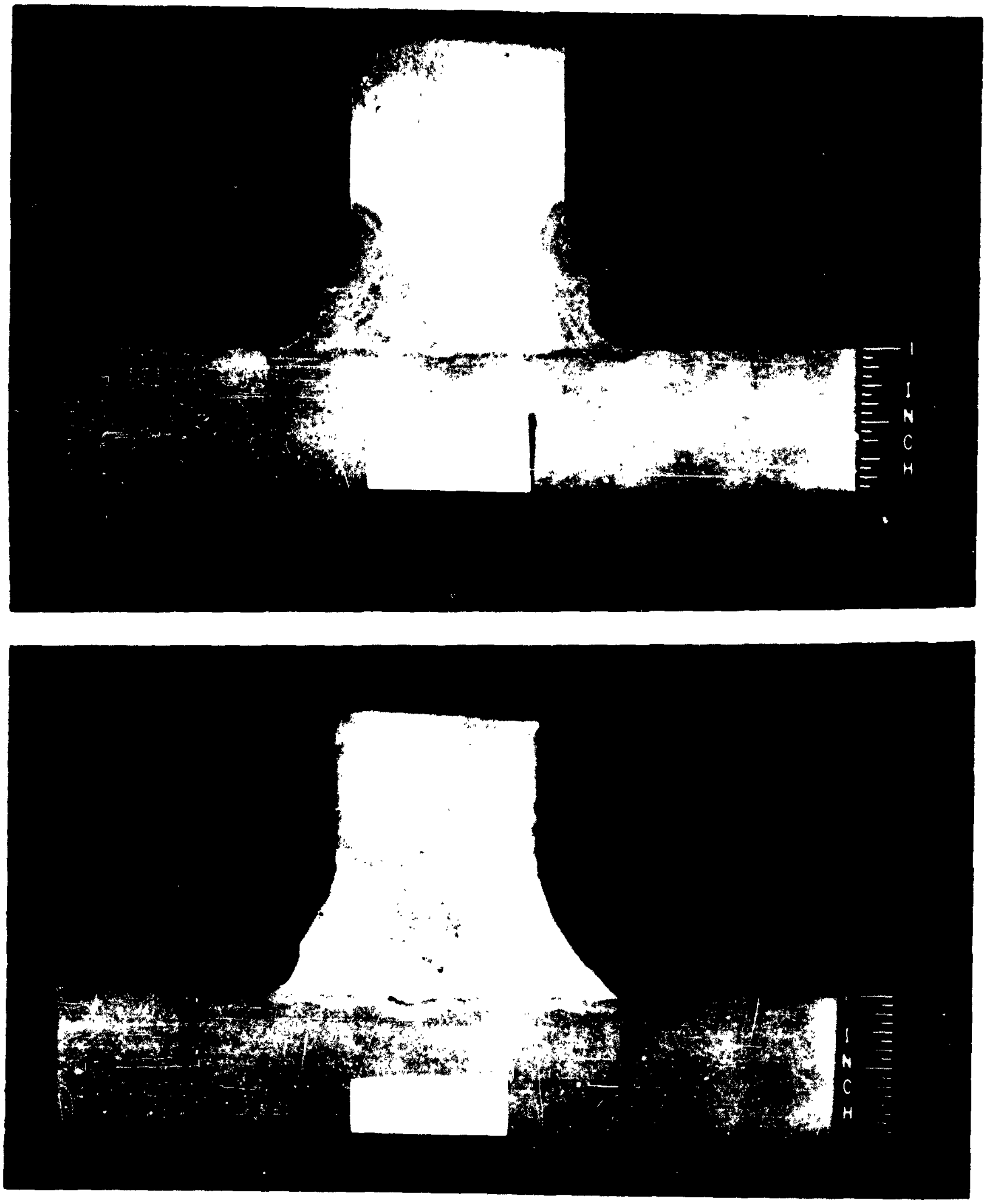


Figure 32 – Macrosections of Ground Fatigue Fractures

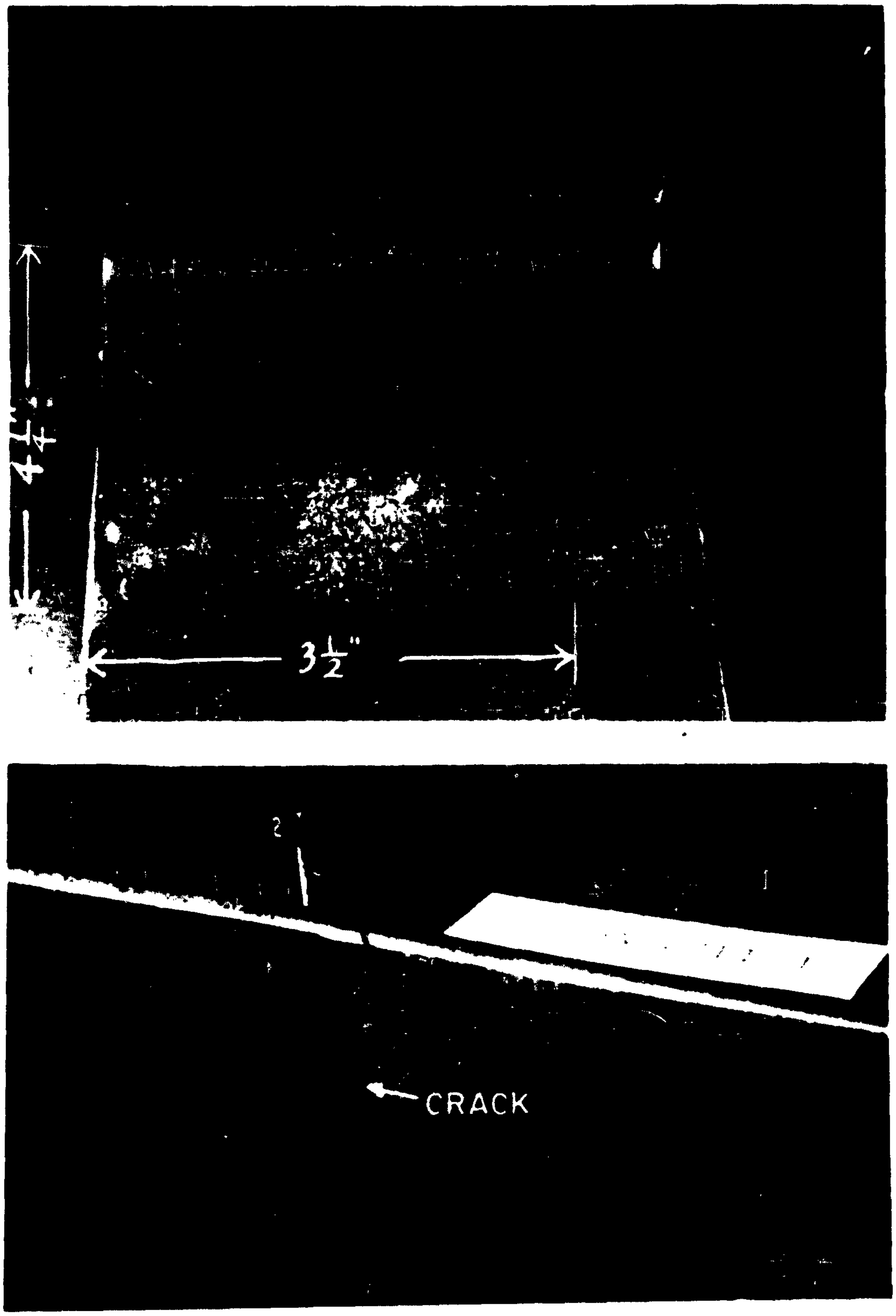


Figure 33 – Ground and Shot Peened Section - Fracture in HY-80 Steel

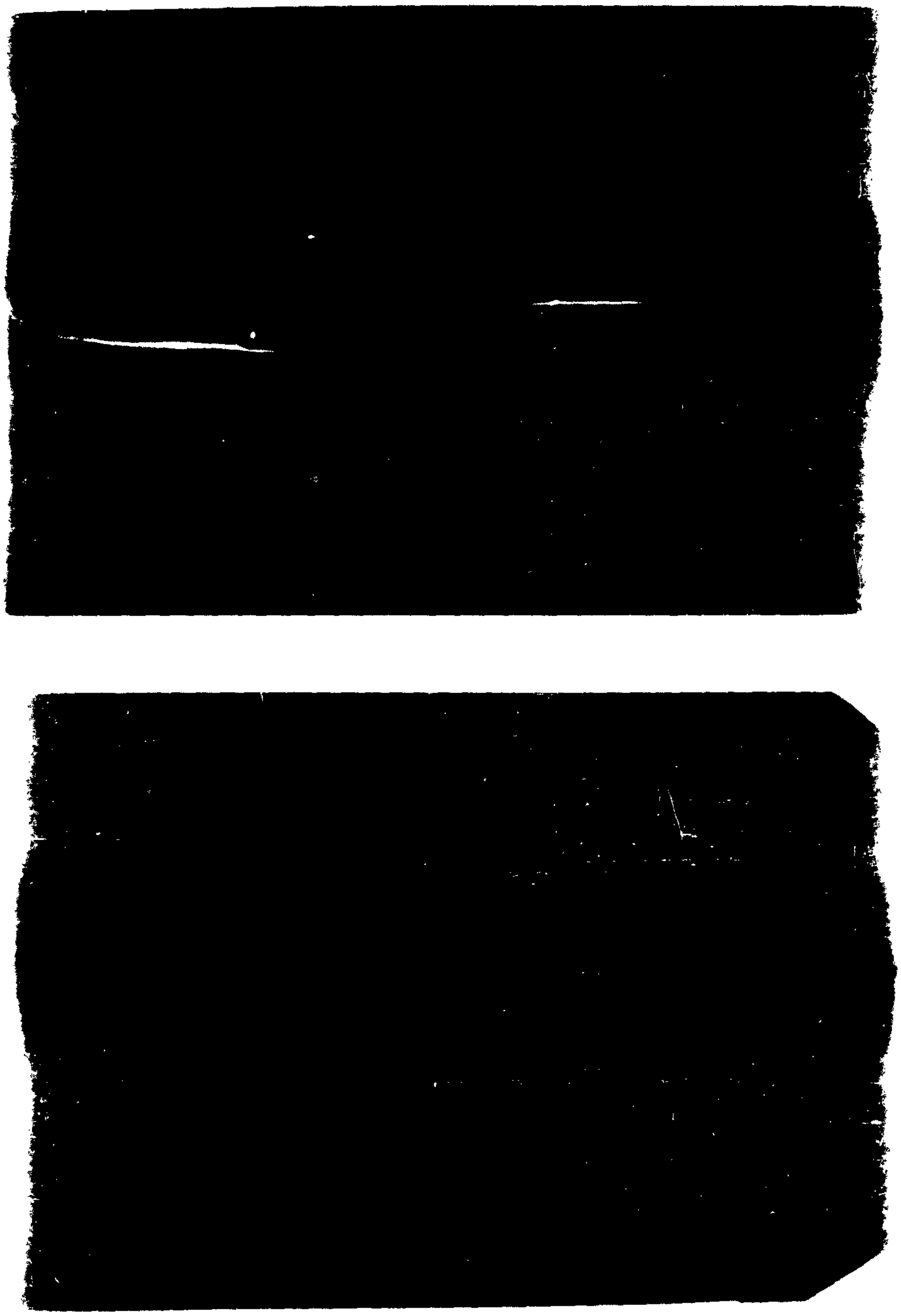


Figure 34 – Radiographs Of Butt Welds After Beam Fatigue Tests

REPORT OF SEMI-AUTOMATIC INERT GAS METAL ARC WELDING HY-80 STEEL OUT-OF-POSITION

by
L. ROBBINS, MARE ISLAND NAVAL SHIPYARD

I. ABSTRACT

Numerous techniques for out-of-position welding with the Inert Gas Metallic Welding Process have been proposed and evaluated in the past for application to HY-80 submarine structures. Early work was confined to use of small diameter wire 0.030 to 0.035-inch diameter, using an extremely short arc, commonly called dip transfer or short arc technique. Argon-Carbon Dioxide gas mixtures were used with the process. The efforts to date, have been unsuccessful, due to the inability of the welded joints to produce adequate toughness under explosion bulge testing. Cold shuts were believed to be the principle cause of failure. This investigation involved the evaluation of the same process using larger diameter wire to overcome the propensity for depositing welds with cold shuts.

Three conditions or welding procedures, as outlined below, were selected for evaluation on one-inch thick HY-80 plating:

Condition No. 1 - Four beads to complete the weld using 1/16-inch diameter electrode.

Condition No. 2 - Four beads to complete the weld using 1/16-inch diameter electrode in the root and 0.045-inch diameter electrode for the cover passes.

Condition No. 3 - Six passes to complete the weld using 1/16-inch diameter electrode in the root and 0.045-inch diameter electrode for the remaining passes.

One butt welded plate was prepared using each condition described above. These plates were examined by radiography and then dissected and prepared into drop weight test specimens. Nil-ductility transition temperature of the deposited weld metal resulting from each condition was determined by drop weight testing.

Condition No. 1 which produced the most desirable nil-ductility transition was used in preparing a butt welded joint for transverse full thickness, reduced section tensile tests and charpy "V" notch impact tests.

Evaluation of the results of the tests described above indicated that the welding procedure, Condition No. 1, was adaptable to submarine fabrication and produced welds in HY-80 plating that were within the general Bureau of Ships requirements.

Six butt welded plates suitable for explosion testing were prepared using welding procedure Condition No. 1 to evaluate the combined performance of weld, heat affected and fusion zone and base metal. Tensile and bend tests were satisfactory. Drop weight and charpy "V" notch tests of the weld metal were also satisfactory, although somewhat lower than normally expected. Explosion bulge tests revealed unsatisfactory performance of the joint. Brittle HAZ failure was experienced with most of the plates when tested at 0°F.

II. INTRODUCTION

The object of this investigation is to evaluate new procedures and techniques developed by Air Reduction Company for semi-automatic inert gas (Metallic Inert Gas) welding processes for making welds on HY-80 steel in the vertical position.

Welding was accomplished working in conjunction with Air Reduction Company representatives and welding techniques employed were those recommended by Air Reduction Company.

This novel technique was intended to overcome the propensity for depositing welds with small cold shuts, experienced with the small diameter electrode. The evaluation was to include a determination of the soundness of the weld by radiographic examination and the physical conditions of the welded joint as revealed by the various methods of destructive testing. Side bend tests were to be made along with tensile tests to determine the adequacy of the welded joints to meet strength and ductility requirements for submarine applications. Charpy "V" notch impact properties would be required for the as-deposited weld metal for evaluation of notch toughness. The weld metal would also be evaluated for the transition temperature from ductile to brittle behavior in the presence of a notch by drop weight tests. The final phase of the investigation would employ the explosion bulge and explosion bulge crack starter tests to evaluate the combined performance of the weld metal, fusion and heat affected zone and base metal.

III. MATERIALS

The HY-80 steel plate for this investigation was obtained from Shipyard stock and represented standard plating for submarine construction conforming to the requirements of Military Specification MIL-S-16216. A chemical analysis was made on each heat for the plates used for all tests and found to conform to the specification requirements. Table 1 includes the analysis of the plates used for these tests.

TABLE 1

ELEMENT	Plates B-3 to B-6, Inclusive PERCENT COMPOSITION	Plates B-1, B-2, J-1 & C-2 PERCENT COMPOSITION
Carbon	0.15	0.13
Manganese	0.20	0.17
Phosphorus	0.011	0.008
Sulfur	0.011	0.024
Silicon	0.19	0.22
Chromium	1.23	1.11
Nickel	2.20	2.07
Molybdenum	0.30	0.34

The electrode used for the tests was obtained from standard stock and conformed to the requirements of Military Specification MIL-E-19822.

The chemical analysis for the electrode is shown in Table 2.

TABLE 2

ELEMENT	PERCENT CONTENT
Carbon	0.07
Manganese	1.33
Phosphorus	<0.005
Sulfur	0.012
Silicon	0.52
Nickel	1.31
Molybdenum	0.46
Vanadium	0.17

Carbon Dioxide gas welding grade was used for all tests. Argon gas was obtained from standard stock. An analysis confirmed conformity to the requirements of Military Specification MIL-A-18455.

IV. PROCEDURE

Preliminary Testing and Test Results.

A number of practice butt joints were welded to familiarize the Mare Island welders with the Air Reduction Company recommended welding techniques and the arc characteristics of the 1/16-inch diameter electrode.

The equipment and data listed below was common to all welds made in this test program.

Welding Power Source - 450 Amp Aircomatic Fillerarc full wave rectifier conditions:

1. Reactor Position - Low
2. Hot Start - On
3. Rise Selector - Off
4. Arc Length Setting - 3-4
5. Current - D.C.R.P.

Welding Torch - Aircomatic Model AH35-A Pull Gun and Controls.

Cooling - Airco water circulator.

Torch Contact Tubes - 1/16-inch and 0.045-inch standard four-inch long.

Torch Gas Nozzle - 5/8-inch diameter.

Argon Gas Regulator - Two stage with dual range flow meter.

Carbon Dioxide Gas Regulator - Single stage with dual range flow meter.

Gas Mixing - Shielding gas mixing was accomplished by a "Y" connection in the line.

Bevel Preparation - Bevel preparation was accomplished by machine planing and planed surfaces were cleaned prior to welding by vacu-blasting with steel grit.

Tack Welding - Tack welds were deposited using a bridge technique and were ground out during welding so as not to be incorporated in the final weld. Plates were preheated to 150°F minimum prior to tack welding and tacks were approximately one-inch long and spaced on approximately six-inch centers.

Preheating - All preheating was accomplished using an oxygen-acetylene torch with a multi-flame heating tip.

Temperature Control - Preheat and interpass temperature determination was accomplished by use of surface pyrometers and temperature indicating crayons.

Physical Testing - All physical tests reported herein were accomplished on plates in the as-welded condition. No stress relieving was done.

Backgrinding - The back side or root of the first pass was background to sound metal prior to depositing the first pass on the second side of the joint.

V. RESULTS OF TEST

After sufficient practice three 35-inch long butt joints were prepared using joint design as shown in Figure 1 and welding procedures as shown in Figures 2, 3 and 4. On completion of welding the three welded butt joints were examined by radiography and met the density requirements of Group 2 of NAVSHIPS 250-692-2. With satisfactory radiographic results each plate was dissected into nine 3-1/2" x 14" x 1" drop weight specimens. Results of drop weight testing are shown on Figures 5, 6 and 7.

Welding procedure, Condition No. 1, had the lowest nil-ductility transition temperature (see Figure 5). Therefore, it was decided to prepare an additional plate for physical tests using welding procedure, Condition No. 1, as outlined on Figure 2. One 18-inch long butt joint was welded and examined by radiography and met the density requirements of Group 2 of NAVSHIPS 250-692-2. Transverse, full thickness, reduced section tensile specimens were prepared from this plate and test results were as shown in Table 3. The tensile properties are transverse to the weld. The reduced cross section for the specimens was one-inch thick by one-one-half-inches wide. The fractures occurred in the base metal, revealing overmatch of the strength level by the weld. There were no abnormalties in the specimens and the welds revealed no surface defects or cracks after fracture. The necking down and fracture was located in the unaffected base metal. Side bend tests were removed from the same plate and bent 180 degrees over a 3/4-inch radiused mandrel. Examination of the bent specimens did not reveal any unacceptable flaws. The charpy "V" notch impact properties of the weld met the 20-foot pound minimum criterion at -60 F. Based on these results, plates of suitable size were prepared for explosion bulge tests. Two comparison test plates were also made with the 11018 and B-88 electrodes using standard Shipyard practices. This was considered advisable to assure that explosion bulge test practices agreed with the standards offered by Naval Research Laboratory. The conditions of welding vertically for for three plates prepared for the explosion bulge test are shown in Table 4.

The preheat and interpass temperatures are within the maximum limits specified for welding HY-80 structures. The heat input as measured by joules per inch exceeds the 60,000 maximum specified for Shipyard practices for one-inch low chemistry plate.

The conditions of welding for the three plates prepared for the explosion bulge crack starter tests are shown in Table 5. Here again it is noted that the heat inputs are high.

Table 6 shows the condition of welding for the 11018 and B-88 electrode welded plates prepared for explosion bulge tests. The welding conditions for these plates for preheat, interpass temperature and heat input were within the specified tolerances for Shipyard practices.

All plates for explosion bulge testing were undercooled to -3°F and held for one hour at temperature. Cooling was done in a tank with the plate completely immersed in the liquid solvent. All the plates were blasted at 0°F, using a four-pound C-3 composition. The elapsed time between removal of the plates from the cooling tank to blast was 30 to 40 seconds.

The photograph of Plate B1 shows brittle failure occurred in the HAZ with a single blast for nearly the entire length of the weld. This failure is typical for HAZ degradation caused by improper thermal quenching.

The photograph of Plate B2 shows the results of the explosion bulge test with brittle failure occurring in the HAZ on both sides of the weld. Tearing also occurred in the base plate on either side of the weld for a short distance. The tearing in the base plate exhibited shear ductile behavior. Two blasts were necessary to produce failure.

The photograph of Plate B3 shows failure again occurring in the HAZ. However, in this case the failure was located in the area of least strain. The longest crack was about two-inches and the shorter crack about 1/4-inch in length and located on either side of the bulge apex. Two blasts were necessary to produce the first evidence of failure.

The photograph of Plate C2 shows the results of three blasts with the plate showing no evidence of failure. In this case, the level of strain as measured by thickness reduction at the peak of the bulge was a little over eight percent. This is indicative of the excellent performance of properly welded HY-80 plating. This is the plate welded with 11018 electrodes.

The photograph of Plate J1 is another example of excellent performance of welded HY-80 plate. This plate was also blasted three times with the weldment showing no failure. The measured level of strain at the peak of the bulge for this plate was over nine percent. In comparison, with plates B1 to B3 inclusive, it is significant to note that the strain level was not nearly as great and in one plate no measurable strain was observed. Both of the vertically welded plates, failure occurred at the measured strain level.

The next series of explosion tests were conducted on Plates B4 to B6, inclusive, using the crack starter for crack initiation.

The photograph of Plate B4 shows the results of crack starter test for the first plate in this series. Failure occurred to almost the full depth of the weld and stopped on either side near the edge of the weld in the base metal.

The photograph of Plate B-5 shows failure again extended for the full depth of the weld under the notch. In this case, however, the crack propagated in an apparent weak HAZ. The beginning of a failure in the HAZ on the opposite side was noted and extended a fraction of an inch on both sides of the transverse fracture.

The photograph of Plate B-6 shows the results of the last plate in this series of tests. Failure again occurred almost to the full depth of the weld. The crack propagated into the base metal on either side for about 1, 4-inch beyond the toe of the weld. As pointed out in previous papers by Puzak and Pellini, superposing a crack-starter weld at the center of the bulge test sample, the test is made selective to the plate. The severity of the test conditions for the weld and HAZ are decreased and those of the plate increased. This factor must be considered in evaluating the performance of the welded plates with the crack-starter welds.

VI. DISCUSSION AND CONCLUSIONS

Reviewing the results reported herein, it is significant to note that a good deal of improvement over previous techniques for out-of-position Metallic Inert Gas Welding has been achieved. The tendency for depositing welds with lack of fusion defects has been overcome with this novel welding technique. The static strength of welded joints satisfies the requirements for joining HY-80 steel by this method for the low chemistry plate. It would be expected that similar results would be obtained for the high chemistry or heavier plating. Degradation of the heat affected zone is very pronounced and is exhibited in most of the plates tested by explosion bulging. From the later results it is concluded that the process will not produce welds which will satisfy the performance requirements for submarine applications. However, there appears to be two avenues open for further investigation. It is entirely possible that satisfactory HAZ performance may be obtained in the high chemistry plating due to the greater hardenability. By preparing two-inch thick HY-80 plates and using the same series of tests reported herein, the use of this process for the high chemistry material can be evaluated by comparison with existing standards. The second proposal, would be to investigate the use of 0.045 to 0.050-inch diameter wire by endeavoring to reduce the heat input by use of smaller weld sizes. Preliminary, but limited work indicates this approach holds excellent possibilities.

WELDING ENGINEERING BRANCH
MARE ISLAND NAVAL SHIPYARD

JOINT DESIGN

FOR

VERTICAL METALLIC INERT GAS WELDING

USING

ARGON AND CARBON DIOXIDE SHIELDING GAS

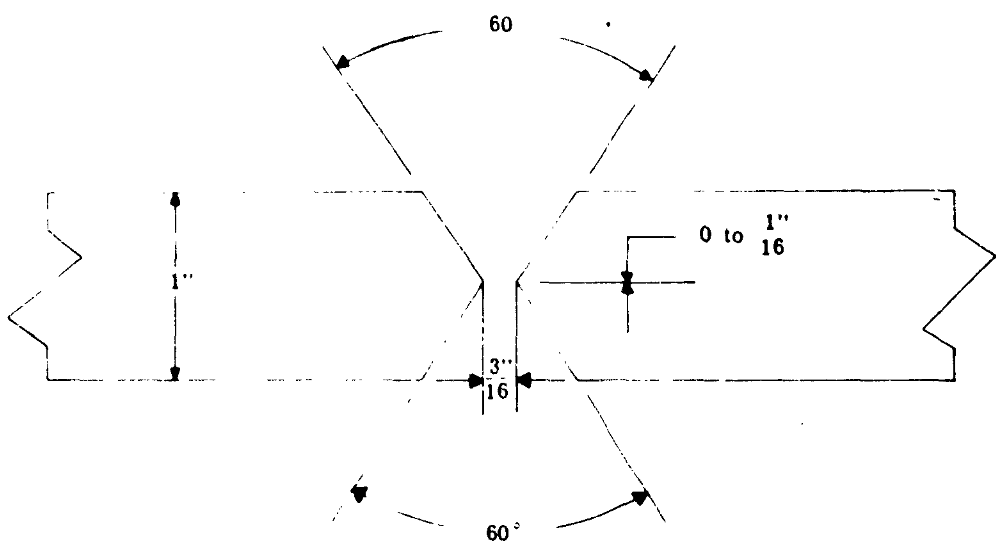


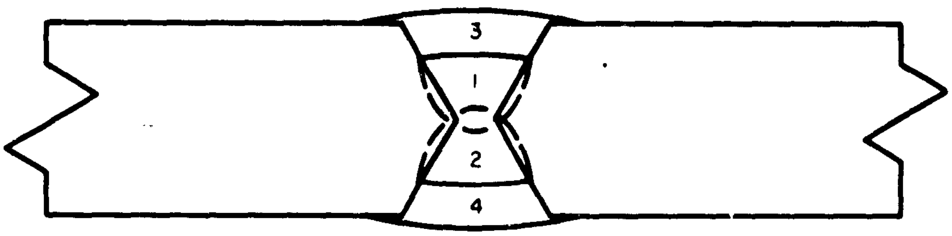
FIGURE 1

WELDING ENGINEERING BRANCH
MARE ISLAND NAVAL SHIPYARD

DROP WEIGHT TEST PLATE NO. 1

WELDING PROCEDURE

CONDITION NO. 1



PASS SEQUENCE

Base Metal: HY-80 Lukens Ht. No. 22291-4

Welding Electrode: Airco Ht. No. 8X1313

Preheat Temperature: 200°F

Welding Interpass Temperature: 200°F - 300°F

OPERATIONAL DATA

Pass No.	Welding Current Amps	Welding Current Volts(Arc)	Travel Speed IPM	Electrode Feed Speed IPM	Electrode Diameter Inch	Energy Input Joules/inch
1	175	19	1.8	92	1/16	111,000
2	175	19	1.85	92	1/16	108,000
3	175	19	2.0	92	1/16	99,500
4	175	19	1.85	92	1/16	108,000

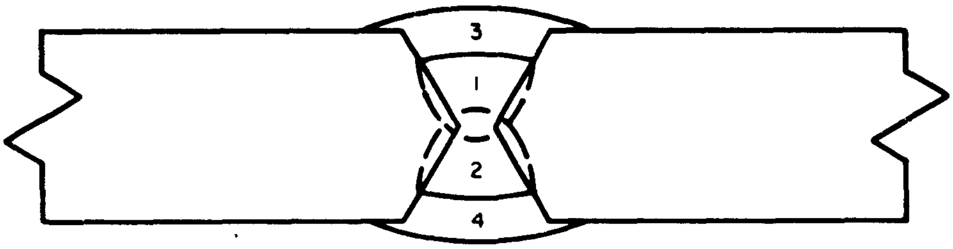
FIGURE 2

WELDING ENGINEERING BRANCH
MARE ISLAND NAVAL SHIPYARD

DROP WEIGHT TEST PLATE NO. 3

WELDING PROCEDURE

CONDITION NO. 2



PASS SEQUENCE

Base Metal: HY-80 Lukens Ht. No. 22291-4

Welding Electrode: Airco 1/16-inch Diameter Ht. No. 8X1313,
0.045-inch Diameter Ht. No. X10161

Preheat Temperature: 200°F

Welding Interpass Temperature: 200°F - 300°F

OPERATIONAL DATA

Pass No.	Welding Current		Travel Speed IPM	Electrode Feed Speed IPM	Electrode Diameter Inch	Energy Input Joules/inch
	Amps	Volts(Arc)				
1	175	19	1.4	94	1/16	142,000
2	175	19	1.9	94	1/16	104,000
3	175	18.5	2.4	200	0.045	82,000
4	175	18.5	2.3	200	0.045	84,000

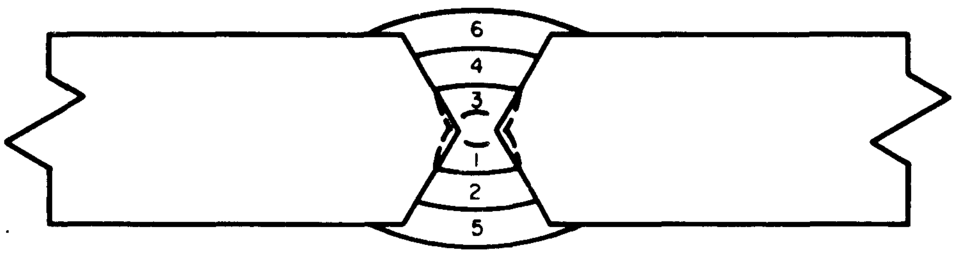
FIGURE 3

WELDING ENGINEERING BRANCH
MARE ISLAND NAVAL SHIPYARD

DROP WEIGHT TEST PLATE NO. 3

WELDING PROCEDURE

CONDITION No. 3



PASS SEQUENCE

Base Metal: HY-80 Lukens Ht. No. 22291-4

Welding Electrode: Airco 1/16-inch Diameter Ht. No. 8X1313,
0.045-inch Diameter Ht. No. X10161

Preheat Temperature: 200 F

Welding Interpass Temperature: 200 F - 300 F

OPERATIONAL DATA

Pass No.	Welding Current Amps	Welding Current Volts(Arc)	Travel Speed IPM	Electrode Feed Speed IPM	Electrode Diameter Inch	Energy Input Joules/Inch
1	145	19	2.1	84	1/16	79,000
2	155	18.5	3.3	84	1/16	53,000
3	155	18.5	2.9	84	1/16	59,500
4	155	18.5	3.2	84	1/16	54,000
5	175	18.5	2.5	200	0.045	78,000
6	175	18.5	3.4	200	0.045	82,000

FIGURE 4

WELDING ENGINEERING BRANCH
MARE ISLAND NAVAL SHIPYARD

DROP WEIGHT TEST RESULTS

PLATE NO. 1

WELDING PROCEDURE *

CONDITION NO. 1

Drop Weight Specimen Size: 1" x 3-1/2" x 14"

Cooling Bath: Michie Sludge Test Solvent

Coolant: Carbon Dioxide (dry ice) and Liquid Nitrogen

Hammer Drop Height: 13-feet

Impact Load: 1,140 foot pounds

Legend

X - Break

0 - No break

Note: Number over "X" or "0" indicates drop No.

TEST TEMPERATURE - °F

-90	-80	-70	-60	-50
5/X	6/X	3/0	1/0	
	7/0	4/0	2/0	
	8/X			

Nil-Ductility Transition Temperature: -80°F

FIGURE 5

WELDING ENGINEERING BRANCH
MARE ISLAND NAVAL SHIPYARD

DROP WEIGHT TEST RESULTS

PLATE NO. 2

WELDING PROCEDURE

CONDITION No. 2

Drop Weight Specimen Size: 1" x 3-1 2" x 14"

Cooling Bath: Michie Sludge Test Solvent

Coolant: Carbon Dioxide (dry ice) and Liquid Nitrogen

Hammer Drop Height: 13-feet

Impact Load: 1,140 foot pounds

Legend

X - Break

0 - No break

Note: Number over "X" or "0" indicates drop No.

TEST TEMPERATURE - °F

-90	-80	-70	-60	-50
	1 X		2 X	3 0
			5 X	4 0

Nil-Ductility Transition Temperature: -60°F

FIGURE 6

WELDING ENGINEERING BRANCH
MARE ISLAND NAVAL SHIPYARD

DROP WEIGHT TEST RESULTS

PLATE NO. 3

WELDING PROCEDURE

CONDITION NO. 3

Drop Weight Specimen Size: 1" x 3-1/2" x 14"

Cooling Bath: Michie Sludge Test Solvent

Coolant: Carbon Dioxide (dry ice) and Liquid Nitrogen

Hammer Drop Height: 13-feet

Impact Load: 1,140 foot pounds

Legend

X - Break

0 - No break

Note: Number over "X" or "0" indicates drop No.

TEST TEMPERATURE - °F

-90	-80	-70	-60	-50
		1 X	5 X	3, 0
		2 X	6 X	4, 0

Nil-Ductility Transition Temperature: -60°F

FIGURE 7

WELDING ENGINEERING BRANCH
MARE ISLAND NAVAL SHIPYARD

PHYSICAL PROPERTIES OF WELDED BUTT JOINT

TRANSVERSE FULL THICKNESS REDUCED SECTION TENSILE TESTS. (WELD ORIENTED AT THE MID POINT OF THE REDUCED SECTION)

PHYSICAL PROPERTIES	TEST RESULTS TEST NO. 1	TEST NO. 2
YIELD STRENGTH (DROP OF BEAM), PSI	86,000	85,200
ULTIMATE TENSILE STRENGTH, PSI	98,900	96,500
ELONGATION IN 2-INCH, %	42.5	45.0
LOCATION OF FRACTURE	PARENT METAL	PARENT METAL

SIDE BENDS. (180° OVER A 3/4-INCH RADIUS MANDREL)

SPECIMEN NUMBER	BEND TEST RESULTS
1	NO CRACKS
2	NO CRACKS
3	NO CRACKS
4	NO CRACKS

CHARPY "V" NOTCH IMPACT TEST. (NOTCHES LOCATED ON THE WELD CENTER LINE, ORIENTED PARALLEL TO THE FINISHED SURFACE OF THE WELD)

SPECIMEN NUMBER	FRACTURE TEMP. °F	ENERGY ABSORBED FOOT POUNDS
1	+70	62
2	+70	63
3	+30	57
4	+30	60
5	0	52
6	0	51
7	-30	34
8	-30	38
9	-60	31
10	-60	29
11	-100	26
12	-100	27

TABLE 3

SEQUENCE AND OPERATIONAL DATA

BASE METAL PLATING: ONE-INCH THICK HY-80, LUKENS HEAT NO. 22291-4

ELECTRODE: AIRCO HEAT NO. 8X1313

PREHEAT TEMPERATURE: 200°F

INTERPASS TEMPERATURE: 200°F - 300°F

SHIELDING GAS: 20 C.F.H. ARGON, 5 C.F.H. CARBON DIOXIDE

OPERATIONAL DATA PLATE B-1

PASS NO.	WELDING CURRENT AMPS	WELDING CURRENT VOLTS (ARC)	TRAVEL SPEED IPM	ELECTRODE FEED SPEED IPM	ELECTRODE DIAMETER INCH	ENERGY INPUT JOULES/INCH
1	175	19	1.7	100	1/16	117,000
2	175	19	2.3	100	1/16	87,000
3	175	19	2.1	100	1/16	94,000
4	175	19	1.7	100	1/16	116,000

OPERATIONAL DATA PLATE B-2

PASS NO.	WELDING CURRENT AMPS	WELDING CURRENT VOLTS (ARC)	TRAVEL SPEED IPM	ELECTRODE FEED SPEED IPM	ELECTRODE DIAMETER INCH	ENERGY INPUT JOULES/INCH
1	175	19	1.7	100	1/16	117,000
2	175	19	2.3	100	1/16	87,000
3	175	19	2.0	100	1/16	102,000
4	175	19	2.2	100	1/16	89,000

OPERATIONAL DATA PLATE B-3

PASS NO.	WELDING CURRENT AMPS	WELDING CURRENT VOLTS (ARC)	TRAVEL SPEED IPM	ELECTRODE FEED SPEED IPM	ELECTRODE DIAMETER INCH	ENERGY INPUT JOULES/INCH
1	175	19	1.71	100	1/16	111,800
2	175	19	2.05	100	1/16	98,000
3	175	19	2.2	100	1/16	91,000
4	175	19	2.1	100	1/16	95,000

TABLE 4

SEQUENCE AND OPERATIONAL DATA

BASE METAL PLATING: ONE-INCH THICK HY-80, LUKENS HEAT NO. 22291-4

ELECTRODE: AIRCO HEAT NO. 8X1313

PREHEAT TEMPERATURE: 200°F

INTERPASS TEMPERATURE: 200°F - 300°F

SHIELDING GAS: 20 C.F.H. ARGON, 5 C.F.H. CARBON DIOXIDE

OPERATIONAL DATA PLATE B-4

PASS NO.	WELDING CURRENT		TRAVEL SPEED IPM	ELECTRODE FEED SPEED IPM	ELECTRODE DIAMETER INCH	ENERGY INPUT JOULES/INCH
	AMPS	VOLTS (ARC)				
1	175	19	1.5	100	1/16	113,000
2	175	19	2.35	100	1/16	86,000
3	175	19	2.05	100	1/16	97,000
4	175	19	1.80	100	1/16	111,200

OPERATIONAL DATA PLATE B-5

PASS NO.	WELDING CURRENT		TRAVEL SPEED IPM	ELECTRODE FEED SPEED IPM	ELECTRODE DIAMETER INCH	ENERGY INPUT JOULES/INCH
	AMPS	VOLTS (ARC)				
1	175	19	1.7	100	1/16	111,800
2	175	19	2.	100	1/16	100,000
3	175	19	2.05	100	1/16	97,000
4	175	19	2.25	100	1/16	89,000

OPERATIONAL DATA PLATE B-6

PASS NO.	WELDING CURRENT		TRAVEL SPEED IPM	ELECTRODE FEED SPEED IPM	ELECTRODE DIAMETER INCH	ENERGY INPUT JOULES/INCH
	AMPS	VOLTS (ARC)				
1	175	19	1.89	100	1/16	103,500
2	175	19	2.49	100	1/16	81,000
3	175	19	2.15	100	1/16	92,000
4	175	19	1.82	100	1/16	104,000

TABLE 5

PROCESS: METALLIC INERT GAS AUTOMATIC

BASE METAL PLATING: ONE-INCH THICK HY-80, LUKENS HEAT NO. 23546-3

ELECTRODE: AIRCO HEAT NO. 8X1312

PREHEAT TEMPERATURE: 150°F

INTERPASS TEMPERATURE: 200°F

SHIELDING GAS: 50 C.F.H. ARGON, 2% OXYGEN

OPERATIONAL DATA PLATE NO. J-1

PASS NO.	WELDING CURRENT		ELECTRODE DIAMETER INCH	ENERGY INPUT JOULES/INCH
	AMPS	VOLTS (ARC)		
1-6	340	30	1/16	50,000

PROCESS: MANUAL ARC

BASE METAL PLATING: ONE-INCH THICK HY-80, LUKENS HEAT NO. 23253-6

ELECTRODE: MIL-11018

PREHEAT TEMPERATURE: 150°F

INTERPASS TEMPERATURE: 300°F MAXIMUM

OPERATIONAL DATA PLATE NO. C-2

PASS NO.	WELDING CURRENT		ELECTRODE DIAMETER INCH	ENERGY INPUT JOULES/INCH
	AMPS	VOLTS (ARC)		
1-14	185-195	22-1/2	5/32	50,000 - 60,000

TABLE 6

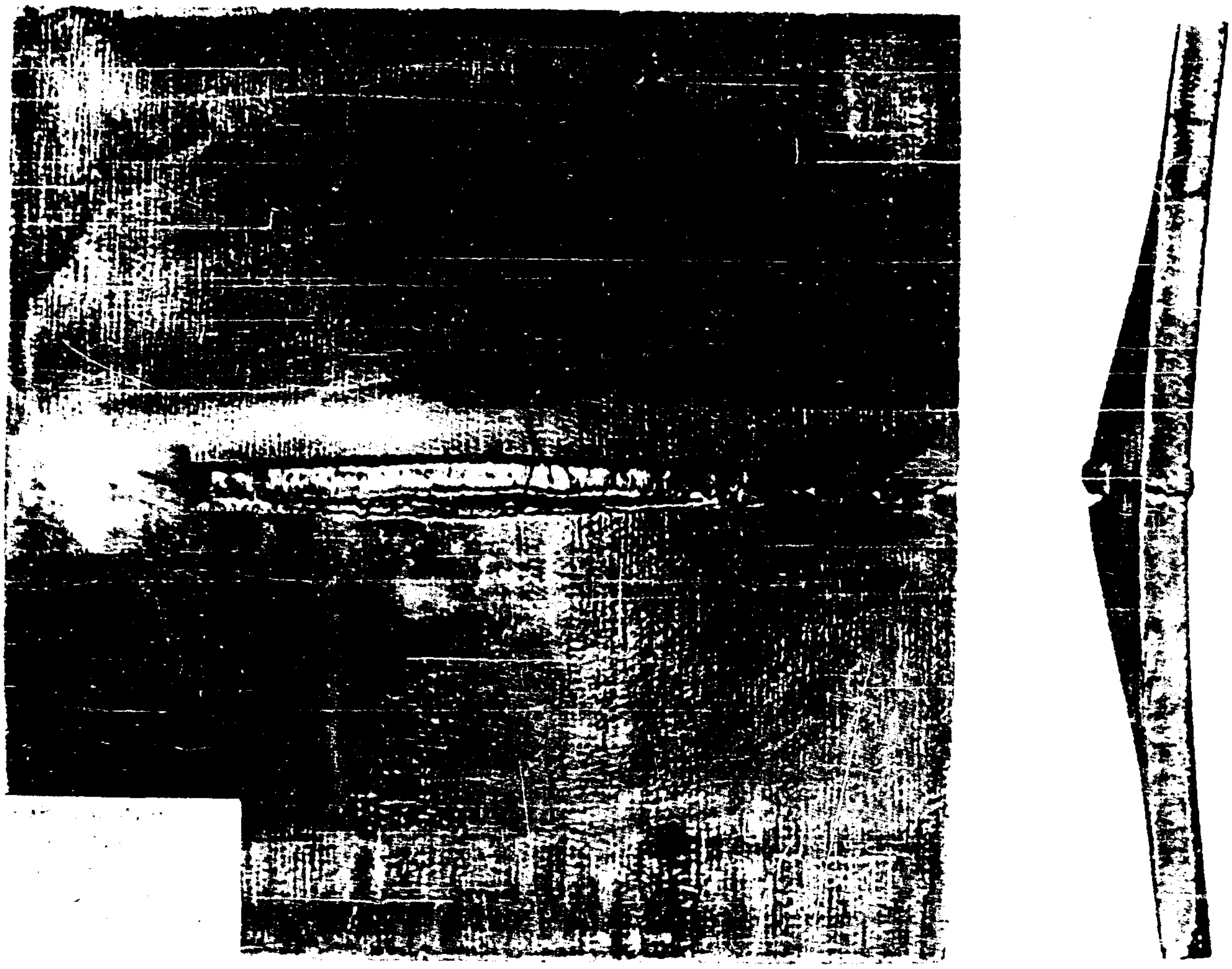


Figure 8 — Explosion Bulge Plate No. - B-1 One Shot. Failure .062" Dia.-B-88 Airco M.I.G. Pull Gun Vert. Pos.

Figure 9 – Explosion Bulge Plate No. B-2 Two Shot, Failure .062" Dia. - B-88 Airco M.I.G. Pull Gun Vert. Pos.

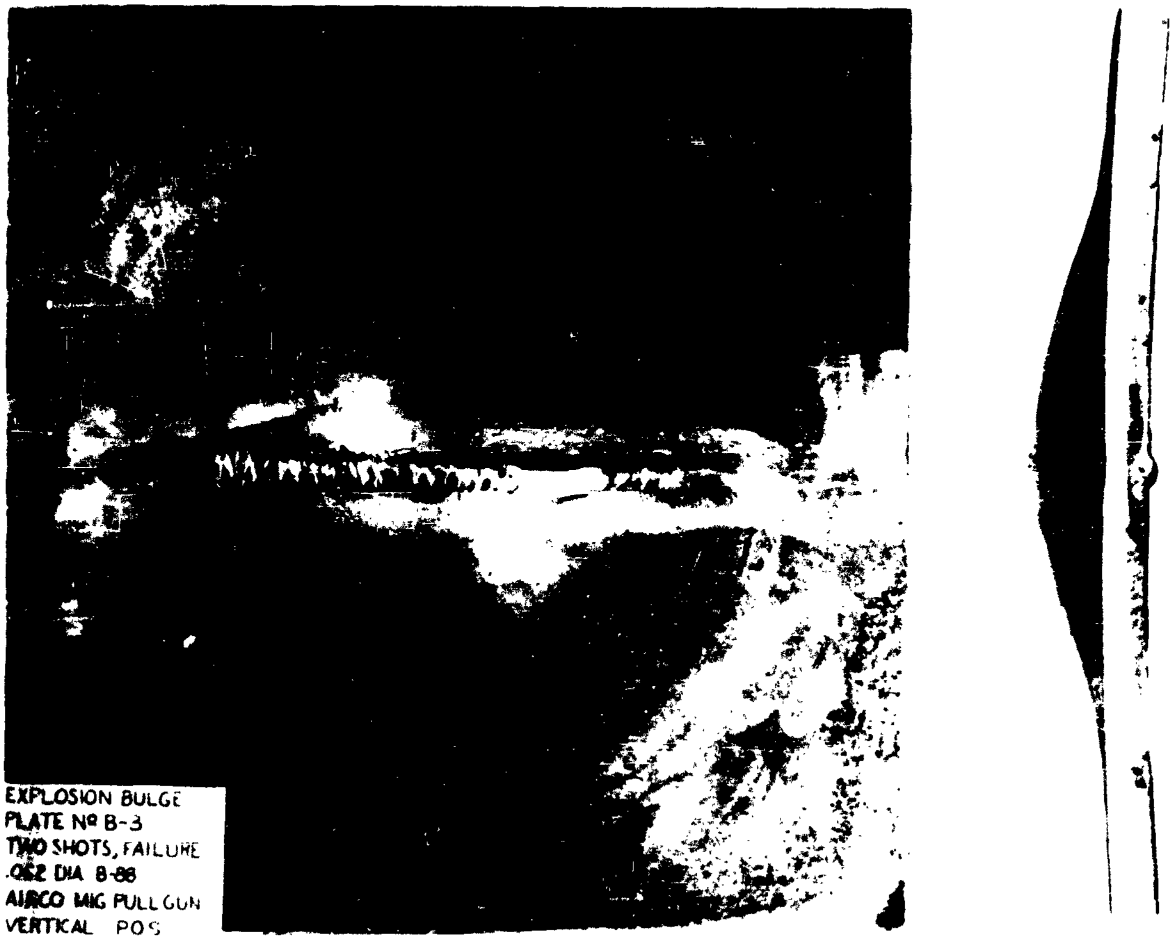


Figure 10 – Explosion Bulge Plate No. B-3 Two Shots, Failure .062 Dia. B-88 Airco M.I.G. Pull Gun Vertical Pos.

Figure 11 — Explosion Bulge Plate No. C-2 Three Shot, - No Failure 5/32" Dia. MIL-110-18 Flat Pos.

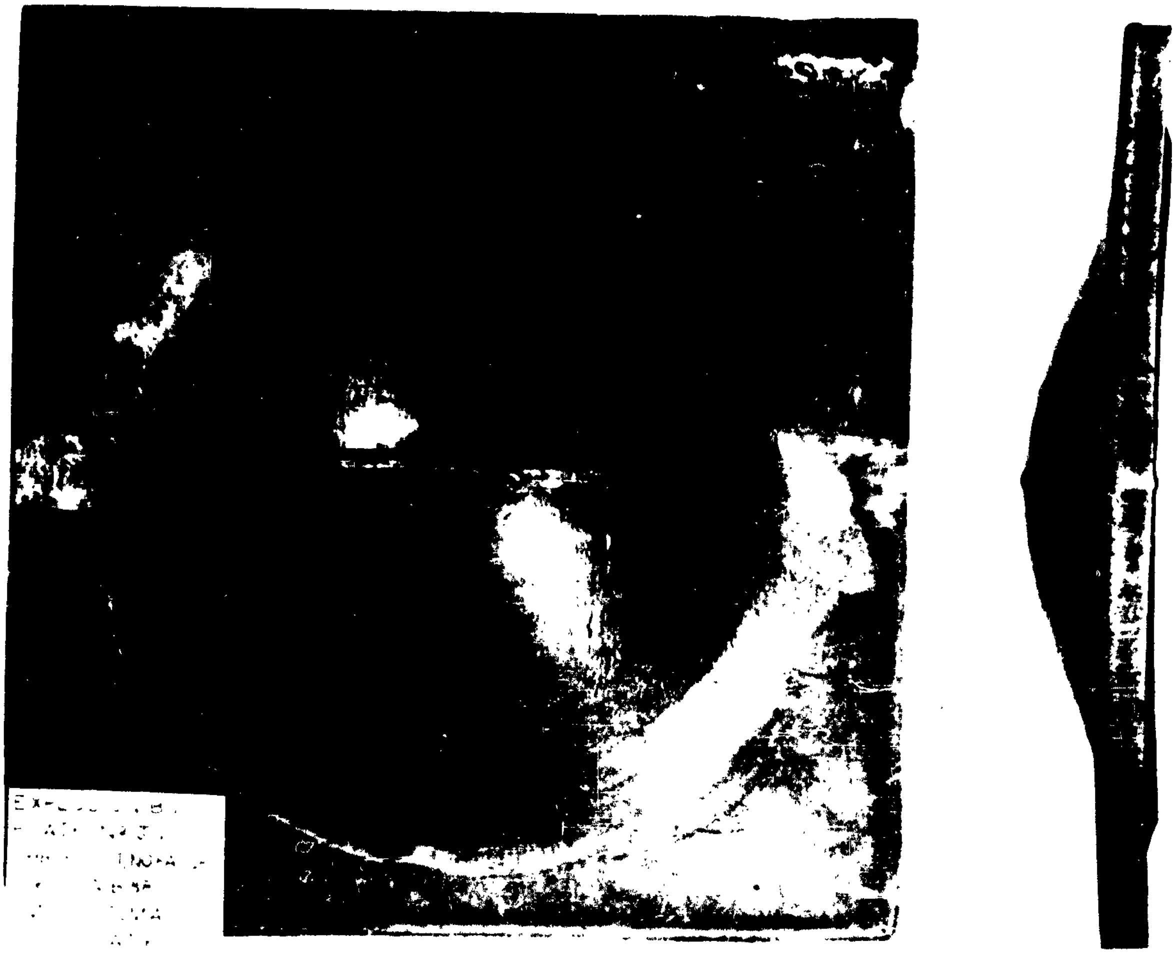


Figure 12 – Explosion Bulge Plate No.-J-1 Three Shot, No Failure .062" Dia. B-88 M.I.G. Automatic Flat Pos.

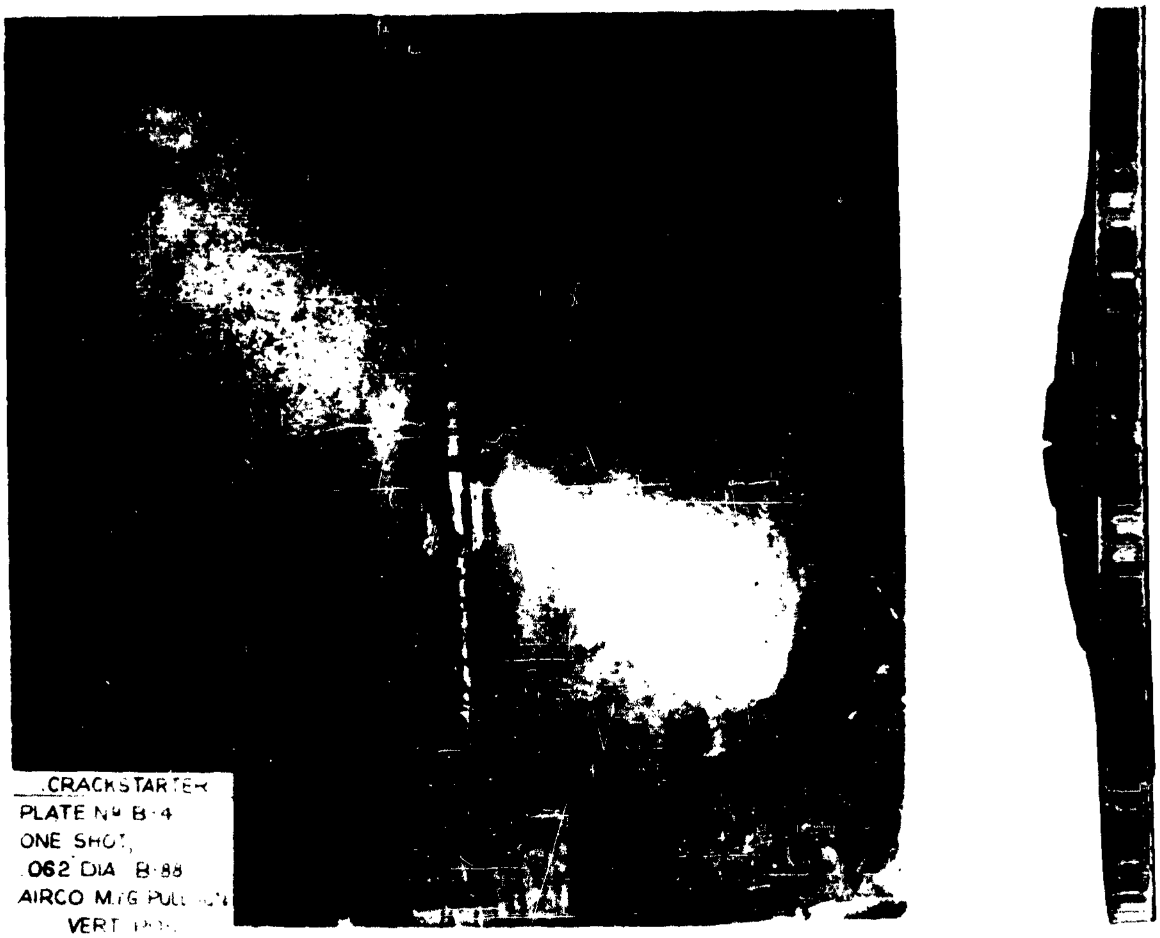


Figure 13 – Crackstarter Plate No. B-4 One Shot, .062" Dia. B-88 Airco M.I.G. Pull Gun Vert. Pos.

Figure 15 – Crackstarter Plate No. B-5 One Shot, .062" Dia. B-88 Airco M.I.G. Pull Gun Vert. Pos.

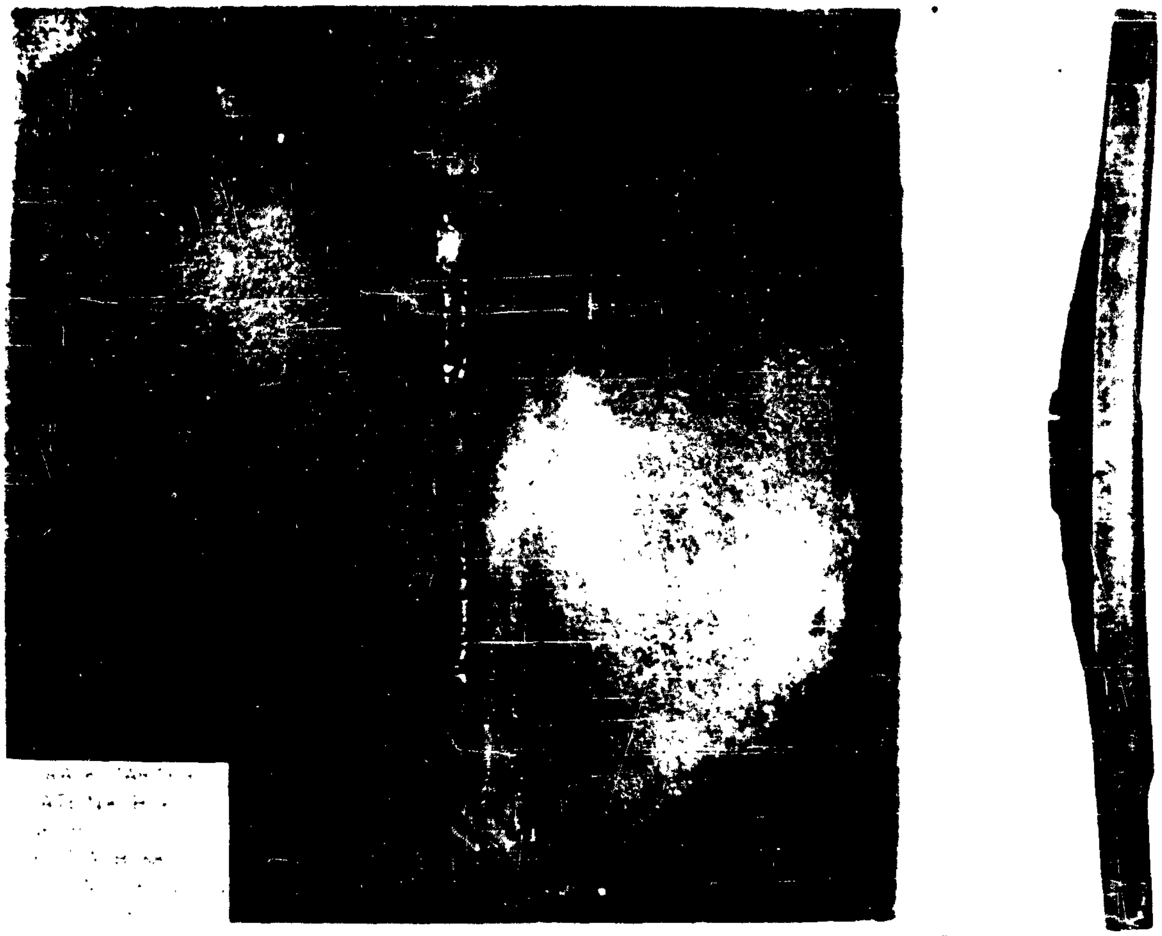


Figure 16 – Crackstarter Plate No. B-6 One Shot, .062" Dia. B-88 Airco M.I.G. Pull Gun Vert. Pos.

THE APPLICATION OF PREHEAT TO SUBMARINE CONSTRUCTION

by

F. Daly, Newport News Shipbuilding & Drydock Co.

The need for preheat in the welding of alloy steels is a well recognized fact, familiar to all fabricators who have dealt with such materials in the pressure vessel or Naval marine construction fields.

The level of preheat required for individual applications of the various alloy steels is a matter upon which agreement is much less general. This is particularly true of the quenched and tempered steels which are usually employed in the as-welded condition and thus are highly dependent upon proper thermal treatment during welding for the degree to which their original toughness remains after welding.

In the application of preheat to submarine construction using HY-80 steel, we are faced with a very basic problem. Stated simply it is this: We must preheat to a level sufficiently high to avoid cracking without exceeding an empirically established maximum preheat value beyond which the toughness of the HY-80 steel will be impaired.

At the outset, it should be understood that this problem is surmountable although it is difficult to live with.

The nature of the problem may best be illustrated by stating that the generally accepted minimum preheat temperature for welding HY-80 steel, over 1" thick with MIL-11018 electrodes, is 200 F. The maximum allowable preheat temperature is 300° F. Since the maximum allowable interpass temperature is also 300° F, it is evident that the temperature rise due to welding must be carefully watched to avoid encroaching on the maximum interpass temperature requirement when the preheat temperature is at or much in excess of 200° F. To clarify the concept of interpass temperature, it may be defined as: The temperature of the previously deposited weld metal at the point where a succeeding weld bead will start. With this background it becomes apparent that the fabricator is working within narrow limits indeed. Admittedly the lower limit, that of preheat, is one he has chosen but his choice has been forced upon him by the requirements of the material with which he is working.

Experience has shown us that, not only must we maintain a certain level of preheat during welding, but that the preheat temperature must be uniform and stable during the entire welding operation. Thus, care must be exercised in the choice of the heating method, to insure that ample energy is furnished in a readily controllable form, and further, controls must be instituted to insure that the chosen method is properly applied and policed during the welding operation to assure that the desired temperature is being realized continuously.

The heating equipment which appears to meet these requirements for the greatest variety of job conditions encountered in HY-80 submarine hull construction is the electrical resistance strip heater.

This heater is used in a number of forms by the various building activities.

From an abstract viewpoint, all types of strip heater must be considered equally acceptable if they satisfy the criterion of providing the minimum required preheat while not creating temperatures above 300°F; regardless of heater type chosen, the fabricator must make a decision as to the watt density desired in a heater. For greatest flexibility, the watt density of each heater should be such that it is capable of satisfying the previously mentioned criterion when the heater is applied in single rows on the thinnest material normally heated by this method. On heavier material or under more severe ambient temperature conditions, duplication of heater units will satisfy the need for increased heat. Alternatives to this method of determining strip heater type and capacity are: To stock heaters in a variety of watt densities or to furnish a variable power supply for the heater system.

The method of attaching strip heaters to the work is a much discussed matter. In the interest of avoiding the potentially harmful effects of attaching the heaters by welding, as is usually done on other classes of work, submarine building activities have used a number of devices aimed at avoiding welded attachments. The most successful of these devices is the cemented stud, since, unlike wire cables, slings and various types of brackets, it can be used on any weldment configuration.

Newport News method uses a percussive or capacitor discharge stud weld for heater attachment. This method requires grinding of the weld site, to a depth of about .015" to remove all base material affected by the weld.

The photographs, figures 1-5, show various applications of one type of heater. In each instance the elements are 1000 watt capacity and the plating 2" or more thick.

While strip heaters are the most widely accepted and probably the least fallible of the heating methods employed in submarine construction, it is difficult to conceive of an entire hull being fabricated without some use of torch heating.

Torch heating should generally be confined to tack-welding operations or to those applications involving the welding of small items within a limited area.

When torch heating is used, care should be taken that a generous area of the surrounding base material, is slowly brought up to preheat temperature with sufficient time allowed for the heat to soak through the thickness of the parts being welded.

Exceptions to the above will be:

(1) Those instances in which torch heating is used as an accessory device to decrease the time required for reaching preheat temperature on material which is being heated with strip heaters.

(2) Those instances in which an element of a weld joint provides insufficient heat sink capacity to warrant the use of strip heaters because of the rapid increase of interpass temperature which will occur when welding is initiated. Examples of the latter are face plates or coamings on lightening and access openings, flanges on light stiffening members, etc. In these latter instances the use of torch heating will be preferred to strip heating.

The application of preheat to weldments of complex shape and those containing stiffeners, bulkheads or other plate elements in more than one plane or direction must be carefully controlled to avoid distortion of the structure or the creation of transient stresses due to non-uniform expansion caused by preheat. Some methods of controlling these effects are:

(a) Preheat and weld only widely separated elements simultaneously within a single weldment.

(b) Preheat and weld intercostal elements on a random basis prior to preheating and welding through elements in a given area.

(c) When possible, apply preheat such that the completed weld will be in compression. Examples: When welding internal shell frames to the shell, the preheat temperature of the shell plating should exceed that of the frame web; when welding external frames to the shell the converse of the above will apply. When welding inserts into hull structure the temperature of the hull plating should be above that of the insert plate, tube or weldment.

(d) The use of weld overlay in weldments of heavy mass and high restraint to permit the lowering of preheat temperature (to favor distortion or stress control.) The weld overlay itself will be deposited prior to joint welding using a high preheat. Use of the overlay will offer assurance of excellent base material heat-affected zone properties and will virtually assure freedom from cracking upon subsequent joint welding while allowing the use of greatly reduced preheat for the joint welding.

The following statements pertain to the application of preheat in general, but are particularly pertinent in the case of HY-80 submarine hull construction:

1. Responsibility for control of preheat, including assurance that it has reached the specified level, continues at this level throughout the welding operation and does not exceed the maximum allowable temperature, must be charged to a specified group of production or inspection personnel. Temperature indicating crayons are considered an adequate tool for this purpose.

2. Provision should be made to protect all heated assemblies from inclement weather.

3. It is highly advisable to plan the welding operation in such a manner that all elements of welding will proceed to completion once started. The continuation of preheat during an intermittent welding operation is considered a necessity but will not by itself assure freedom from cracking.

4. In the event of loss of preheat either locally or on an entire assembly due to power or equipment failure, welding should cease until proper preheat is again established. If the weldment has cooled to ambient temperature while in a partially complete condition, a magnetic particle inspection should precede re-institution of preheat.

5. Injudicious placement of heaters should be avoided.

To the extent that the heaters interfere with the welding or allied operations there is a danger that careless mechanics will remove or disconnect them thereby increasing the likelihood of cracking. At best, preheat is a necessary evil, to the production workman. Education will temper this attitude but only evidence of careful consideration of his problem will make it bearable.

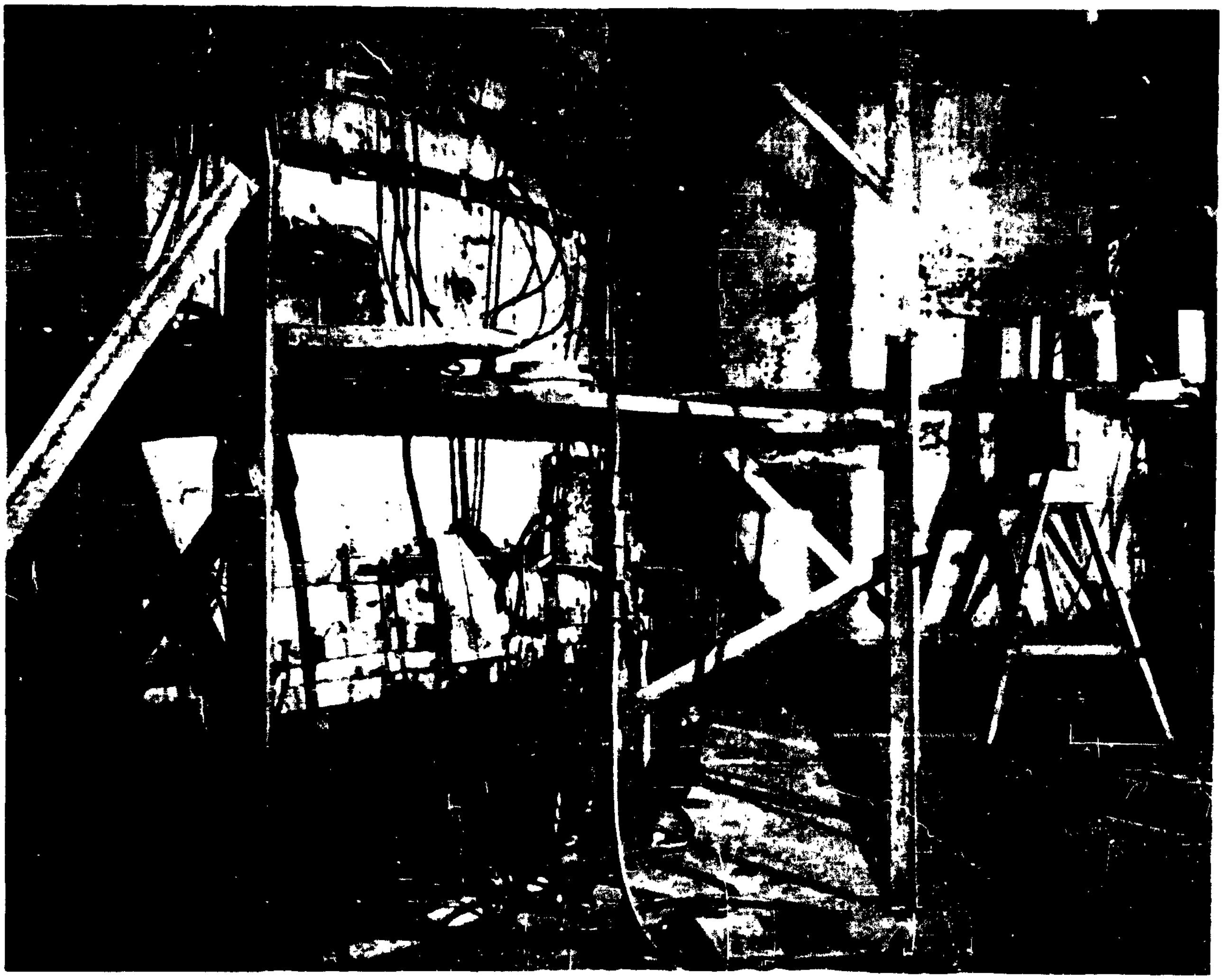


Figure 1 – Strip Heaters on Submarine Hull Section for Internal Frame to Shell Attachment Weld. Note Heater Power Distribution System.

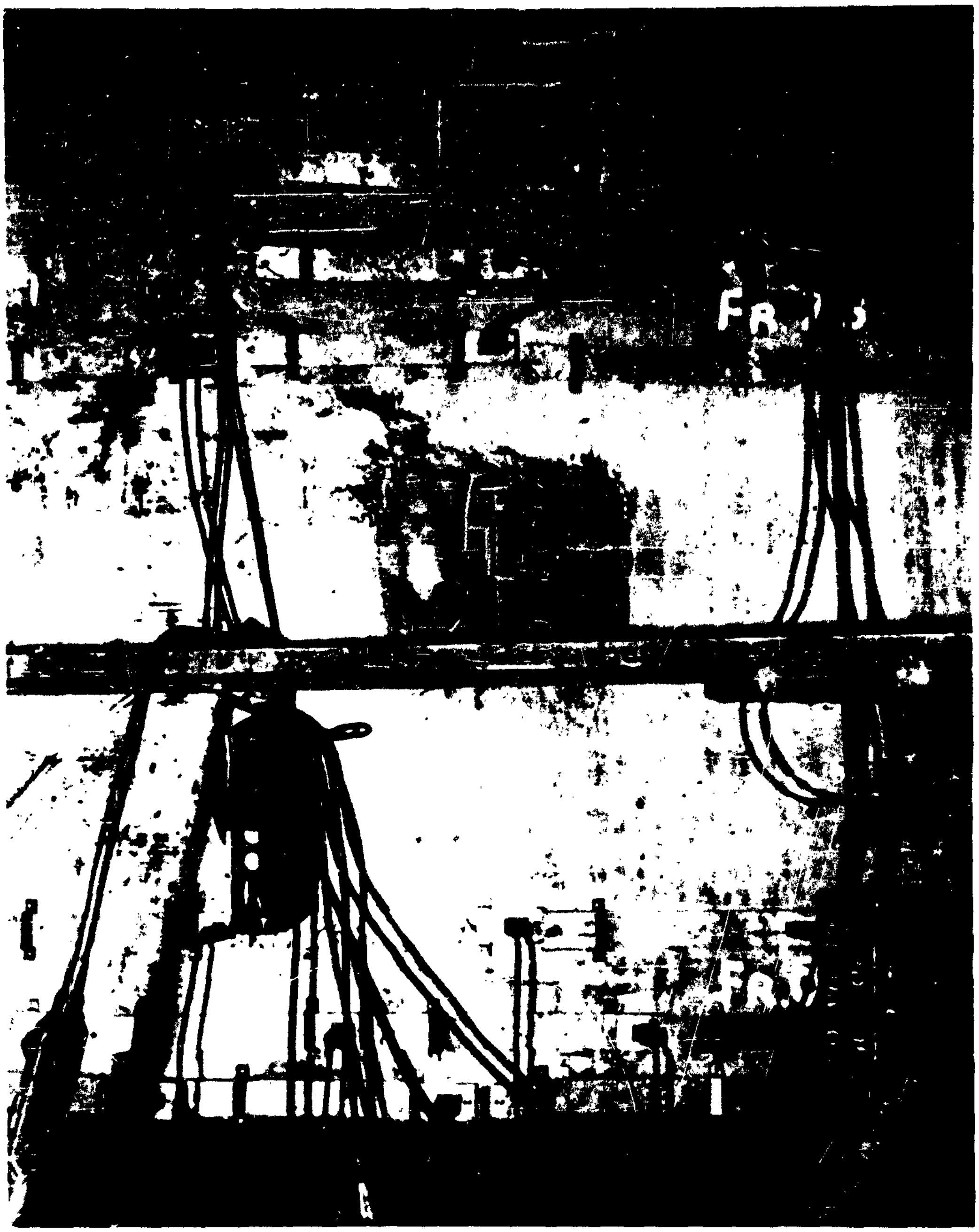


Figure 2 – Close-Up of View in Figure #1

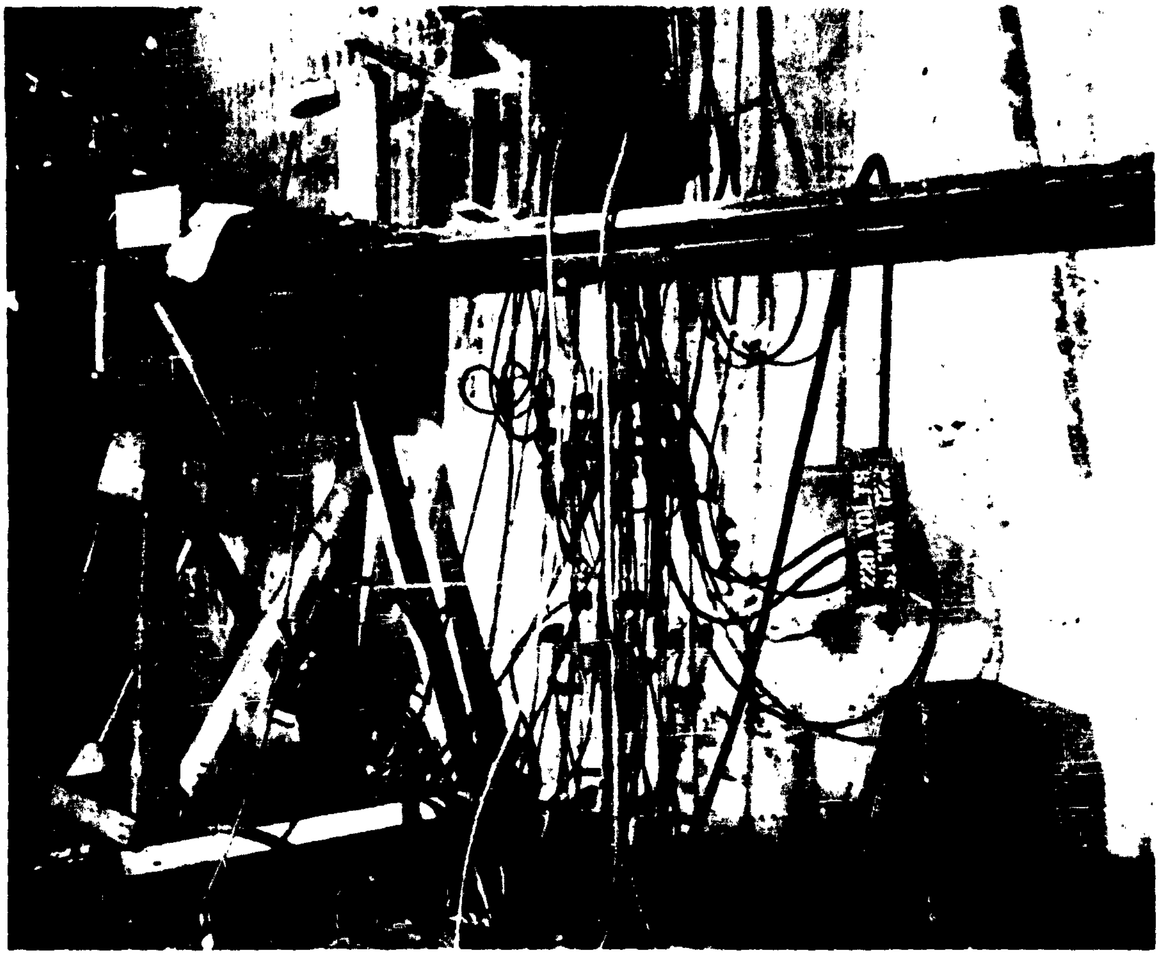


Figure 3 – Strip-Heaters for Vertical Butt Weld in 2-1/4" HY-80.

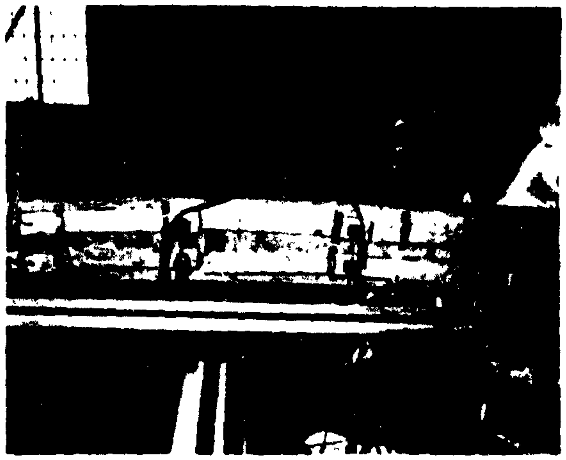


Figure 4 — Heaters on Flange Plate for Internal Frame Pre-Assembly Weld.

Figure 5 — Heaters on Overhead Portion of Circumferential Butt Weld on Shipway.

A REPORT ON THE DEVELOPMENT OF A CRACK RESISTANT ELECTRODE FOR HY-80

By

S. I. Roberts - Head Welding Engineer
Portsmouth Naval Shipyard
Portsmouth, N. H.
March 22, 1960

Abstract - This is a discourse of one phase, of developing, proving by test, and approving by controlled production use the crack sensitive nature of some coated electrodes. The electrode involved is the iron powder coated type in the range of above 80,000 psi yield strength of the AWS classification, 9018. This covers the selection of the electrode most suitable from several samples, and a method of grading or predicting which will perform better in production use.

History: The performance of ship plate in World War II, demonstrated the need for a higher strength material, particularly a more tough material that would be resistant to brittle fracture. The added requirement would be that the material would have good weldability. The HY-80 and its cousin the commercial T-1 steel is the result.

This HY-80 is a quenched and tempered steel of high toughness and high resistance to crack propagation, especially at low temperatures. For our thinking in fabrication we might broadly say that this steel receives its strength from its quenched and tempered heat treatment, as contrasted to the strength from chemistry of our strength steels used in the past. This obviously is a rather loose description and not a full description of this material, but it is sufficient for our need at this writing. This being a quenched and tempered steel requires somewhat more flexibility in our thinking when we have cracking problems. For we do not have a steel designed to good weldability as proven by many laboratory tests and, indeed still can be. Yet major problems of production use have been, and still are encountered.

The part of this quenched and tempered steel in the heat effected zone is changed greatly in different areas and spread over a wide range of reheat treatment. A portion may be quenched relatively severe while another area may be heat treated differently. Part may have a reheat similar to a temper, the degree depending on many factors.

It remains for the field activities to acquire the know how by trial and error to adapt this steel to successful welding. The laboratories have done their work well, and now it is a problem of the many variables in the shop and in the field.

Because of the complicated heat treatment from welding, further confused by many variables of production and by extremely high rigidity and restraint, it is easy and prudent to say "we don't know", as to the cause of cracks. Certainly there is a combination of many causes that result in cracks in the welds, and in the HAZ.

Comparative electrode test -

We began this test on the free admission that we just don't know what causes the cracks and why some electrodes do have a less propensity toward producing cracks. Again we do not know what properties in the electrode make the difference. We simply try to predict the type that will perform better in production welding. Eventually we hope to isolate the factors that contribute to the better performance. We reasoned that if many different crack producing configurations could be placed on a plate, reducing the variable, some electrodes may prove better than others. We therefore made different welds on a plate as shown in sketch No. 480, and 523. It is immaterial what kind of welds are made on the plate if identical conditions exist in the vertical columns except for the electrodes. However, we have found that a variety of welds as shown in the sketch 480, will result in a more reliable reading, as it reveals weakness in many different areas of the weld metal or HAZ.

To obtain a comparison, the welds are flushed off smooth with the plate surface and the plate bent to reveal any weakness. Using a known crack producing procedure, with the wide variety of conditions, gives us a good norm to predict which electrode can be expected to give better production welding.

Repeating, we purposely try to create weld metal or HAZ micro-fissuring weakness and then subject the plate to abnormal fiber stress to reveal this or any weakness. Different electrodes do have a varying effect on the plate.

The indications as shown in sketch 539 are obtained by coating the plate surface with liquid penetrant white developer, then magnetic particle inspect the plate, using red ferro powder. This enables a photograph of the area to show the number and extent of all cracks, in true detail. A close-up photograph is made of separate areas to obtain exact crack detail to transfer to a sketch. This enables one to read the comparison quickly and accurately.

The Bureau of Ships (Code 637) furnished a sample of type S580 electrode and also a 3 1/2% nickel type. These did not satisfactorily compare with the 11018 which we use as a standard. After several different brands and types showed no comparative advantage, a brand "R" repeatedly produced much less cracking. This brand even compared favorably with type 310 (25-20) for comparative cracking. The physicals were satisfactory to the design engineers, so a small order (5000 lbs) was procured, conforming to the minimum requirements of specification Mil-E-19322, type 9018, for the physical characteristics.

This electrode was used in production for non-critical, troublesome areas such as BLHD penetrations, attachments, foundations, and similar applications that had caused trouble when using 11018. This aspect was important as it verified the difference as revealed in our comparative test. In other words we needed to verify that the superior performance would also be apparent in actual production. To prove beyond doubt the superiority of this brand, we did not use the 9018 until the 11018 was tried and cracked at least once, and usually several times. Only then did we repair with the 9018.

The results were very good. Areas that were extremely troublesome were repaired satisfactorily. Repeated inspection reaffirmed the quality and the absence of cracks at the time of repair and later.

After this demonstration of superiority, the use for repair of cracks in the Main Ballast Tank 4A and 4B, was authorized. The isometric sketch No. 469, and one typical detail on Sketch No. 469-6-1, indicates the extremely high restraint and rigidity of this structure. Most all of the members shown are HY-80 over 1" thick.

The summary list indicates the extent of the troubleand lists the thirty areas, their size and number of repair attempts with 11018. Using only moderate preheat (70°F) not one crack appeared in the 9018 repair. Nor were there any related cracks in the area near the repair often associated with preheated welding in rigid structures such as this. An important item concerning preheat was, it is believed, that the <u>entire</u> tank was uniformly warm. This item was behind schedule, and so much "round the clock" work had heated it to an even heat. This supported the belief of many Welding Engineers that an even, tho low, preheat is better than higher local preheat in areas of strong rigidity.

To test the supplier's ability to reproduce this electrode, we placed another order (10,000 lbs). This was tested by comparing it with 11018 and other brands of 9018. The crack resistant characteristics as revealed by the comparison bend test, were not quite as good as the first order, yet better than other brands and the 11018. The sketch (No. 539) shows the approximate comparison. This is only approximate, due to the fact that the indications of cracks on the sketch were not scaled from the photo enlargement. However, it is the electrode "D" in the sketch, and it revealed better performance.

In production there were isolated reports of a minor number of cracks although the full results of production use is not available at this writing.

There are two other brands that have proven superior in the bend test. Procurement of 5000 lbs of each of these brands has been completed. The comparative bend test will be conducted on these and if the reaction is similar to the sample tested, they will be placed in production. This limited controlled use will be in accordance with instructions outlined in sketch No. 462-B. Because of the limited quantity they will be used mainly for repairs. Especially in the "tough" areas to get a production comparison with previous work.

It is believed that the specific characteristics can be isolated from this work and the electrode can then be manufactured to a predictable crack resistant characteristic.

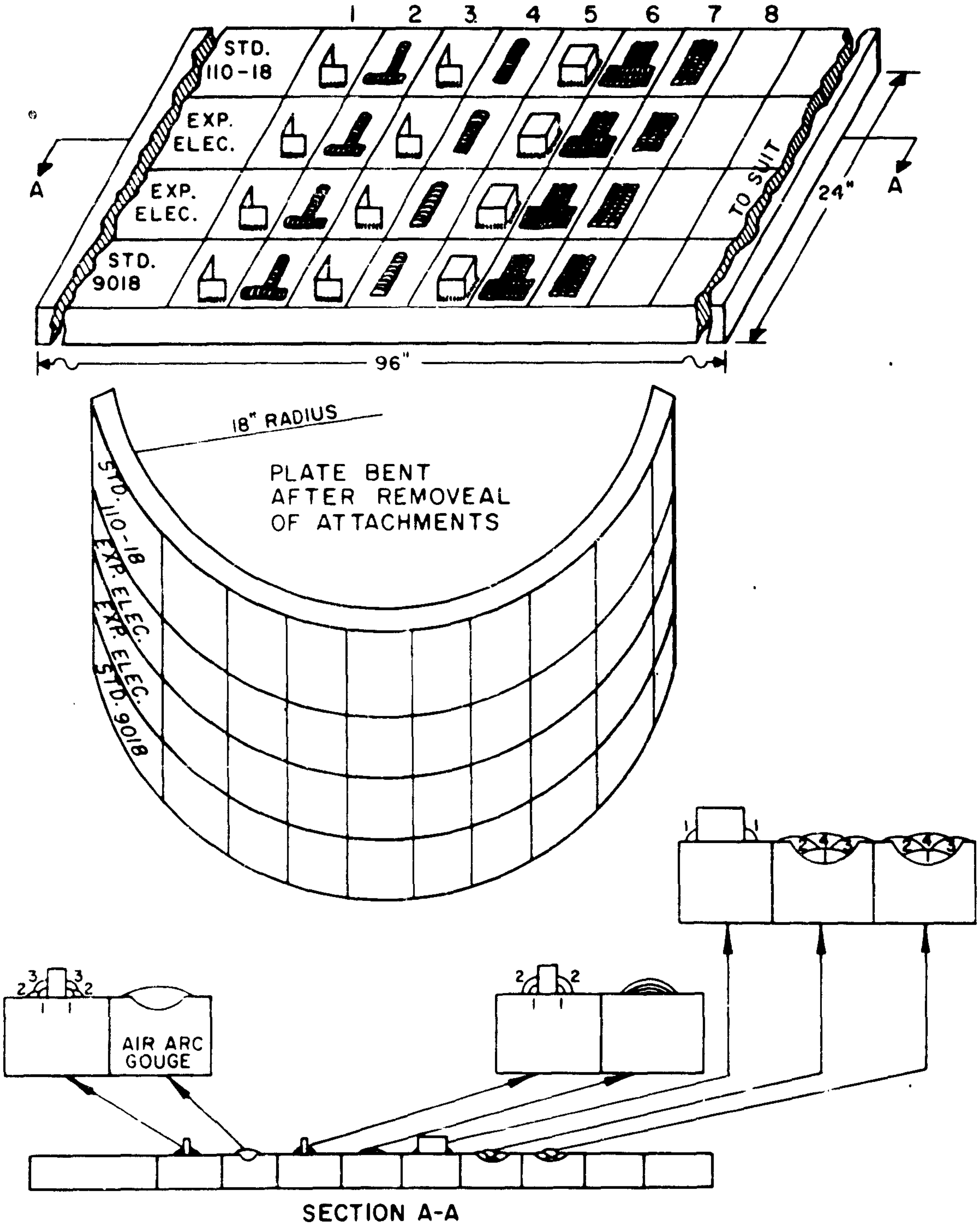
The chemical and physical data was compiled by Portsmouth on several different heat numbers of Brand "R". (stress relieved and as welded)

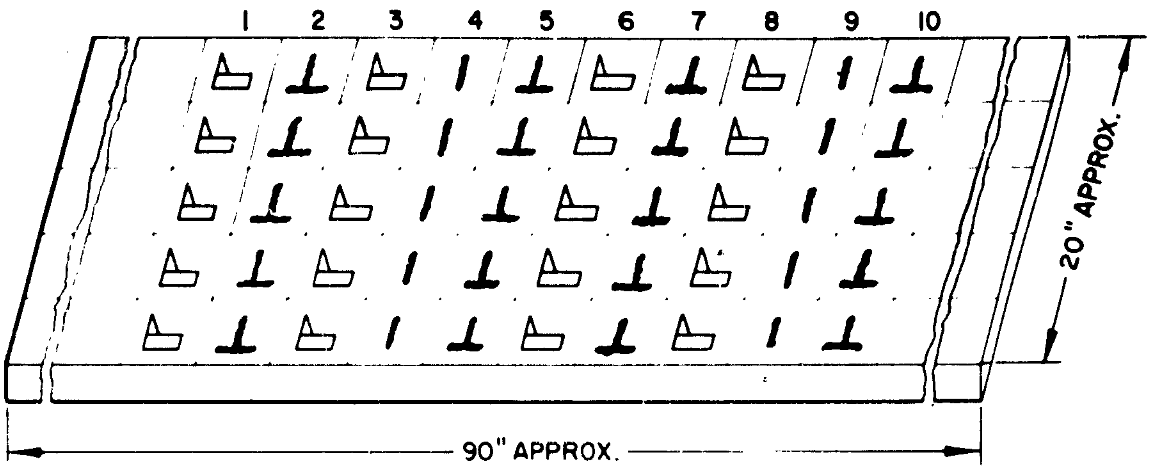
The range of Portsmouth's and those supplied by the vendor, are as follows;

<u>Chemistry</u>	<u>Low</u>	<u>High</u>
C	0.06	0.09
Mn	0.60	1.15
P	0.009	0.02
S	0.025	0.028
S	0.34	0.48
Mo	0.26	0.32
Ni	1.42	1.69

<u>Physicals</u>	<u>Low</u>	<u>High</u>
Yield	85,000	100,000
Tensile	99,000	106,000

Percent elongation in 2" - 22% - 26%
Charpy V at - 60°F - 21 ft lbs - 45 ft lbs.


1
2
3
4
5
6
7
8
STD. 110-18
EXP. ELEC.
EXP. ELEC.
STD. 9018
A
A
TO SUIT
24"
96"
18" RADIUS
PLATE BENT
AFTER REMOVEAL
OF ATTACHMENTS
STD. 110-18
EXP. ELEC.
EXP. ELEC.
STD. 9018
AIR ARC
GOUGE
SECTION A-A



- Description of attachments and simulated repairs -

1. Columns 1 and 6 - 2" X 2" angle iron clips welded with one pass.
2. Columns 2 and 7 - Arc-air gouged Tee groove in plate surface filled with one bead.
3. Columns 3 and 8 - 2" X 2" angle iron clips welded with 2 beads.
4. Columns 4 and 9 - one bead on plate surface about 1" long.
5. Columns 5 and 10 - Arc-air gouged Tee groove in plate surface filled with 3 beads the last of which covers 1/2 of the first 2 beads.

PROCEDURE

1. Plate surface was ground free of paint and scale.
2. Arc-air gouging accomplished in areas designated.
3. Weld attachments and simulated repairs as indicated.
4. Magnetic particle inspect each weld when plate cooled to ambient temperature.
5. Remove angle clips and grind welds smooth and flush with plate surface.
6. Magnetic particle inspect welded areas after rolling plate to about an 18" radius with the welded surface in tension.

NOTES:

1. Each area to be worked was cooled to 40°F immediately before welding was started.

2. Each vertical row of attachments and simulated repairs was welded on the same day.

3. All welding was done by the same operator.

4. The voltage and amperage range used was 24-26 and 180-200 respectively.

5. Current and travel speeds were maintained as nearly equal as possible for welds in the same vertical column.

6. Chilling of the plate before welding was done to induce weld cracks as a medium for comparison and is not an indication of production welding practice in use at this shipyard.

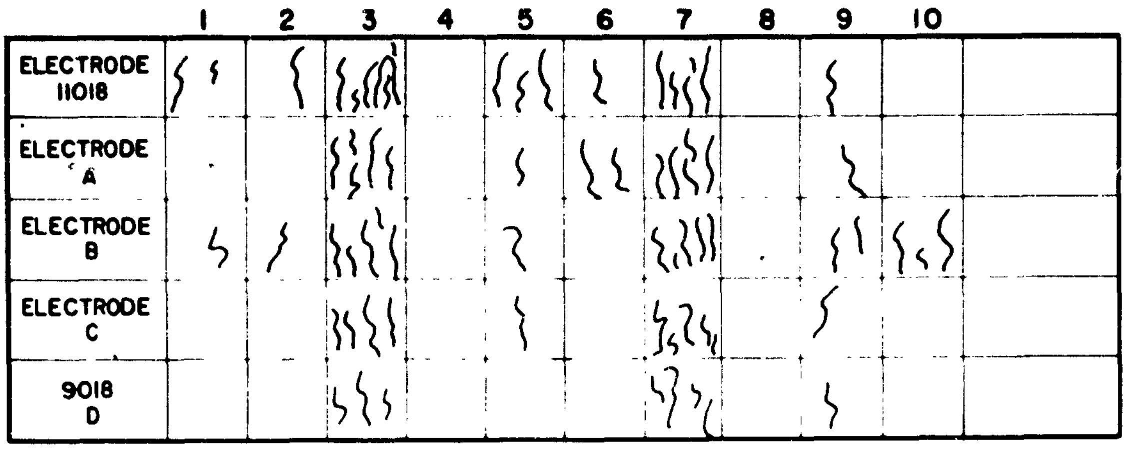
7. Variables have been minimized in conducting this test in order that each electrode receive identical treatment.

This test is designed to reveal weakness or micro-fissuring in the weld metal, diluted weld, or the HAZ of HY80.

The variety of welds applied evaluates the different conditions caused by electrodes. This number also gives a good norm to evaluate the results. To repeat the above procedure instructions, details must be maintained identical in the Vertical columns except for the change of electrodes.

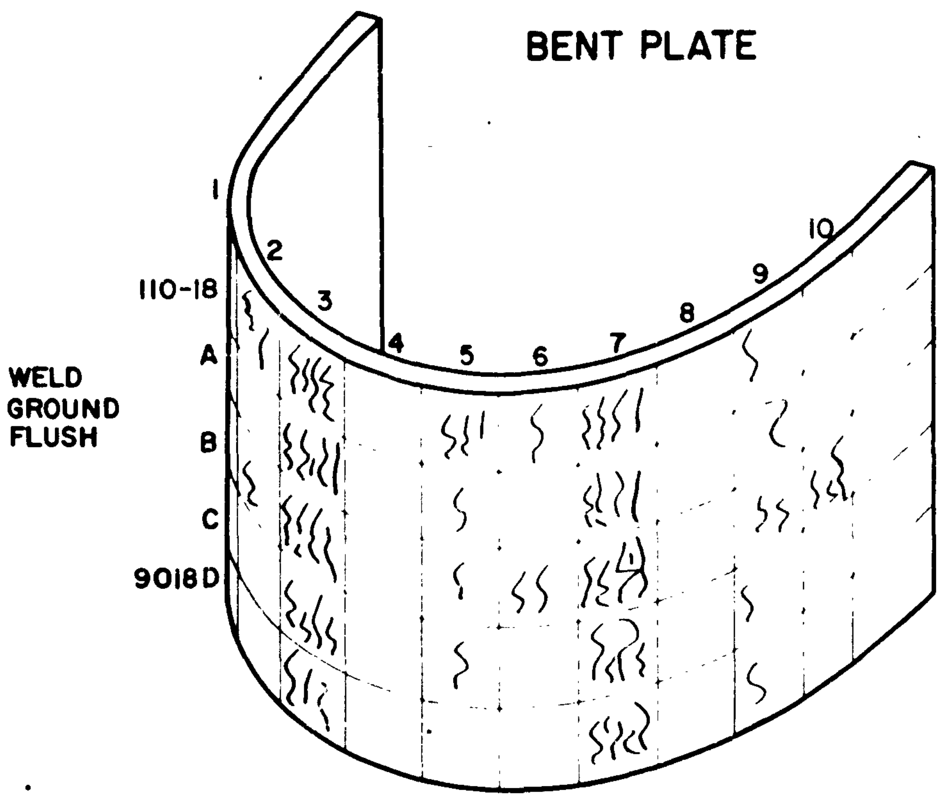
Only by this leveling off of the variables can a true comparative evaluation be made.

Sheet 2. of 2.
WE Sketch No. 523



RECORDED CRACKS

BENT PLATE



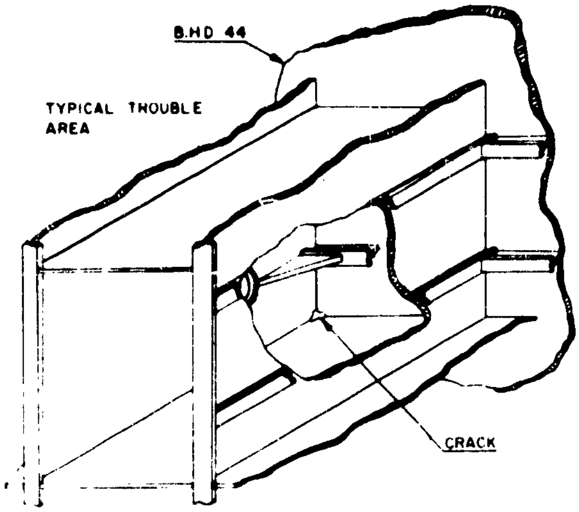
SUMMARY REPORT OF 9018 ELECTRODE

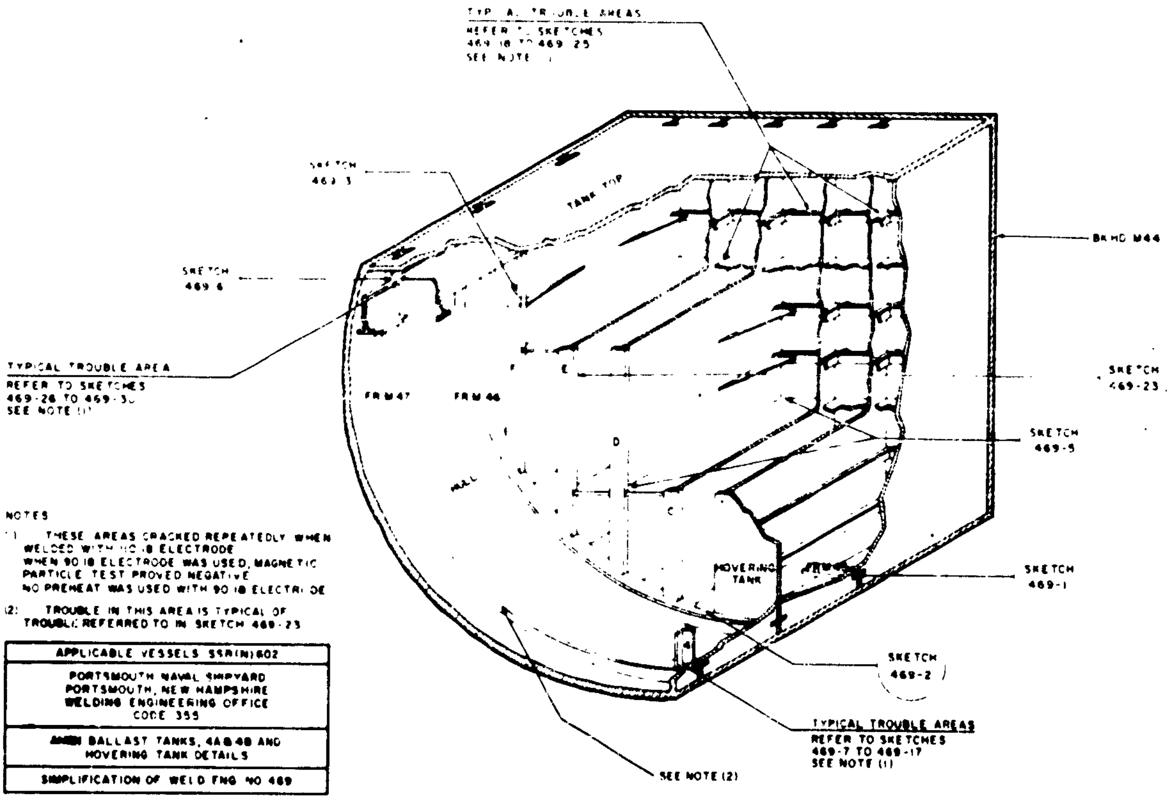
Sketch No.	Type of Crack	Size of Repair	No. of Repairs with 11018	9018 Final Results
MAIN B. TANKS, 4A & 4B - SSN(N)602				
469-1	Long. & Trans	4 1/2" X 1"	6	
-2	" "	1. 1 1/2 X 3/4" X 1/2"	3	
	" "	2. 3" X 1/2" X 1/2"	5	
	" "	3. 3" X 1/2" X 1/2"	5	
-3	" "	3" X 1" X 1 1/2"	3	
-4	" "	1. 40" X 2" X 2"	Repeatedly	
	" "	2. 11" X 2" X 2"	"	
-5	" "	1. 4" X 2" X 1 1/4"	4	
	" "	2. 5" X 1 1/2"	6	
-6	" "	1. 4" X 3/4" X 1/2"	Repeatedly	
-7	" "	3" X 2" X 1"	5	ALL FINAL REPAIRS WITH 9018 NO CRACKS
-8	" "	4" X 3/4" X 1/2"	2	
-9	" "	14" Long	Repeatedly	
-10	" "	3" X 1" X 3/4"	4	
-11	"	7 1/2" X 1 1/2" X 1	4	
-12	Long. & Trans.	4" X 1/2" X 1/2"	Repeatedly	
-13	Long.	3" X 3/4" X 1/2"	1	
-14	Long. & Trans.	4" X 2" X 3/4"	3	
-15	" "	4" X 1/2" X 1/2"	4	
-16	Long.	3 1/4" X 1/2" X 1/2"	1	
-17	Long.	2" X 1/2" X 1/2"	7	
-18	"	3" X 2" X 3/4"	2	
-19	"	6" X 1" X 1/4"	3	
-20	Long. & Trans.	3" X 1" X 1/2"	Repeatedly	
-21	" "	6" X 1" X 1"	"	
-22	" "	1 1/2" X 1 1/4" X 1/2"	"	
-23	" "	36" X 2" X 1	"	
-24	Long.	4" X 1" X 1/2"	"	
-25	Long. & Trans.	1. 5" X 1" X 1/2"	"	
	" "	2. 4 1/2" X 1/2 X 1"	"	
	" "	3. 18" X 2" X 2"	"	
-26	Long.	6" X 1" X 1 1/2"	4	
-27	Long. & Trans.	4 1/2"	7	
-28	" "	9" X 1" X 3/4"	3	
-29	Long.	7" X 2" X 1/2"	2	
-30	"	4 1/4" X 1" X 3/4"	1	

NOTES

1. Original weld material was 11018.
2. Various preheat from 70°F. to 200°F. and different sequences were used without success.
3. Final repair was made using preheat of 70°F. with 9018 electrode.
4. Magnetic Particle Inspection after five days showed no cracks.

9018 ELECTRODE
PORTSMOUTH NAVAL SHIPYARD
Welding Eng. Branch
Abraham Lincoln SSB(N)602





NOTES

(1) THESE AREAS CRACKED REPEATEDLY WHEN WELDED WITH NO 18 ELECTRODE
WHEN 90 18 ELECTRODE WAS USED, MAGNETIC PARTICLE TEST PROVED NEGATIVE
NO PREHEAT WAS USED WITH 90 18 ELECTRODE

(2) TROUBLE IN THIS AREA IS TYPICAL OF TROUBLE REFERRED TO IN SKETCH 469-23

APPLICABLE VESSELS SSR(N)602
PORTSMOUTH NAVAL SHIPYARD PORTSMOUTH, NEW HAMPSHIRE WELDING ENGINEERING OFFICE CODE 355
MAIN BALLAST TANKS, 4A & 4B AND HOVERING TANK DETAILS
SIMPLIFICATION OF WELD ENG NO 469

PURPOSE: To provide revised local instructions for the handling, stowage, and use of 9018 type electrodes. These are experimental electrodes supplied from different manufacturers for controlled production use to develop information for specification writing.

ELECTRODE: Description - Electrode, Welding, 5/32" dia. Type AWS 9018

Color Coding;	Primary	(end)	Red
	Secondary	(spot)	Orange
	Group		Green

STOCK DESIGNATION: PNS local stock No. GL-3432-L00-7580. Manufacturers brands as released by Code 355.

CONTROL: Experimental Type 9018 electrodes will be used only on controlled production. Electrode will be held in locked stowage ovens, the key held by the responsible supervisor. Electrode shall be issued by signed IBM card recording the area where the electrode is to be used. Dry the electrode in an oven at 250°F. to 350°F. a minimum of four (4) hours prior to use. Electrodes exposed to atmosphere for four hours are to be returned to the ovens for reheating.

USAGE: This 9018 is released for controlled production use per PNS ltr 355/250 10310 of 30 Dec 1959 to BUSHIPS. Its use will be limited and governed by the following rules:

A. The physicals of any electrode used will meet or exceed the specification Mil-E-19322 for type 9018 electrode.
B. Record will be made of the location and history of all 9018 electrode used on HY-80.
C. Each lot of electrode will be tested for satisfactory performance prior to release for use in production.
D. No welding will be permitted on plates that are at less than 70 F temperature.
E. No 9018 electrode will be used on butts or seams in the pressure hull, either in the shell plate or bulkheads.
F. No 9018 electrode will be used for the attachment of external frames to shell plate.

It is requested that these rules be closely followed and that any cracking or unusual results be confirmed and reported immediately to Code 355 so that reliable specifications can be developed.

CODE 355 SHIPYARD WELDING ENGINEER:

WELDING ENGINEER'S SKETCH NO. 462-B	PORTSMOUTH NAVAL SHIPYARD, PORTSMOUTH, N. H. PRODUCTION DEPARTMENT	WELDING PROJECT NO. WE-
Supersedes 462A DATE: 13 Jan 1960	INSTRUCTIONS FOR USE OF 9018 ELECTRODES SS(N)593 SSB(N)602	SHEET 1 OF 1 ENCLOSURE:

DIST.	P&E	354	307	308	207	303	230	240	250	252	590	533B	X-11	X-26	X-31	X-38	X-56	355C	310
	2	12				10	2	1	1	3	3	1	5	50				3	5

J.O.
ESTIMATOR:
DATE ISSUED:

EXPLOSION TEST PERFORMANCE OF SMALL-SCALE SUBMARINE HULL WELDMENTS

by

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Washington, D.C.

ABSTRACT

Underwater explosion tests of full-size submarine-hull sectors appeared to show the new hull materials might not be as effective as at first anticipated. Analysis of localized ruptures indicated the cause to be a too-rigid framing design for the high-yield-strength steel HY-80 rather than a deficiency of the material. Simulated hull-structure components have been used in explosion tests to ascertain if design was responsible for the HY-80 submarine-hull-sector failures and to demonstrate, if possible, the validity of structural performance prediction based upon explosion-bulge test results of materials. Comparison tests were made between structure components fabricated with the high-tensile-strength steel, HTS, and with HY-80. The HTS weldment samples were prepared by two welding procedures authorized for HTS (manual-arc, Mil E-8016 electrode and submerged-arc, Mil B-3 wire). The HY-80 weldment samples were prepared by two authorized welding procedures (manual-arc, Mil E-11018 electrode and automatic inert-gas-shielded metal-arc, Mil B-88 wire, A + O_2 cover gas) and two proposed procedures, (manual-arc, Mil E-310-15 electrode and semiautomatic inert-gas-shielded metal-arc, Mil B-88 wire, A+CO_2 cover gas, vertical welding).

In explosion tests conducted at 30°F and 0°F with simulated highly restrained joints, the HTS samples developed extensive brittle plate failures, whereas the HY-80 samples developed relatively short ductile tears, indicating superior plate toughness of the HY-80 under identical joint-design conditions as for the HTS. No differentiation could be made in the performance of the weld metals, because the rigid joint design protected the weld from high strain by concentrating the strain in the plate adjacent to the weld seam.

The structure component and explosion test die were modified to permit greater strain development in the weld metal. Tests were made with HY-80 components fabricated with the two approved weld metals (Mil E-11018 and Mil B-88) and an austenitic weld metal (Mil E-310-15). The test results showed that the Mil E-310-15 weld metal develops unique and extensive fusion-line failures. The two approved weld metals developed no failures despite the increased straining.

These tests duplicated the explosion-bulge test results of materials by themselves, which indicated the HTS to be brittle at 0°F and 30°F and that the Mil E-310-15 weld metal develops a weak fusion-line which serves as a ready path of failure. These duplications support the concept that structure performance could be predicted from tests of materials. The structure test results also showed that under identical framing design, the HY-80 is superior to the HTS.

INTRODUCTION

Past efforts of the U.S. Naval Research Laboratory's long-term specialized welding-research program have been based on establishing the fundamental factors which determine the fracturing performance of weldments (1, 2). These studies have entailed extensive tests of available structural materials conducted over a range of temperatures. This research has demonstrated the importance of test temperature upon resulting fracture performance and has resulted in the formulation of new concepts (3, 4) which provide for a more exact definition of the properties required for the weld, the heat-affected zone, and the parent material of weldments used in ship and submarine construction. The concepts derived from these investigations have served as the basis for the procurement of plate (HY-80, Mil S-16216 C) and weld materials (B 88, Mil E-19822 and E-11018, Mil E-19322) currently specified by the Bureau of Ships for new submarine hulls.

The use of explosives for performance evaluations of welded joints and prime plate materials is a long-established Navy procedure. For many years, large open-ended cylinders containing welded joints were immersed in water with a charge which was exploded either in the center of or removed from the cylinders. On a still larger scale, full-size submarine-hull sectors have been similarly tested for purposes of evaluating fabrication procedures and optimum joint configurations. Generally, however, these full-scale sector tests were conducted only in the summer months, when the water temperature was relatively high.

New submarines are designed for much deeper submergence than has ever been considered before; stricter specifications for hull requirements, including material strength, toughness, and scantling design, were necessary to combat the greater water pressure. An apparent difficulty developed when initial explosion tests of full-scale sectors of the new HY-80 hull structures indicated that they might not be as effective as anticipated. Localized tears were developed at certain locations in the framing members which did not penetrate the Sector's pressure hull. Although the nature and locations of the tears suggested that the difficulty was related to the design of the framing rather than to deficiencies of the material, questions were raised concerning possible differences in fracture performance which might result from tests of materials by themselves, as contrasted with actual tests of highly restrained structural joints.

If, as suspected, the framing design was responsible for the localized tears developed in the HY-80 sector tests, it was essential to investigate the behavior of various weld-joint configurations in order to develop improved design details. It was also considered necessary to demonstrate the validity of predicting structural performance on the basis of test results of materials exclusively. Because of the cost and the impracticability of controlling test temperatures for the large-scale sector tests, there was a need for the development of smaller-scale tests suitable for screening studies. This report describes new developments in the procedures for NRL's explosion-bulge test (5), which now permit the testing of structural components, such as the stiffeners for the pressure hull. The new procedures allow for the use of relatively small sections (approximately 2 x 2 ft) which are readily fabricated and permit rapid investigation of a wide variety of design methods.

The materials considered for this investigation included the conventional high-tensile steel (HTS, Mil S-16113) previously employed for submarine construction and the new-tough, high-strength HY-80 steel currently specified for all new submarine construction. Several different plates of each steel were used for the various weldments to be described. These were selected at random from stock at the Philadelphia Naval Shipyard and used after checking to insure that each complied with respective specification requirements. The majority of the weldments were fabricated by PNSY under normal shipyard welding conditions; however, a few weldments were fabricated under laboratory conditions by C Company with plate material supplied from PNSY.

TEST PROCEDURES AND RESULTS WITH HTS STRUCTURAL JOINTS

Figure 1 gives the dimensions and joint configuration of the simulated structural components considered for initial tests of HTS material. Several components were fabricated with the two weld metals authorized for the welding of HTS (manual stick electrode, Mil E-9816, and automatic submerged-arc electrode wire, Mil B-3). These components were explosion-bulge tested on the rectangular test die illustrated in Fig. 1. The spacing between T-frames and test-die radii was chosen to provide support so as to simulate the high degree of restraint developed in the submarine at design positions which feature external framing opposite internal bulkheads or tank compartments. The die radii precluded gross bulging opposite the T-frames, so that only 1 percent or less thickness reduction was developed in the hull plate adjacent to the fillet-weld regions.. The explosive charge used for all specimens was 7 lbs of pentolite; however, the offset distance of charge to plate was varied from 15 to 18 in. for some tests in order to facilitate comparisons between HTS and HY-80 specimens at the same relative level of deformation developed at the apex of the bulge. Complete test data are given in Table I.

Figures 2-4 illustrate the results obtained with the HTS specimens manually welded with Mil E-8016 electrodes. In the tests conducted at 30 F (Figs. 2 and 3), the fractures started in the HTS at the toe of the fillet welds, and complete penetration of the hull plates was developed on the first shot. At 0 F (Fig. 4), similar fractures were developed; however, propagation of these fractures was sustained through the hold-down regions of the plate and resulted in complete separation of the specimen. The brittle fractures which developed in these HTS structural components are in complete accord with predictions based upon previous 0 and 30 F tests of average-quality HTS (6).

For the HTS samples automatically welded with submerged-arc Mil B-3 electrode wire, complete penetration fractures of the HTS hull plates were also obtained on the first shot (Figs. 5-7). In addition, two of these specimens also developed secondary fractures in the submerged-arc fillet welds. One of the T-frames was partly blown off in the 30°F test (Fig. 5), and one T-frame was completely blown off in the 0°F test (Fig. 7). As shown by the photomacrograph inserts, these secondary fractures started in the HTS web section at the toe of the fillet weld but propagated almost exclusively in the weld metal. Previous tests of submerged-arc weldments

(7, 8) have shown this weld metal to be susceptible to brittle fracture at 0°F and 30°F. Thus, in addition to the fractures developed in the HTS, the weld-metal fractures developed in these structural components are also in agreement with predictions based upon materials tests exclusively.

RESULTS WITH HY-80 STRUCTURAL JOINTS

Simulated structural components similar to the configuration shown in Fig. 1 were also fabricated with HY-80 steel. In addition to the Bureau-approved weld metals (manual stick electrode Mil 11018 and automatic, inert-gas, metal-arc Mil B-88), samples were welded with the manual stick electrode, Mil 310-15 (austenitic- 25 percent Cr, 20 percent Ni), and with semiautomatic, inert-gas, metal-arc electrode (vertical position welds with Mil B-88 electrode using experimental cover gas of 80 percent argon + 20 percent CO_2) and included for comparison purposes. These components were all explosion tested with conditions similar to those described previously for the HTS samples. Thickness-reduction measurements indicated that the restraint afforded by the die radii also precluded the development of more than 1 percent thickness reduction in the HY-80 hull plate at locations adjacent to the fillet welds. For comparison with HTS results, it was established that a 15-in. standoff of the 7 lb charge resulted in approximately the same relative level of deformation (5 to 6 percent thickness reduction) at the apex of the HY-80 bulge as was developed by an 18-in. standoff for HTS samples.

The appearances of the various HY-80 samples after one explosive shot are typified in Figs. 8 and 9. Test data for these samples are included in Table I. In each case, ruptures were started in at least one of the T-sections in these HY-80 samples at the positions of high restraint adjacent to the toe of the fillet weld. However, in only two samples (Nos. 7 and 14) did the resulting rupture penetrate through the 1-in.-thick hull plate. This penetration was relatively small and barely visible on the tension side of the sample. All other HY-80 specimens exhibited only small tears which only partially penetrated the 1-in.-thick hull plate.

Irrespective of the weld metal employed for these HY-80 specimens, no significant difference could be observed in the pattern of initial fracture developed at the first shot. A second explosive shot was given to each of these HY-80 specimens. Figure 10 is representative of the fractures which developed after the second shot in the various HY-80 samples welded with different electrodes. In each case where the first shot had developed a partial penetration crack adjacent to the fillet weld, the crack was extended and full penetration of the hull plate at that area was developed by the second shot. In addition, for the T-sections which were not cracked on the first shot, a partial penetration crack at the toe of the fillet weld was developed by the second shot (compare Fig. 8 with Fig. 10).

Macrosections were cut from the penetration-failure areas of these samples for examination. Irrespective of the weld metal employed, the fracture pattern was similar for all HY-80 samples. As shown in Fig. 11, the partial-penetration failures, denoted by Area A, developed as tensile ruptures. The extension of these failures to full penetration on a subsequent shot, area B, occurred in a punching or true-shear manner. Thus, design positions which feature external framing opposite internal bulkheads, or tank compartments are shown to represent a particularly unfavorable design "hard spot." The high restraint and restricted movement incurred at these positions precludes the development of much deformation in the HY-80 and is conducive to the formation of shear-type failures via the punching mechanism described above. It should be noted, however, that the high-energy-absorption shearing characteristics of the HY-80 at these temperatures precludes brittle fractures and extensive propagation such as that developed in HTS. Thus the resulting fractures in simulated structural joints of HY-80 are limited to relatively short shear-tears.

RESULTS WITH MODIFIED HY-80 STRUCTURAL JOINTS

In submarine fabrication, some of the highly restrained fillet welds of framing members to the pressure shell occasionally require costly weld-repair operations of small fabrication cracks occurring at the toe of the fillet weld. To alleviate such cracking tendencies and to reduce overall production costs, some of the shipyards have requested Bureau permission to make frame-to-shell welds with austenitic Mil 310-15 electrodes. However, a performance evaluation of the Mil E-310-15 weld metal in such a joint as compared to that of the approved ferritic weld metals had to be made prior to such approval. The explosion tests described previously for structural joints, simulating conditions of external framing opposite internal bulkheads, failed to discriminate in fracture performance between the various weld metals employed in the HY-80 samples. The reason for this failure was that the test conditions concentrated most of the strain in the hull plate at the toe of the fillet weld, thereby insufficiently straining the weld joint as a whole. The solution was to spread out the deformation over the entire weld joint and prevent excessive localization at this critical region. Accordingly, the test die and specimens of the type shown in Fig. 12 were prepared to study possible differences in fracture performance of different weldment combinations. Only the Bureau-approved weld metals (Mil 11018 and Mil B-88) and the proposed austenitic Mil 310-15 electrodes were considered for this evaluation.

The primary difference between the conditions of the modified T-sector test and that of the original test described earlier is that related to the support rendered by the die at the web-to-hull fillet joint. In the modified test, the support opposite the T-section is not nearly so great. Explosion tests of these samples could develop more tensile strains on the weld metal and permit discrimination in the performance of various weld metals and/or welding techniques. As was expected, the fracture behavior was similar for both specimens welded with the Bureau-approved weld metals. Figure 13 illustrates the appearances of those specimens after a second explosive shot of 7 lb at a 15-in. standoff distance. The fractures, which started in the HY-80 at the toe of the fillet weld, did not penetrate through the 1-in. hull plates. A third shot was required for these samples before the fractures were observed to penetrate through the hull plates. As shown in Figs. 14 and 15, however, the penetrations are short tears barely visible on the tension side of the specimens; this is indicative of the high fracture resistance of HY-80.

The pattern of failure which developed in the specimen welded with the austenitic Mil 310-15 electrodes, however, was significantly different from that described above. As shown in Fig. 16, extensive tearing in the web section of the specimen was developed by two shots of explosive at a 15-in. offset distance. After the third shot, the T-frame was completely separated from the hull plate (Fig. 17). The source and path of propagation of fracture were uniquely confined to the fusion line between the austenitic weld and ferritic plate. Such extensive failures have previously been shown to be typical of failures to be expected at all ambient temperatures in austenitic-ferritic weldments which are subjected to deformation loadings (9). Accordingly, the use of austenitic welds for framing attachments to the pressure shell at locations which may be subjected to deformation is considered to be especially hazardous.

SUMMARY AND CONCLUSIONS

In previous investigations, all deductions and conclusions have been based upon the results of explosion-bulge tests of materials, as prime plate or nonrestrained butt welds. In those studies, the HTS plate and the submerged-arc weld materials were found to be characterized by partial or high brittleness at temperatures of 0° to 30°F. Specification-quality HY-80 materials, on the other hand, were shown to be highly notch tough and resistant to brittle fractures at these temperatures. In the present investigation, which featured tests of highly restrained structural joints, the fracture performance and extent of failures which developed in the various samples were in complete agreement with results of previous studies. Thus it is concluded that the fracture performance which may be developed in these materials in highly restrained structures is predictable from results of tests on the materials themselves as prime plate or nonrestrained butt weldments.

The similar fracture performance shown by these materials, whether in unrestrained or highly restrained weldments, implies that the performance is dependent upon material properties and not upon structural design. That is, if one material behaves more poorly than another in an unrestrained test, it will be poorer in a restrained test as well.

Structural design is of particular importance, however, in determining the procedure by which failure may develop in notch-tough materials at particular design locations. For the test specimens which simulated the conditions of external framing opposite internal bulkheads, the ultimate failures which developed in the notch-tough HY-80 samples were identical irrespective of the weld metal employed. The high restraint developed at such locations precludes the development of deformation in the weld region, so that under explosive loadings, failures are ultimately developed via a punching or shearing mechanism when the material is overloaded. Improved performance can be expected at these "hard-spot" regions by design details which are aimed at spreading out the deformation and preventing excessive localization of strain at critical regions.

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TABLE 1

Explosion Test Data

Test Specimen No.	Steel	Welding Process (1)	Electrode Mil Type	Test Conditions Temp. (0 F)	Charge Wt. (lb)	Stand Off (in)	Test Shot	Failures Developed at T-Joint (2)
1	HTS	M	8016	30	7	15	1	2 - FPP - 11 in.
2	HTS	M	8016	30	7	18	1	1 - FPP - 12 in., 1 PPP - 11 in.
3	HTS	M	8016	0	7	15	1	1 - FPP - 16 in., 1 CFP - 30 in.
4	HTS	SA	B-3	30	7	15	1	1 - FPP - 12 in., 1 FPP - 14 in. + 1 PPW - 22 in.
5	HTS	SA	B-3	30	7	18	1	1 - FPP - 9 in., 1 - FPP - 14 in.
6	HTS	SA	B-3	0	7	15	1	1 - FPP - 12 in., 1 - FPP - 20 in. + 1 FPW - 22 in.
7	HY-80	M	11018	30	7	15	1	1 - FPP - 9 in., 1 - PPP - 6 in.
8	HY-80	M	11018	30	7	18	1	1 - PPP - 4 in., 1 - PPP - 9 in.
9	HY-80	M	11018	0	7	15	1	1 - PPP - 8 in.
9	HY-80	M	11018	0	7	15	2	1 - FPP - 11 in., 1 - PPP - 6 in.
10	HY-80	IG	B-88	30	7	15	1	2 - PPP - 5 in.
11	HY-80	IG	B-88	30	7	18	1	2 - PPP - 5 & 7 in.
11	HY-80	IG	B-88	30	7	18	2	2 - FPP - 10 in.
12	HY-80	IG	B-88	0	7	15	1	2 - PPP - 6 in.
13	HY-80	IG	B-88 Vertical	0	7	15	1	2 - PPP - 6 & 12 in.
14	HY-80	IG	B-88 Vertical	0	7	15	1	1 - FPP - 9 in., 1 - PPP - 8 in.
14	HY-80	IG	B-88 Vertical	0	7	15	2	2 - FPP - 11 & 12 in.
15	HY-80	M	31015	0	7	15	1	2 - PPP - 6 & 8 in.
16	HY-80	M	31015	0	7	15	1	2 - PPP - 5 in.
17	HY-80	M	31015	0	7	15	1	2 - PPP - 5 & 9 in.
17	HY-80	M	31015	0	7	15	2	1 - FPP - 9 in., 1 - PPP - 8 in.
18	HY-80	M	31015	0	7	15	1	2 - PPP - 5 & 10 in.
19	HY-80	IG	B-88	30	7	15	2	1 - PPP - 10 in.
19	HY-80	IG	B-88	30	7	15	3	1 - FPP - 15 in.
20	HY-80	M	11018	30	7	15	2	1 - PPP - 8 in.
20	HY-80	M	11018	30	7	15	3	1 - FPP - 11 in.
21	HY-80	M	31015	30	7	15	2	1 - FPFL - 17 in.
21	HY-80	M	31015	30	7	15	3	1 - CFFL - 22 in.

Notes

(1) **M** - manual, stick electrode; SA - submerged-arc; IG - inert-gas metal-arc

(2) FPP - Full penetration plate; PPP - partial penetration plate; CFP - complete failure plate; PPW - partial penetration weld; FPW - full penetration weld; FPFL - full penetration fusion line; CFFL - complete failure fusion line

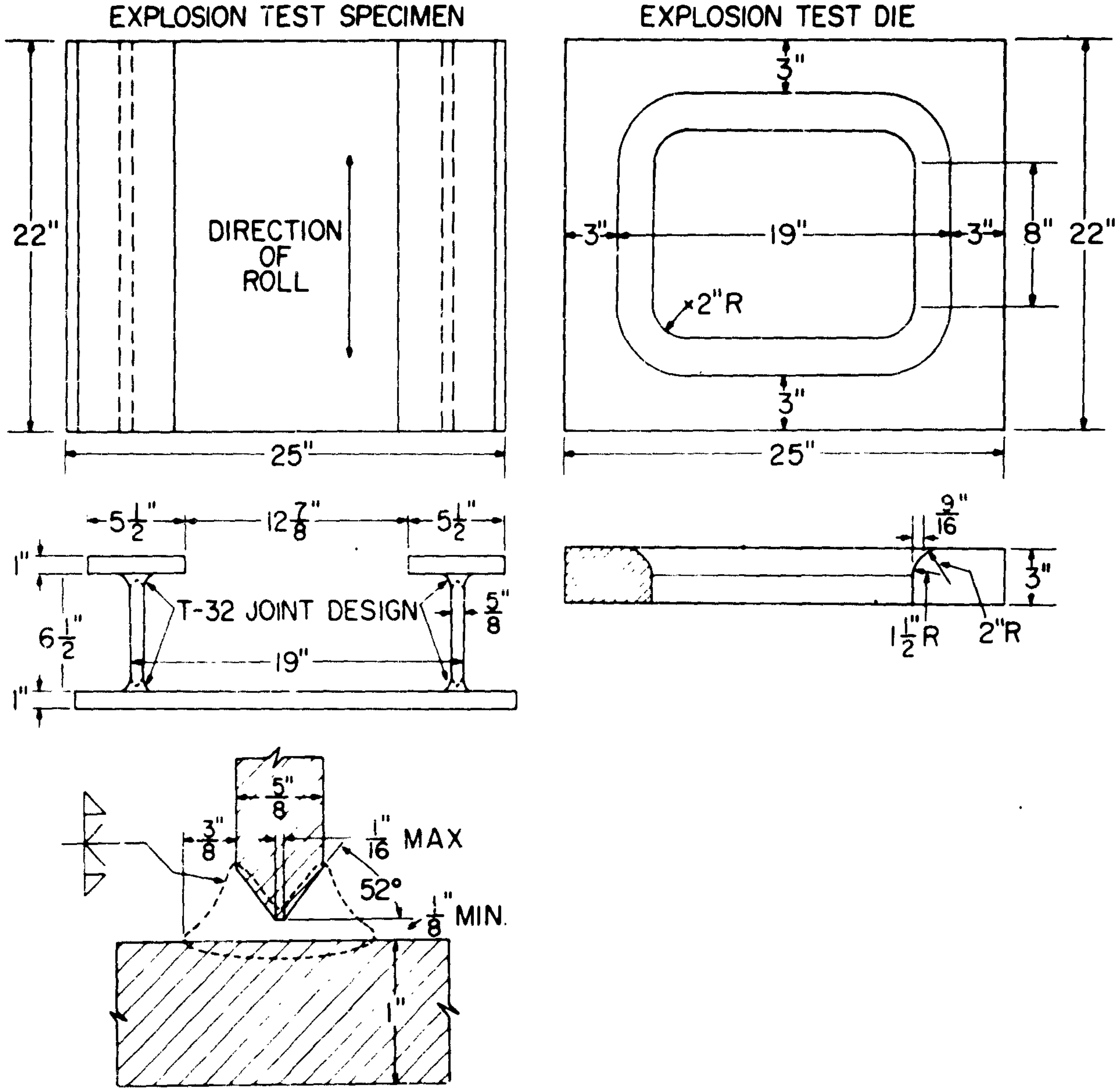

Figure 1 – Simulated structural component used as explosion test specimens and weld joint design (left); configuration of explosion test die (right)

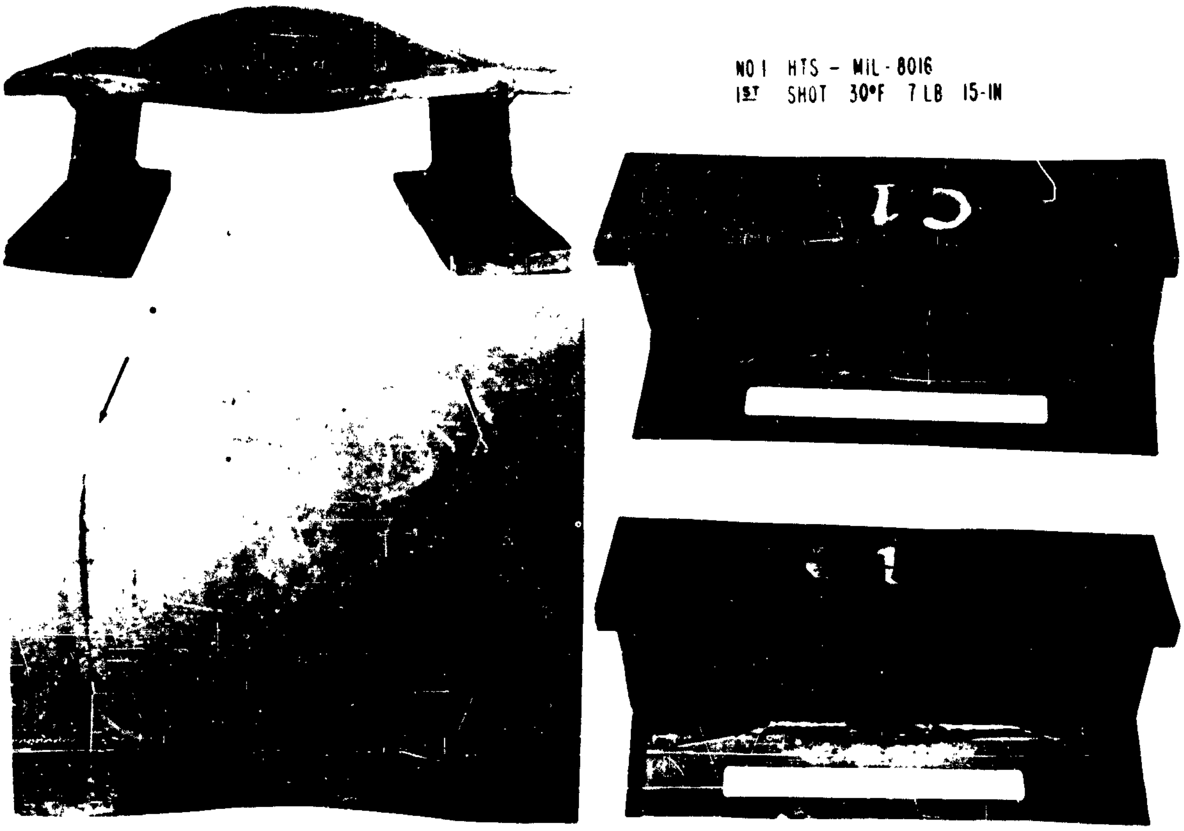

Figure 2 — Test specimen No. 1 after one explosive shot. Arrows indicate extent of ruptures.

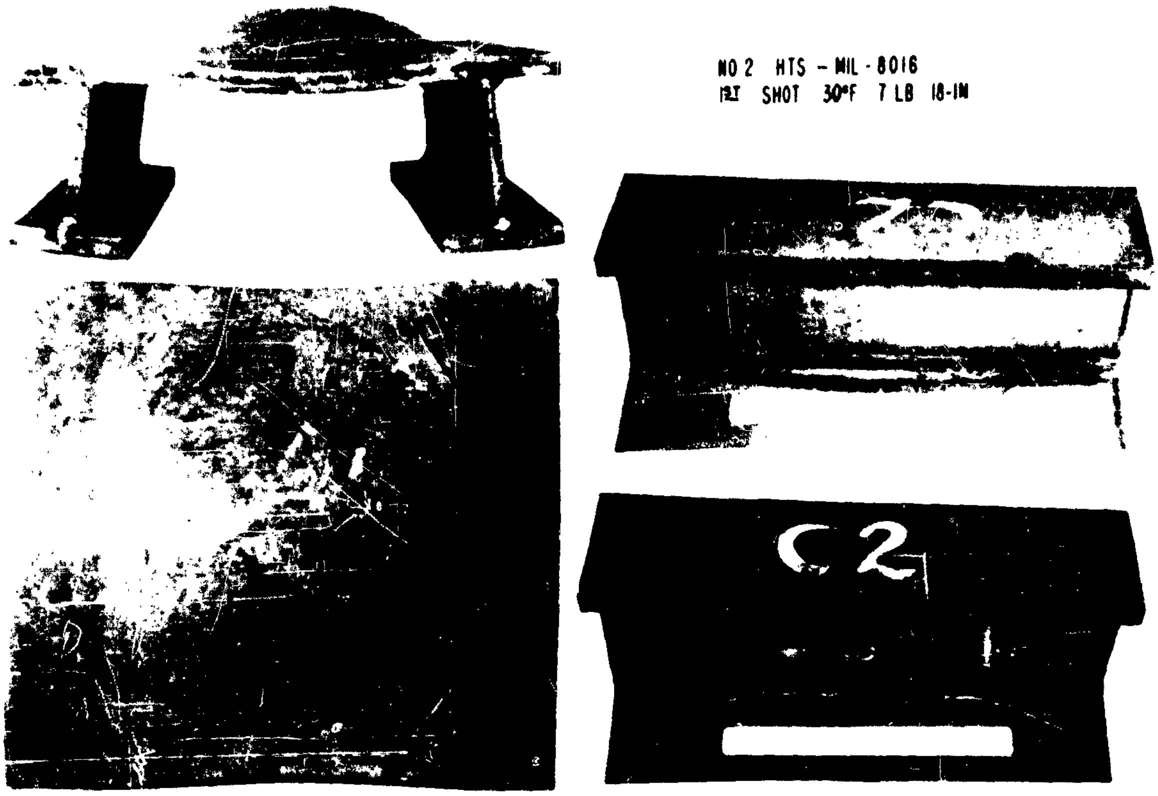

Figure 3 — Test specimen No. 2 after one explosive shot. Arrows indicate extent of ruptures.

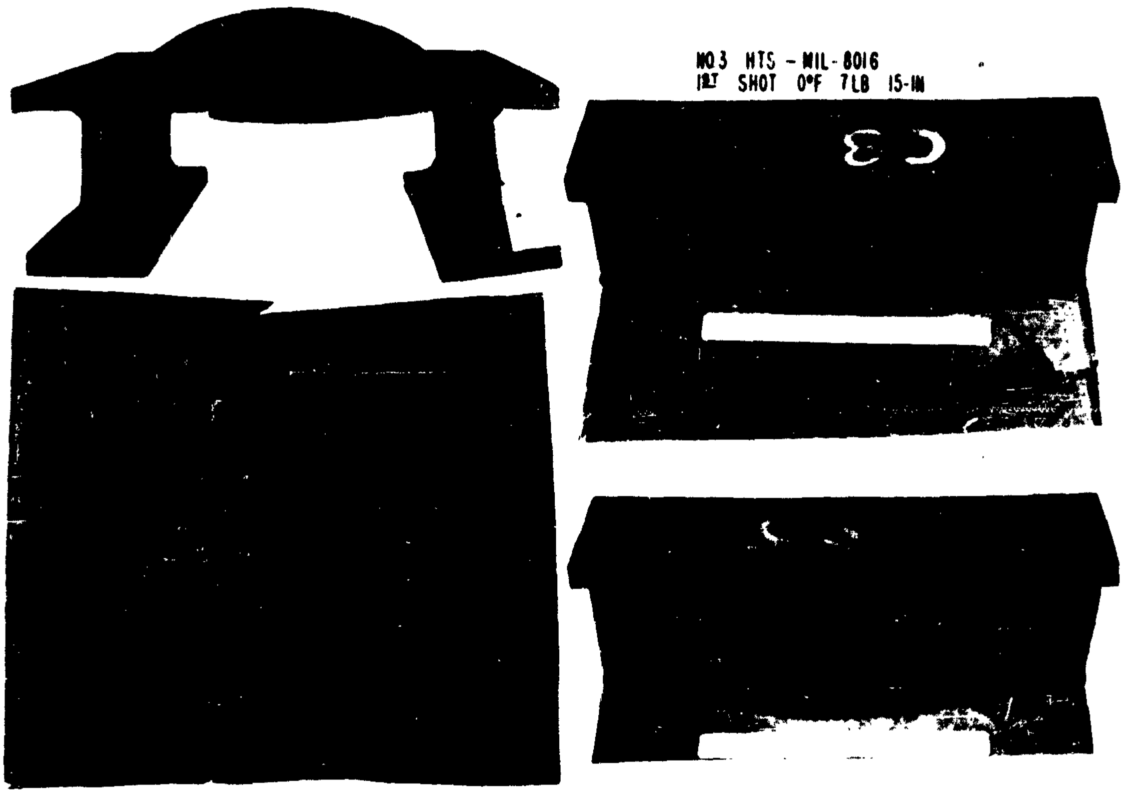

Figure 4 – Test specimen No. 3 after one explosive shot. Complete brittle fracture at 0°F.

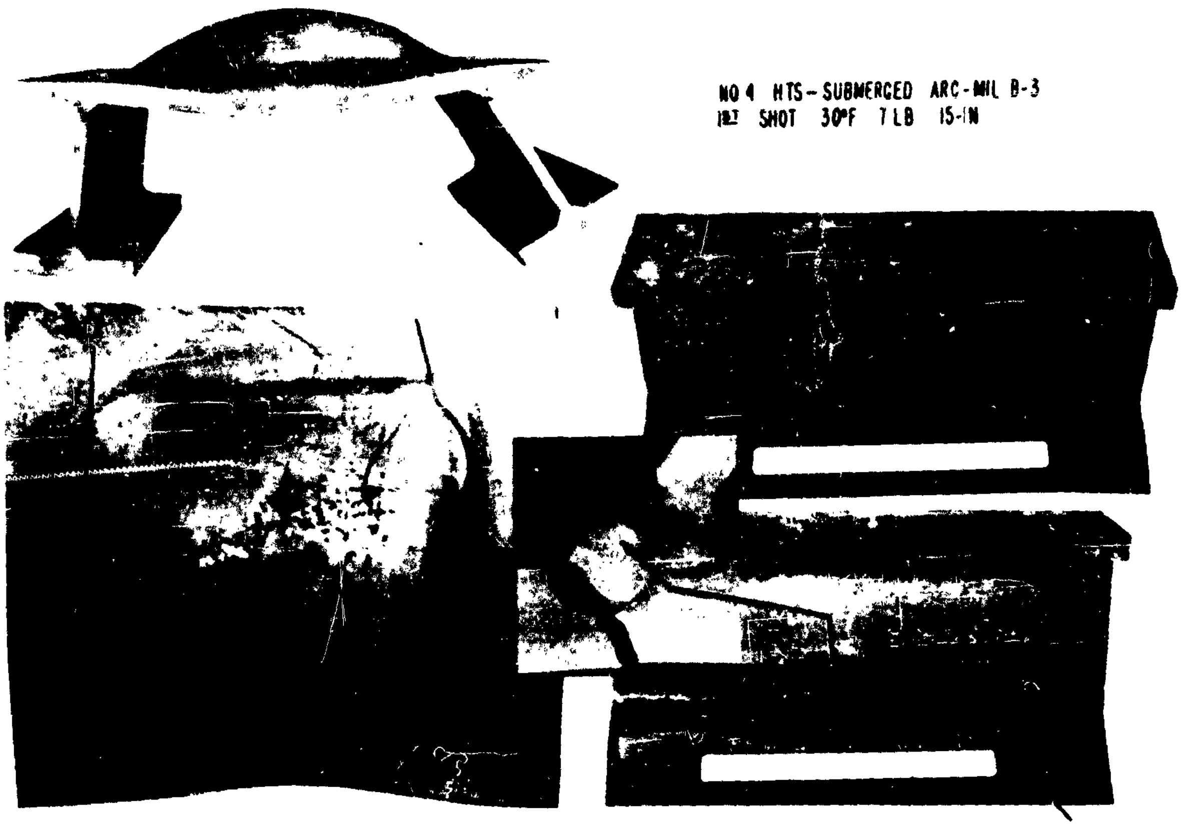

Figure 5 – Test specimen No. 4 after one explosive shot. Arrows indicate extent of ruptures. Insert shows submerged-arc weld failure.

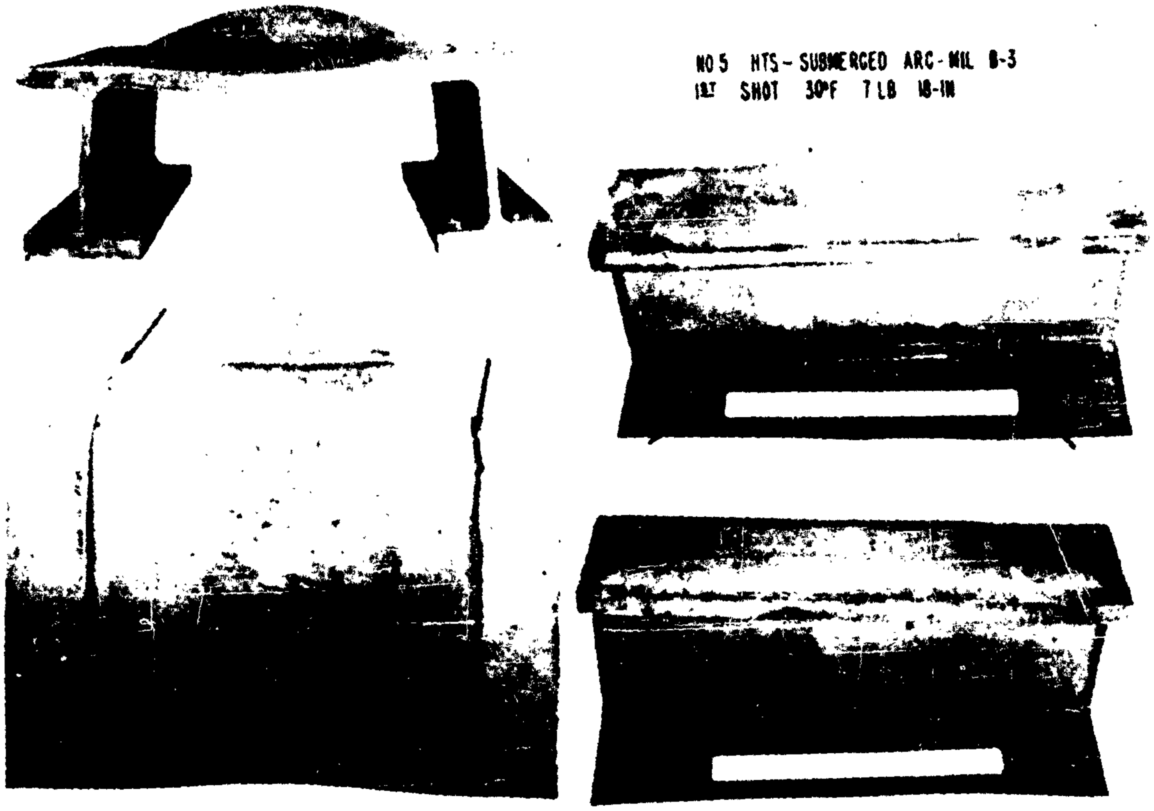

Figure 6 — Test specimen No. 5 after one explosive shot. Arrows indicate extent of ruptures.

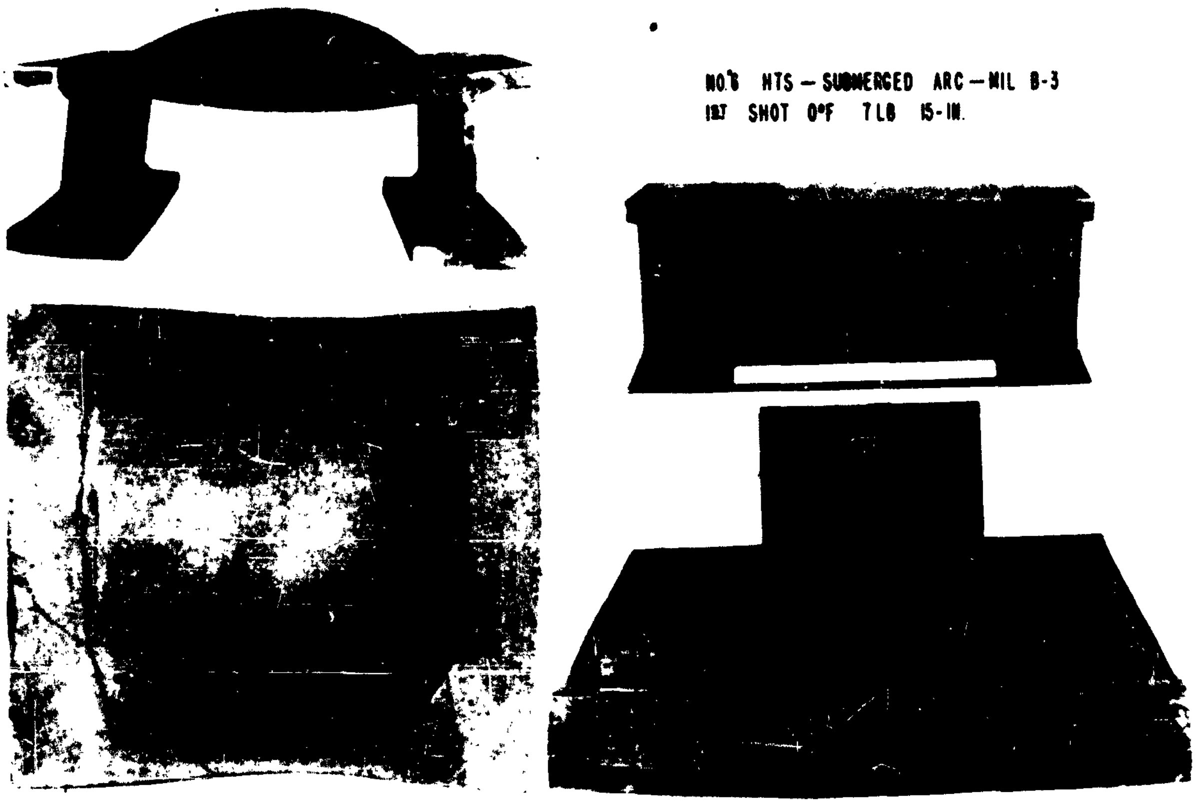

Figure 7 — Test specimen No. 6 after one explosive shot. Arrows indicate extent of ruptures. Insert shows submerged-arc weld failure.

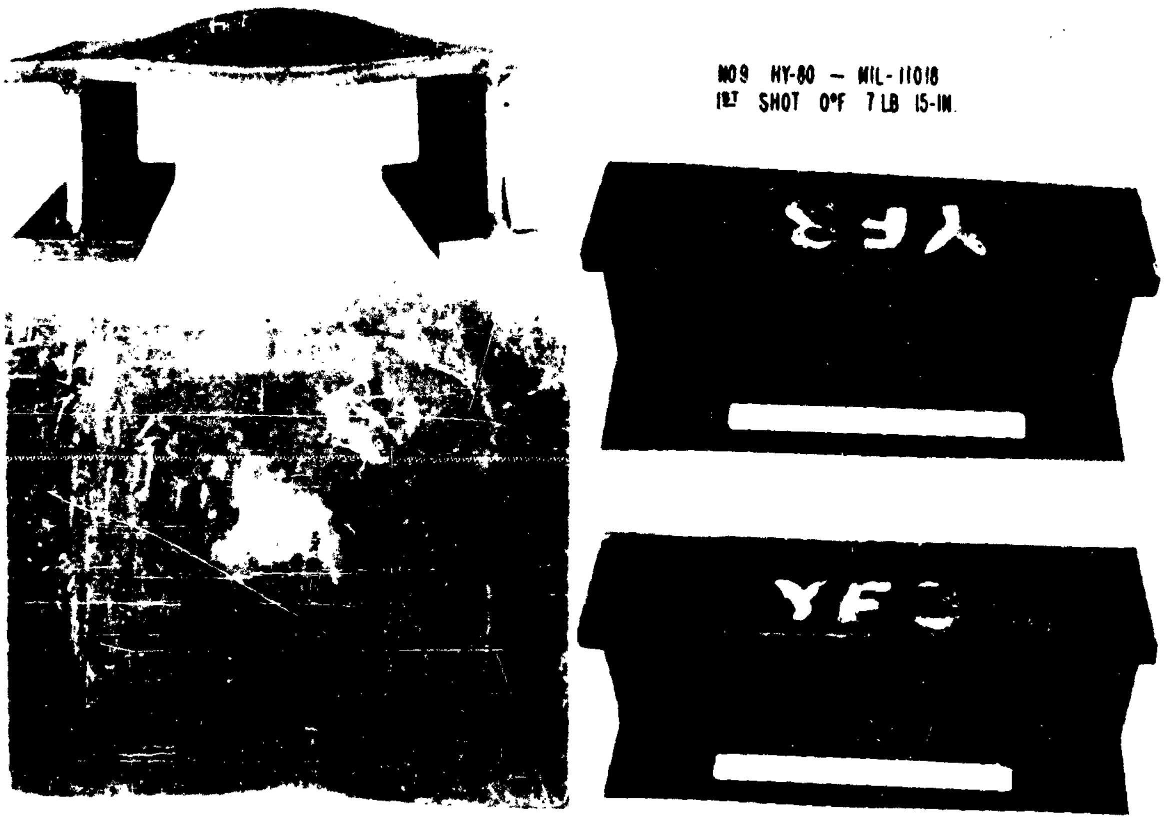

Figure 8 – Test specimen No. 9 after one explosive shot. Arrows indicate extent of ruptures.

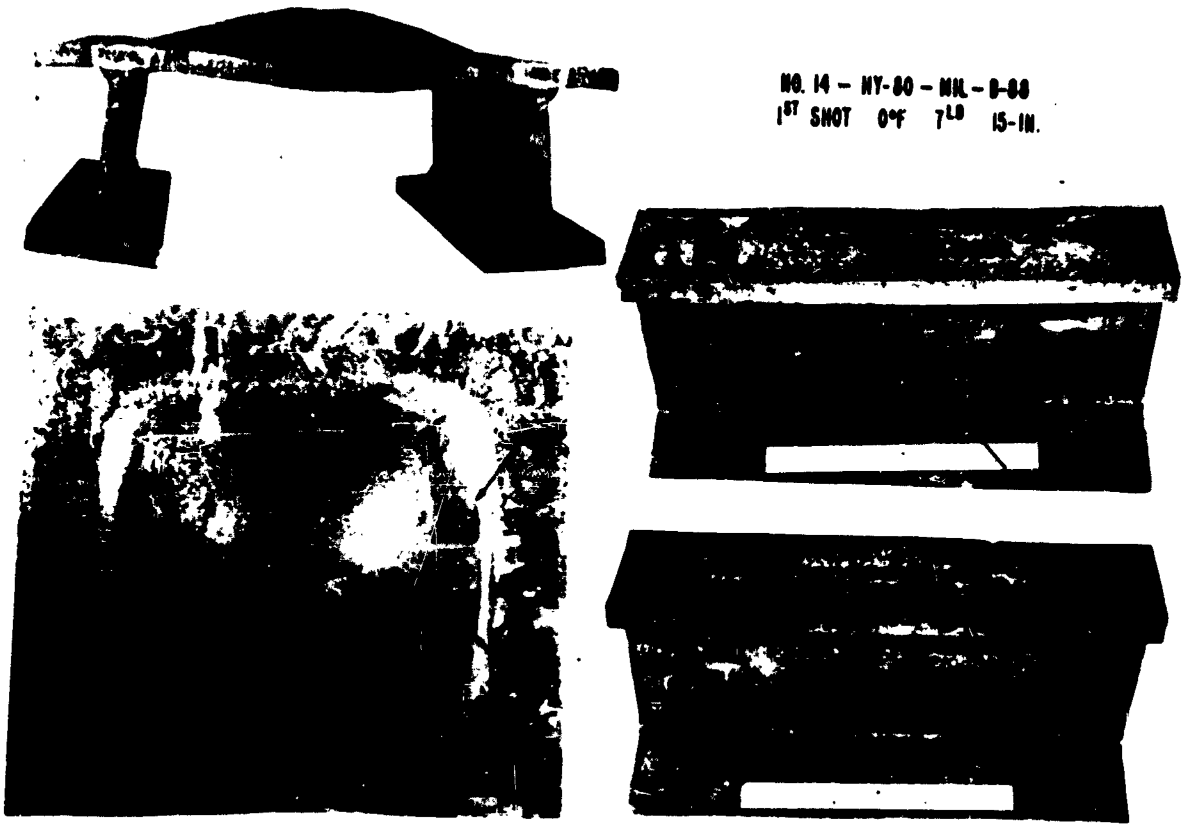

Figure 9 – Test specimen No. 14 after one explosive shot. Weld made vertical up. Arrows indicate extent of ruptures.

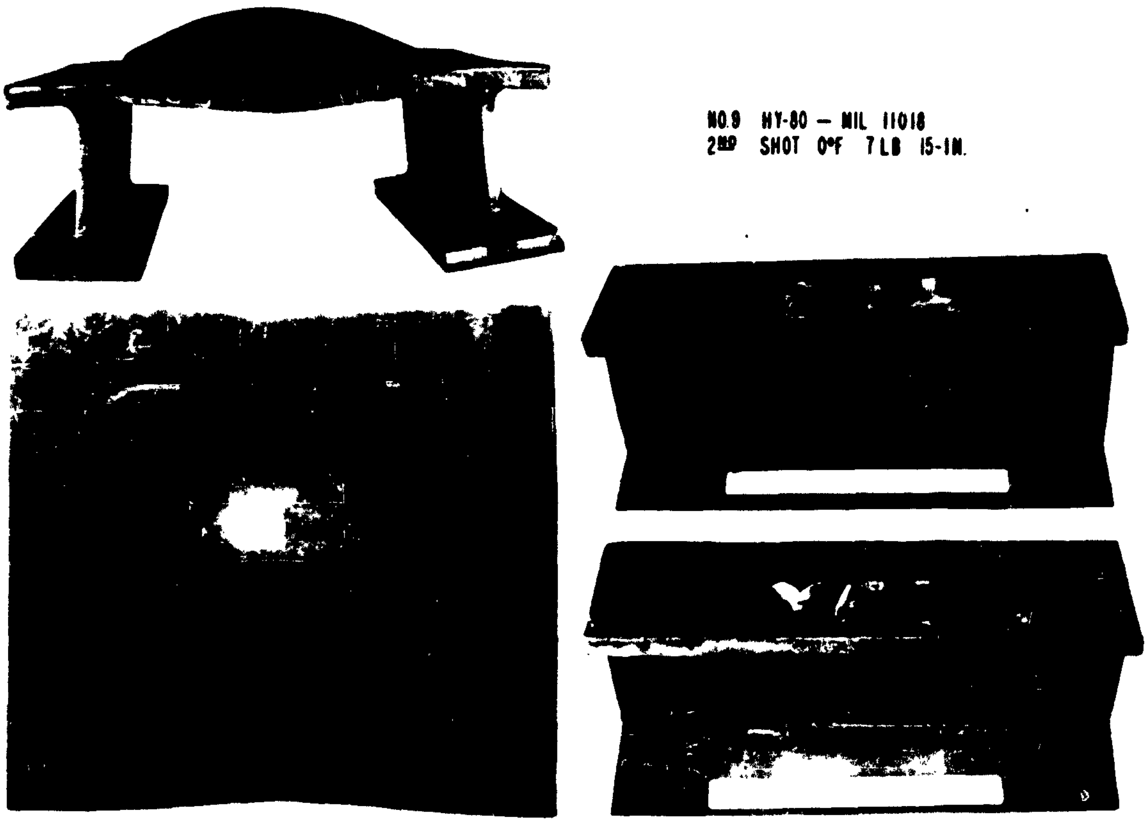

Figure 10 – Test specimen No. 9 after two explosive shots. Arrows indicate extent of ruptures.

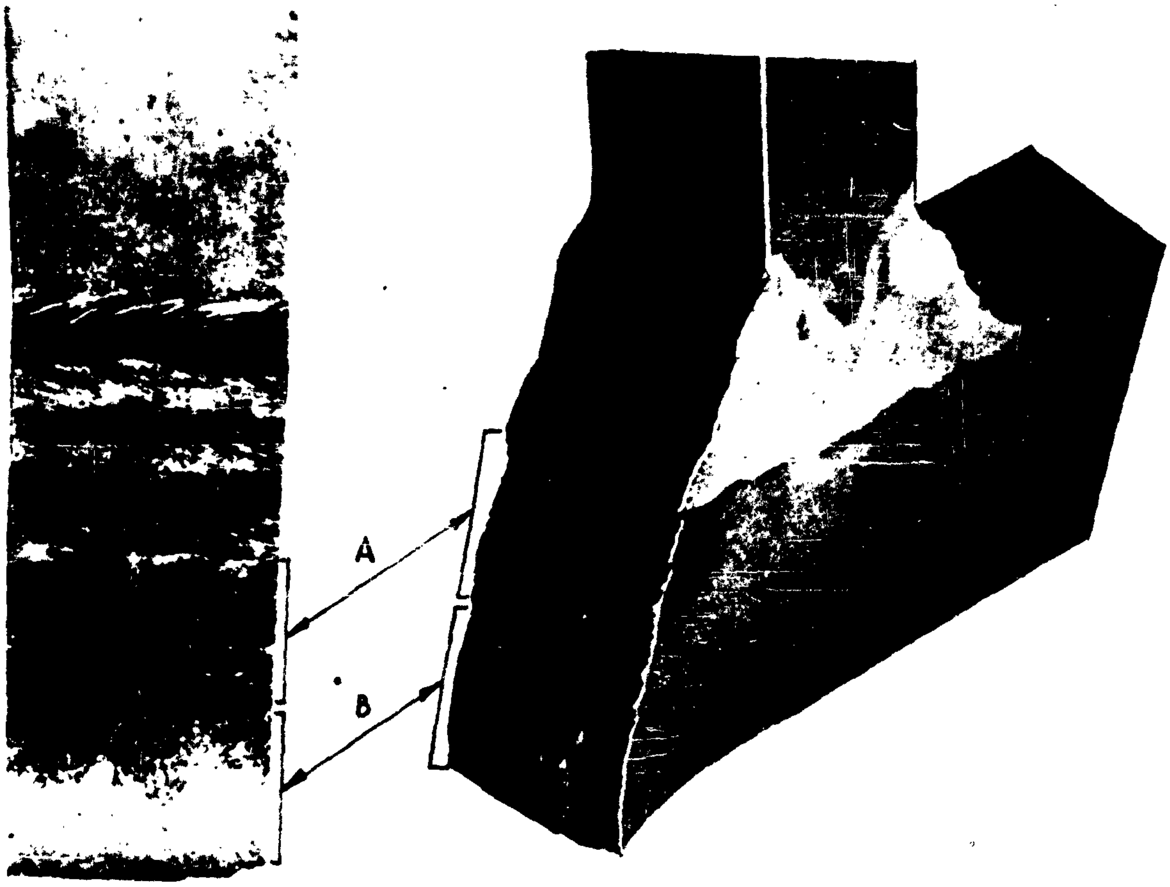

Figure 11 – Typical fracture of HY-80 test specimens showing tensile rupture (A) and shear rupture (B) in failure process.

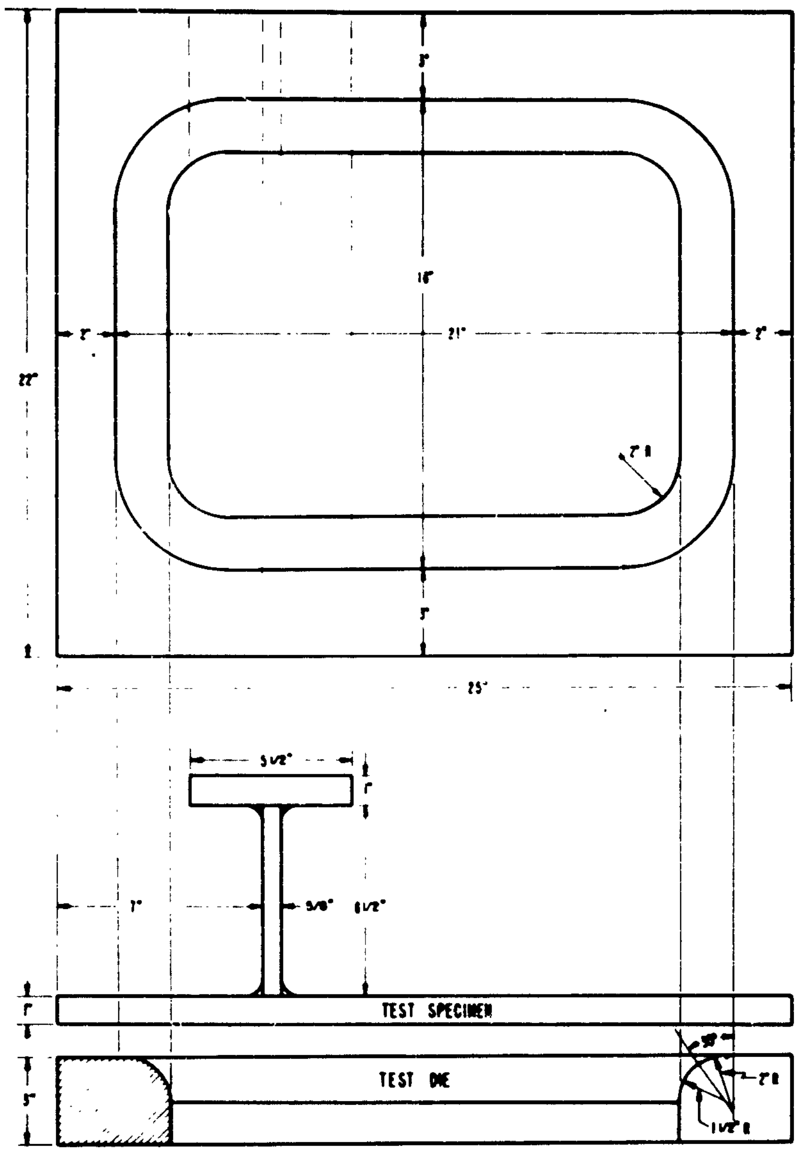

Figure 12 — Modified explosion test specimen and test die designed to produce greater distribution of strain over weld joint. Note diminished support of die beneath tee web.

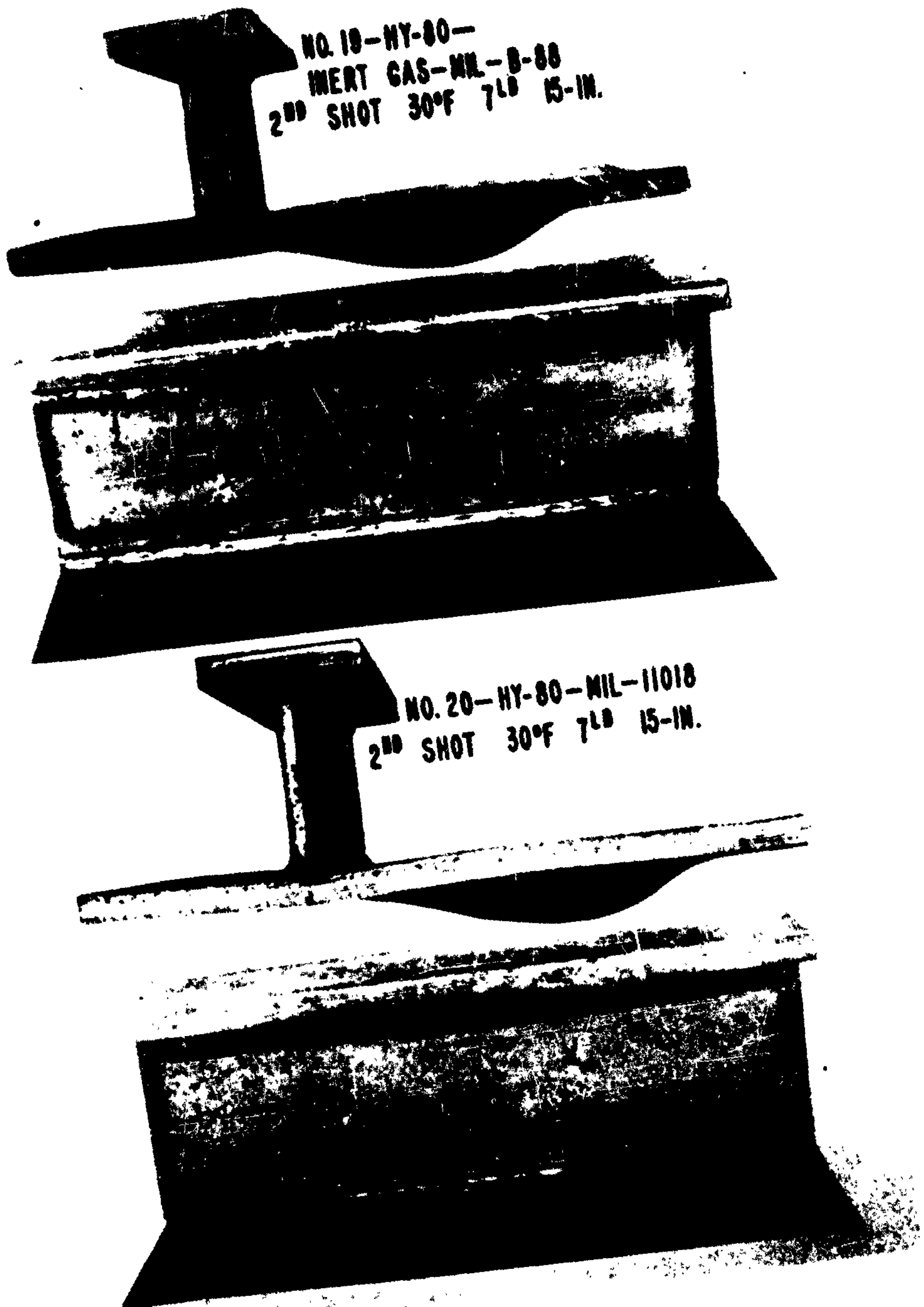

Figure 13 – Test specimens No. 19 and 20 after two explosive shots. Both specimens welded with approved weld metals. Arrows indicate extent of ruptures.

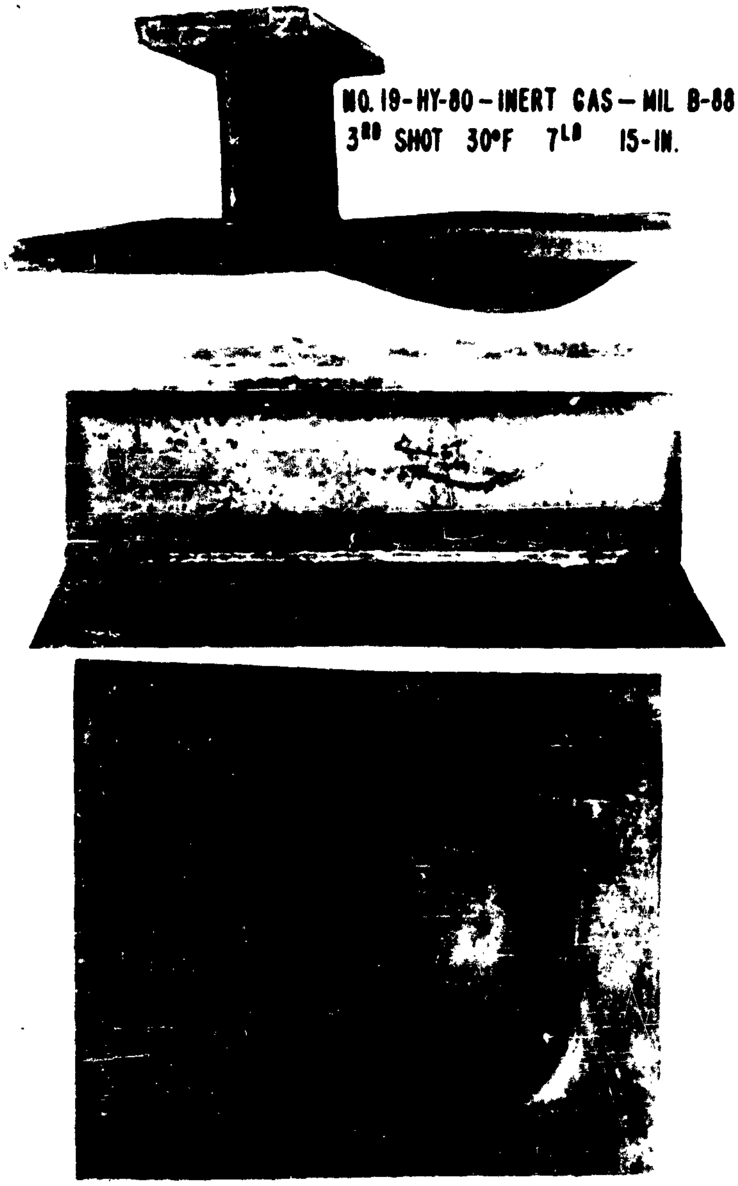

Figure 14 – Test specimen No. 19 after three explosive shots. Arrow indicates extent of rupture.

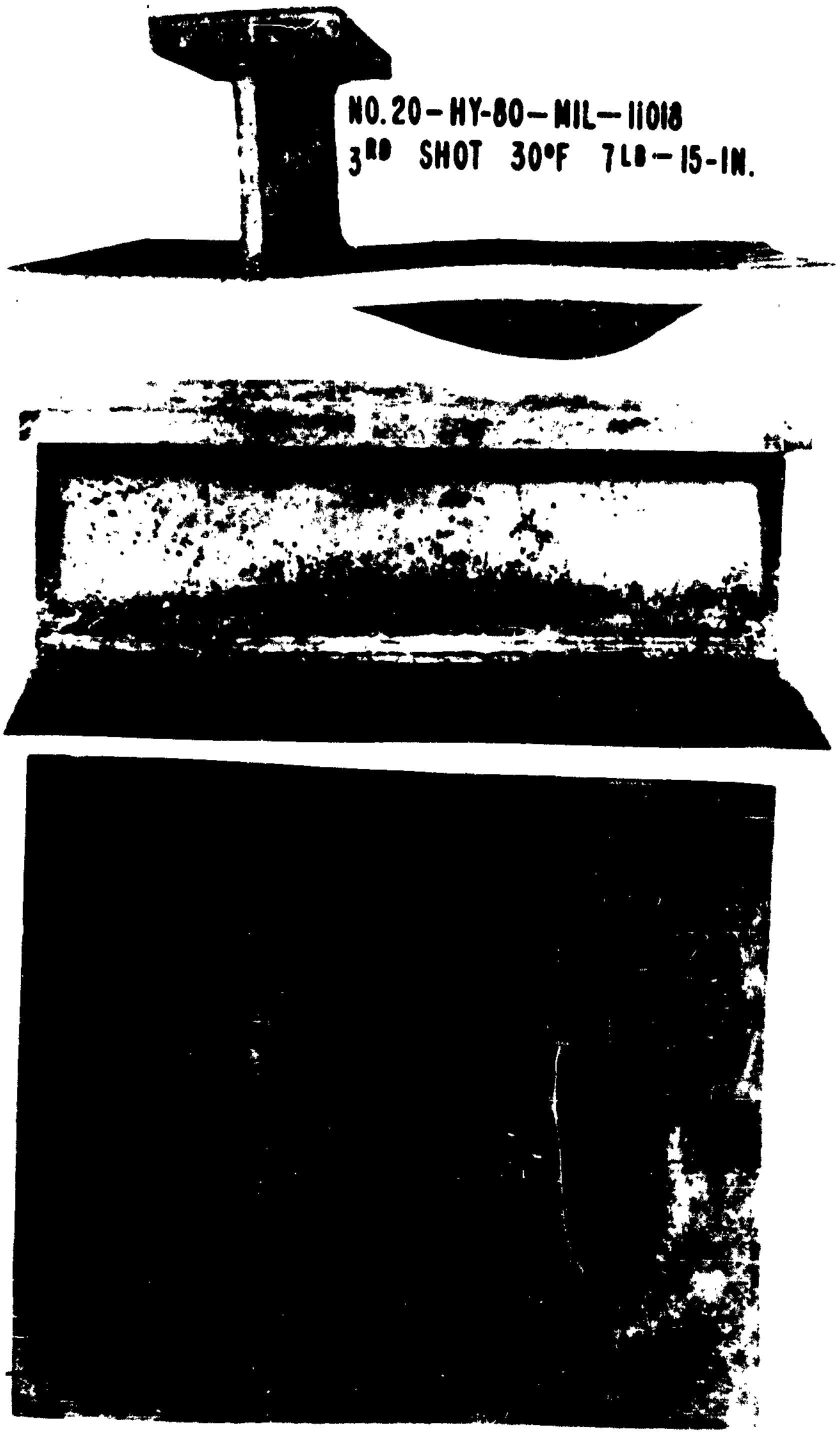

Figure 15 – Test specimen No. 20 after three explosive shots. Arrows indicate extent of rupture.

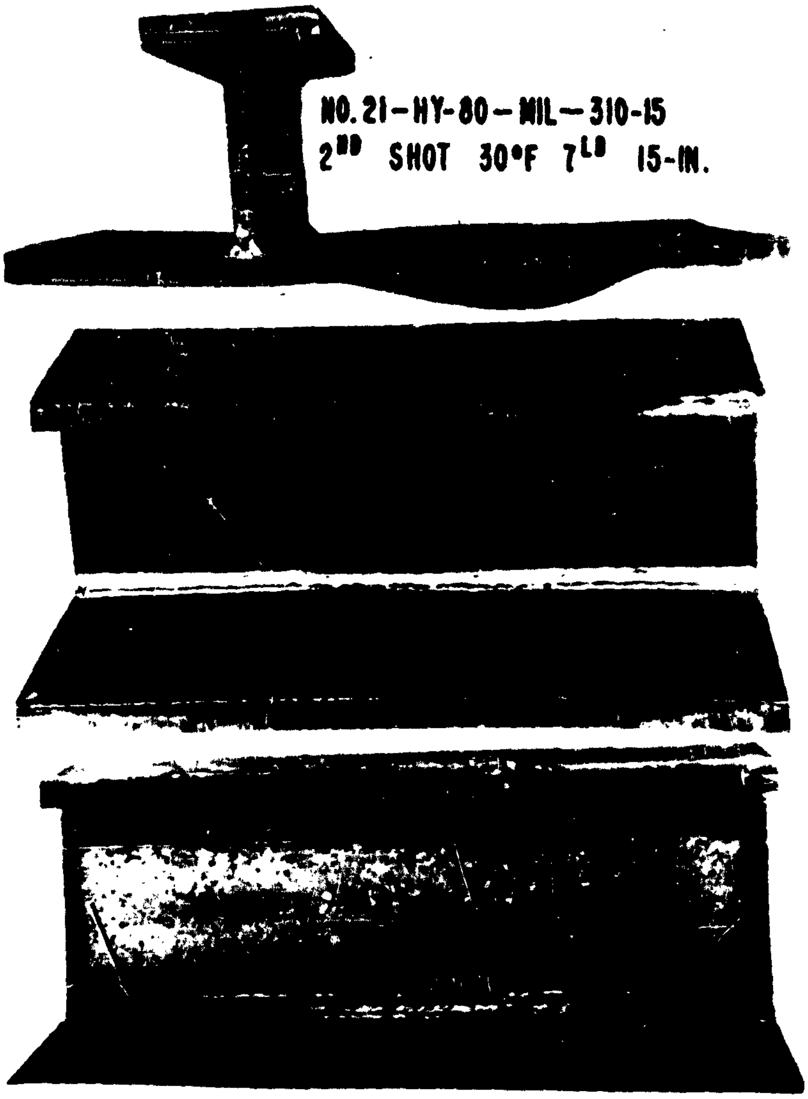

Figure 16 – Test specimen No. 21 after two explosive shots. Arrows indicate extent of rupture in web section.

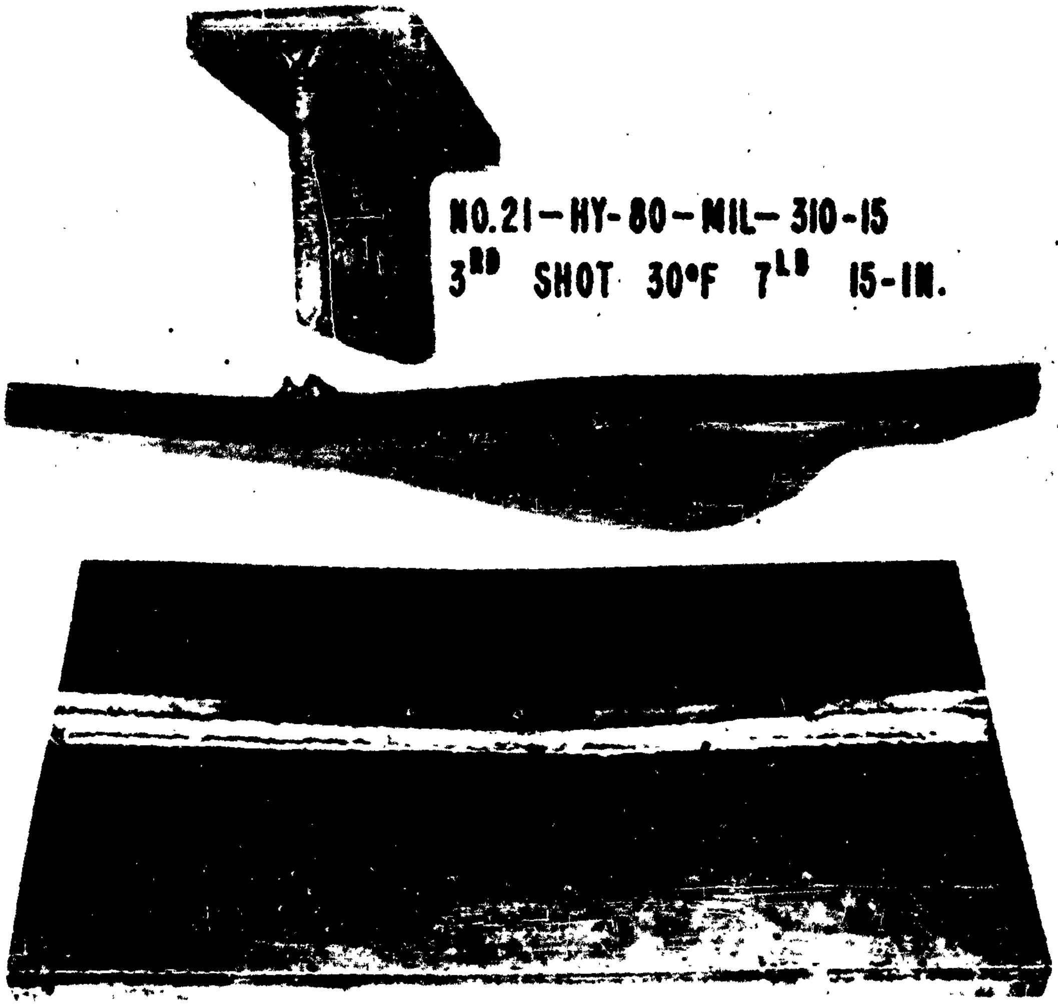

Figure 17 – Test specimen No. 21 after three explosive shots showing complete fusion-line separation of web section.

EXPLOSION-BULGE TEST PERFORMANCE OF EXPERIMENTAL SUBMERGED-ARC WELDMENTS OF HY-80

by

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Abstract

The materials and welding processes currently used for fabricating critical Navy structures, such as submarines, have received Bureau approval because they have been shown to produce weldments which possess maximum resistance to fracture at cold water temperatures. The demands of the current HY-80 submarine construction program make it desirable to have additional, approved automatic welding procedures to supplement the existing manual and automatic welding processes. To date, no submerged-arc welding process has been approved for this application because of generally poor performance of such weldments in explosion-bulge tests. This report presents recent test results for new submerged-arc welding developments.

Test results described herein showed that certain combinations of submerged-arc materials and techniques produce weldments which do not meet minimum fracture performance requirements necessary for submarine service. The weldments produced in these cases are considered unsatisfactory because they exhibit potential paths of low resistance to fracture propagation in welds of either brittle or low-energy-absorption shear features. Other test results are presented for experimental materials which demonstrate that it is possible to produce highly notch-tough, high-strength submerged-arc weld deposits. It is believed that such materials and techniques will be suitable for automatic submerged-arc weldments with weld metal toughness characteristics equal to or superior to those currently obtained with Bureau-approved electrodes.

INTRODUCTION

Explosion bulge studies have shown that the Q&T high alloy steels are much more suitable for "military case" structures (submarine hull, torpedo defense system, etc.) than normalized medium-carbon or low-alloy steels. With Q&T steels, it is possible to develop the optimum combination of strength and notch toughness required to best withstand at cold water temperatures the massive structural deformations expected under explosive attack. Of all commercially available Q&T alloy steels, it has been demonstrated that weldments of the alloy designated as HY-80 (Mil-S-16216C) could provide the greatest assurance of complete resistance to brittle fracture at these low temperatures (1, 2, 3, 4, 5). During recent years, the use of HY-80 has steadily increased for all critical BuShips submarine construction.

To date, the submerged-arc welding procedures have not been approved for the welding of HY-80 structures because explosion-bulge test results have shown that the commercially available high strength materials and submerged-arc techniques produce either brittle weld deposits or inferior HAZ regions at submarine operating temperatures (3, 5). Certain features, such as the magnitude of the HY-80 construction program, the shipyard availability of equipment and trained operators, and the reduction of eye-safety hazards inherent to submerged-arc welding techniques, have made it desirable to develop and qualify submerged-arc welding materials and procedures suitable for automatic welding of HY-80. Accordingly, a continuing development and test program involving NRL, Naval and industrial shipyards, and industrial welding equipment companies was established by BuShips (Code 637). This report presents recent explosion-bulge test results for new submerged-arc welding developments. Specific details concerning procedures and materials used for all weldments to be described herein are given in Table 1.

PERFORMANCE OF HY-80 WELDMENTS OF COMMERCIALLY-AVAILABLE SUBMERGED-ARC MATERIALS

The explosion-bulge test conditions employed in this investigation duplicated those used previously in other investigations of HY-80 weldments. All explosion tests were conducted at 0°F test temperature to permit comparisons with previously reported tests of various Q&T steel (4-8). In conventional explosion-bulge tests, explosive shots which develop small deformations (2-4% thickness reduction) are repeated until the first visible signs of failure are obtained. Generally, testing of any one sample is discontinued if no visible failure is observed after the 3rd shot. Such techniques permit a differentiation between weldments by delineating the critical regions and the level of deformation at which failures may start and subsequently propagate in a given weldment. For screening purposes aimed at a reduction of testing time and costs, occasional weldments were modified by the addition of crack-starter welds and tested with only one explosive shot*.

The majority of 1-in. thick weldments received for this investigation were generally larger than the 20-in. square size required for explosion tests. Prior to bulge testing, the surplus material was removed for NRL studies of plate and weld metal properties. For those weldments with sufficient material, the NDT temperatures of the HY-80 also were established by drop-weight tests of sub-size specimens cut from the plate surfaces. Table 1 lists the NDT temperatures for 10 of the HY-80 plates investigated herein. As expected for specification quality HY-80, the range of NDT temperatures (-100° to -200 F) indicates that all of these plates would exhibit 100% shear fracture characteristics (i.e. highest possible resistance to fracture) at cold water temperatures.

The submerged-arc welding process is particularly amenable to the use of welding conditions which result in the rapid deposition of a large amount of weld metal. However, in early tests HY-80 weldments made with commercially available submerged-arc materials and high J/in.* welding conditions (70,000 to 108,000 J/in.) were found to be characterized by high brittleness of the weld or the HAZ (3). Subsequently, similar weldments made with lower J/in. welding conditions (approximately 45,000 J/in.) were shown to develop explosion test failures which were predominantly brittle fractures within the weld metal (5). For this investigation, the commercially available submerged-arc materials were used by two different welding equipment manufacturers to fabricate additional HY-80 weldments. Relatively low J/in. welding conditions (32,400 J/in.) were used by one company with its commercial electrode and an experimental Ni-alloy flux to prepare samples 1-3. The low shelf values obtained in weld metal Charpy V tests (Fig. 1, Top) indicate this weld deposit to be characterized by low-energy shear features. In addition, the impact values obtained at -60°F test temperature (11 to 25 ft-lb) are significantly inferior to those obtained with welds that are Bureau approved for the welding of HY-80 (20 ft lb minimum at -60°F). Previous investigations of other low-energy shear materials (welds and plate) have shown them to be unsatisfactory for "military-case" structures (3,4).

The appearances of samples 1-3 after one shot in the explosion test are shown in Fig. 2. The numbers shown on each weldment represent sample No. and test temperature (top) and total number of shots (lower right). Of particular significance is the fact that each of these low J/in. samples developed failures which were uniquely confined to the fusion line of the weldments, as shown by the photomacrograph in Fig. 2, Bottom right. Similar failures in HY-80 weldments have been observed only when austenitic type electrodes (Mil 310-15) were used (6). The extensive fusion-line failure which developed in the sample modified with a crack-starter weld (Fig. 2, Bottom left) indicates exceptionally low resistance to fracture propagation, and, therefore, that the materials and low J/in. welding conditions which were used are conducive to the development of an undesirable condition in HY-80 weldments.

Samples 4-6 consisted of single V butt welds that were described as having been fabricated with a "special composition" of the company's commercial submerged-arc products. Weld metal Charpy V tests (Fig. 1, Bottom) indicated this deposit to be brittle at 0°F and lower test temperatures. Brittleness of this weld deposit was also indicated by the development of numerous, transverse (square-break) weld cracks in the explosion-bulge tests conducted at 0°F (Fig. 3). The high resistance to fracture (-170°F NDT) of the HY-80 plate is shown by the complete refusal of the plate to propagate any of the brittle weld cracks. Complete failure of these bulge test samples occurred in each case on the 1st explosive shot principally via weld paths and separation of the brittle weld at or near the fusion line.

*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.

*J/in. represents energy units per inch of weld expressed as Joules/in. and calculated from the welding conditions (Amps x Volts x 60 sec/min divided by in./min travel speed). The J/in. factor is indicative of the heat generating conditions in welding because 1 Joule is approximately equal to 0.24 calorie.

SUBMERGED-ARC WELDMENTS MODIFIED WITH NOTCH TOUGH SURFACE WELDS

Earlier investigations demonstrated the feasibility of using overlays of notch-tough welds to prevent the initiation and propagation of brittle fracture in otherwise brittle, structural mild steels (7). In those studies, crack-starter tests were used to indicate that notch-tough overlays could be valuable in the prevention of initiation or in stopping the propagation following short runs of the fracture. However, these studies pointed out that practical application of the principles required consideration of the load characteristics of the structure. Although the previous crack-arresting studies were not considered for "military-case" applications, the principles involved were investigated by one industrial welding equipment manufacturer and the Mare Island Naval Shipyard (MINSY) as an alternate procedure to improve the explosion-bulge test performance of submerged-arc weldments. Their techniques involved welding of the major portion of the weld-joint by various submerged-arc procedures and completing the final surface layers of the weld deposit with Bureau-approved, notch-tough electrodes (manual Mil-11018 or automatic Mil-B-88).

Only two basic compositions were used for the submerged-arc portion of the weld deposits in the modified samples 7-22, inclusive. The submerged-arc materials and welding conditions used for samples 7-10, inclusive, were similar to those which developed low-energy-absorption Charpy V features for the weld metal as reported in Fig. 1, Top, for samples 1-3. Figure 4 depicts results of Charpy V impact tests conducted with specimens cut from the modified submerged-arc weldments obtained from MINSY. Low impact values were obtained with the specimens that were machined so as to test the submerged-arc (center) portion of the weld (Fig. 4, Bottom). In comparison, a considerable increase in Charpy impact resistance was obtained with the specimens machined so that one side of the specimen consisted of notch tough Mil-B-88 weld metal (Fig. 4, Top). Examination of the fractured Charpy specimens disclosed that shear-lips were developed at various test temperatures on the side of the specimen containing the notch-tough cover weld, but were not developed on the side containing the submerged-arc weld material. Similar Charpy V test results were obtained with the samples containing Mil-11018 weld metal overlays.

Table 2 summarizes the results obtained in explosion-bulge tests for the modified submerged-arc weldments. Samples 7 and 9 were submitted for test with the weld-crowns ground flush with the plate surfaces. Failures did not develop until the 4th shot for the ground samples, whereas failures occurred on the 2nd shot for the companion samples, Nos. 8 and 10, tested with weld-crown intact. Such performance is as expected and is attributable to the presence or absence of the geometrical notch at the toe of the weld crown. However, the general mode of failure was the same in all these samples (Nos. 7 to 10) which developed as fusion-line ruptures, (Fig. 5, Top and Bottom left), similar to those previously described for samples 1-3.

The details provided in Table 2 indicate that 10 out of 12 modified submerged-arc samples showed no visible failure signs after 3 shots in the explosion test. In addition, the failures which developed on the 4th shot on 4 out of 8 samples fabricated by MINSY were generally minor weld-tears which did not penetrate through the thickness, as shown in Fig. 5, Bottom right. Such performance in the explosion bulge test would normally be considered excellent, and these results appear to be superior to the one-shot, generally extensive failures obtained in previous tests of almost all other submerged-arc weldments.

In order to determine the type of fracture which could be forced in such modified weldments, sample No. 7 was subjected to an additional explosive shot after the development of the initial, limited failure along the fusion-line as shown in Fig. 6, Top. As described previously, the submerged-arc portion of this sample was characterized by low-energy shear (i.e. not brittle) features. Figure 6, Bottom, indicates that extensive weld-metal fracture was developed under the explosive load conditions which forced propagation of fracture in this sample. Accordingly, modified weldments which utilize materials that produce weld deposits of brittle or low-energy shear characteristics are not desirable for "military-case" structures, which require maximum resistance to fracture.

PERFORMANCE OF EXPERIMENTAL SUBMERGED ARC WELDS

In addition to independent efforts of the equipment manufacturers, some of the shipyard laboratories have been conducting Bureau-sponsored, extensive development investigations aimed at improving submerged-arc weld properties. Initial shipyard approaches to the development of suitable submerged-arc weldments involved the use of various flux materials with the Bureau-approved electrode (Mil-B-88) that was developed for the consumable-electrode inert-gas-shielded welding process. Because Charpy V test results of such weld deposits were found to be considerably inferior to those obtained with the inert-gas-shielded process, subsequent investigations have been concerned with the development of new electrode compositions in addition to studies of the effects of new combinations of flux materials. Screening of different combinations of submerged-arc materials has been based upon Charpy V or drop-weight results of the various weld deposits.

Several combinations of different submerged-arc materials have been reported to develop weld deposits that display nil-ductility-transition (NDT) temperatures below -100°F. These welds, however, have invariably displayed such low Charpy V shelf characteristics as to be unsuitable for "military-case" structures. Recent reports by an industrial research laboratory on a Bureau sponsored investigation have indicated the development of new flux materials which are successful in producing notch-tough submerged-arc welds with high-energy-absorption Charpy V features (8). Another similarly successful development of a notch-tough submerged-arc weld deposit by an industrial shipyard is to be described later. Bureau permission to investigate the explosion-bulge test performance of submerged-arc weldments made with two experimental electrodes developed by an industrial and a naval shipyard was received after shipyard results in drop-weight and Charpy V tests indicated that these weld deposits would be notch tough at cold water temperatures (NDT values for weld metal lower than -60 F or Charpy V higher than 20 ft-lb at -60°F).

For the electrode developed by the industrial shipyard (tentatively named Dynawire 80S), a commercially available flux material (GR. 80) was used to study changes in fracture performance of a series of weldments made with maximum J in. welding conditions which varied from approximately 40,000 to 80,000 J in. Representative weld-metal Charpy V and drop-weight test results for these samples are presented in Fig. 7. The weld-metal Charpy specimens of the 80,000 J in. welds did not develop full-shear fractures in tests at 60 F. The dotted portion of this curve has been extended to the temperature at which 100% shear fractures might be expected in Charpy V tests of this weld deposit. Generally, the Charpy V results of Fig. 7 indicate that low-energy-absorption features were developed by each of these weld deposits. Further, it should be noted that with increasing J/in. conditions, a small but perceptible decrease in weld metal impact resistance was developed at all test temperatures.

Of the various explosion test samples investigated herein, the prime plate areas of all except No. 28 (Fig. 8, Bottom left) exhibited high resistance to propagation of fractures at 0°F. The HY-80 plate material used for weldment No. 28 was shown in Table 1 to display an NDT of -100°F. The limited tearing of this plate is indicative of borderline FTP performance at 0°F. NRL experience and tests of similar materials (9) have indicated that this plate would display complete resistance to brittle fracture (i.e. 100% shear) at all temperatures of 30°F or higher.

Table 3 summarizes the results obtained in explosion-bulge tests for the submerged-arc weldments made with experimental materials. Out of six 40,500 J/in. weldments, one sample withstood 3 explosive shots with no visible failure indications, and two of these samples which failed after the 2nd shot are illustrated in Fig. 8, left. Sample No. 26 shown in Fig. 8, top right, is representative of the type of 3rd shot HAZ failures which developed in three of the 40,500 J/in. weldments. The failures in the above samples were limited in each case to the plastically deformed (bulge) areas of the samples. Out of the two 51,300 J/in. weldments which were bulge tested, one sample had not failed after the 3rd explosive shot while the other, after only 2 shots, developed a HAZ failure which propagated even through the hold down region, as shown in Fig. 8, Bottom right.

Figures 9 and 10 illustrate the results of explosion tests of the 60,000 and 80,000 maximum J/in. submerged-arc weldments made with the experimental Dynawire 80S electrode and Gr. 80 flux. Each of these samples developed complete failures with the application of one shot. Fractures in these samples appeared to start in the HAZ portion of the weldments but were propagated predominantly in the weld metal. The reason for modifying weldments with a crack starter weld is shown in Figs. 9 and 10 by the results obtained with one modified sample in each of these groups (weldments 34 and 39). The disclosure of such extensive paths of low resistance to fracture propagation in a crack-starter modified weldment should ordinarily preclude the necessity or expense of conducting additional conventional bulge tests with similar weldments. As seen in Figs. 9 and 10, identical failures along similar paths of low fracture resistance were obtained in conventional bulge tests of the other 60,000 and 80,000 J in. weldments.

The results described above for weldments made with similar materials are believed to show that a progressive degradation of HAZ toughness properties can be expected in HY-80 welded with increasing J/in. conditions. In each respective series, failures appeared to start in the HAZ of the samples. It should be recognized that extensive propagation of the fractures in the 60,000 and 80,000 J/in. samples was sustained principally in the low-energy shear weld metal. However, the samples fabricated with the higher J/in. conditions developed ruptures involving the HAZ on fewer shots, and, therefore, at lower levels of plastic deformation in the bulge test. Of particular significance with respect to the early ruptures in the latter samples was the fact that numerous transverse fissures were revealed in macroscopic examination of the HAZ portions of the various bulge specimen fractures. The photomacrograph insert in Fig. 10, Bottom right, shows a condition typical of that observed in the HAZ portions of the fractures developed in all of the 60,000 and 80,000 J/in. weldments. The weldments fabricated with lower J/in. conditions were returned to the industrial shipyard before they could be sectioned and examined for similar transverse crack indications. The presence of such flaws would facilitate the development of early ruptures in explosion bulge tests.

When little or no preheat is used in the welding fabrication of high-tensile steels, moisture in electrode coatings, or on joint surfaces, or hydrogen produced in the welding-arc atmosphere have been shown to be important factors in the development of HAZ fissuring similar to that observed in these weldments (10, 11). It is possible that precautions had not been taken in storage or during use to preclude moisture absorption in the flux materials used to fabricate the above weldments. Because these weldments were fabricated without preheat, it is believed that the materials and procedures used resulted in the development of similar HAZ flaws irrespective of the J/in. involved. However, the thermal effects of welding with the lower J/in. resulted in less degradation in HAZ properties and, therefore, greater resistance to the initiation of failure in the bulge test than that developed in the high J/in. weldments.

As a result of the above test results, additional submerged-arc weldments were not submitted for NRL appraisal until research conducted by the industrial shipyard indicated that the same electrode used with a new flux material developed considerably higher Charpy V energy absorption values at all test temperatures. Specific details concerning the weld metal, flux compositions, and welding techniques used were not provided by the shipyard. A small sample received for weld metal evaluation purposes was described as having been fabricated with the Dynawire 80S electrode and flux "A" under conditions which developed a maximum 40,500 J/in. and with a 200°F preheat and interpass temperature control. Concurrently, weld metal Charpy V and drop-weight test results of an experimental electrode and flux developed at the MINSY suggested that their materials also might prove to be satisfactory for submerged-arc welding of HY-80. Accordingly, samples involving three flux combinations and two J/in. conditions, as shown in Table 1, were received from MINSY for weld metal and explosion bulge test evaluations.

The Charpy V properties of these experimental submerged-arc weld deposits are summarized graphically in Fig. 11. In each case, the fracture appearances of the Charpy specimens indicated that these weld deposits were not brittle at cold water temperatures. Drop-weight tests conducted for samples 41 and 44 revealed NDT temperatures for these weld deposits of -140° and -160°F, respectively. Thus, test results obtained with these experimental materials are superior to those of all other previously tested submerged-arc welds. It should be noted, however, that the MINSY weld deposits are still characterized by relatively low-energy shear features (maximum Charpy V shelf values of approximately 35 to 45 ft-lb). Weld metal Charpy V and drop-weight test results of the industrial shipyard weld (No. 44), on the other hand, are considered to be the best of any submerged-arc weld metal previously tested at this Laboratory.

A separate report is to be issued by the Naval Weapons Laboratory concerning the generally excellent bulge test performance of 2-in. thick weldments prepared with materials and conditions similar to those reported herein for sample No. 44. The appearances of the MINSY experimental weldments after completion of the explosion bulge tests are illustrated in Fig. 12. With the exception of one transverse weld-tear developed in specimen No. 40, the failures in each of these samples were confined to the HAZ areas of the weldments. For the samples welded with approximately 43,000 J/in. (Fig. 12 Top) the ruptures in the HAZ developed on either the 2nd or 3rd shot; however, propagation of these failures were limited in nature in that they were confined to the plastically deformed bulge area and did not penetrate through the full thickness of the plate. For the 53,000 J/in. samples, complete rupturing occurred on the 2nd and 3rd shot as shown in Fig. 12, Bottom. Since similar conditions of preheat and interpass temperature control were reported for all of these samples, it is assumed that the higher J/in. conditions contributed to the development of the more extensive failures in the latter samples. It should be recognized, nevertheless, that the performance obtained with these bulge test specimens represents a considerable improvement over that of previously tested submerged-arc weldments which invariably developed complete ruptures on one explosive shot.

SUMMARY AND CONCLUSIONS:

As is common for all high strength, Q&T steels, the thermal effects of welding can develop microstructural conditions in the HAZ of HY-80 which display inferior properties to those of the unaffected plate material. Conventional laboratory test specimens are unable to indicate the degree of HAZ degradation which may result from welding variables. Such degradation, however, is readily apparent in explosion-bulge tests because the weld metal, heat-affected zone, fusion line and base metal are all subjected to an essentially uniform load field. Thus, variables in welding conditions, or materials which develop inferior regions in a given weldment can be measured qualitatively by (1) the level of deformation (1, 2, 3, or more shots) required for initiation of failure and (2) by the extent of subsequent fracture propagation in that region.

Test results obtained in this and previous investigations have consistently demonstrated that HY-80 weldments fabricated with welding conditions of approximately 40,000 to 50,000 J/in. develop an explosion test performance superior to that obtained with similar materials welded with considerably higher (60,000 to 80,000) J/in. In all of these investigations, however, quantitative evaluations of the degree of HAZ degradation developed by specific J/in. levels have never been fully established because of complications involving materials or other variables. In this investigation, for example, the complexities involving

HAZ fissures coupled with extensive fracture propagation in low-energy shear weld metal precluded quantitative evaluation of the degree of HAZ degradation developed in 60,000 and 80,000 J/in. samples welded without preheat. Accordingly, it should be recognized that the cumulative results from shipyard fabrication experience and various Bureau sponsored HY-80 weldability investigations conducted by NRL and other shipyard or industrial laboratories have been considered in the preparation of the BuShips summary instructions of the basic rules for welding of HY-80 (12). These instructions are aimed not only at alleviating problems concerning shipyard fabrication cracking in restrained welds, but also aimed to minimize HAZ degradation and provide maximum structural integrity of the end-product even under conditions of explosive attack.

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

(1) Test results presented herein indicate that weld deposits of inferior notch toughness can be developed by certain combinations of submerged-arc materials and techniques. A potential path of low resistance to fracture propagation is afforded by welds of either brittle or low-energy-absorption shear characteristics. Such weld characteristics at any service temperature precludes them from being suitable for "military-case" applications, where high resistance to fracture is required.

(2) Specification quality HY-80 employed throughout this investigation was demonstrated to be highly resistant to the initiation of fracture at 0°F test temperature (i.e. NDT of -100°F or lower for all plates). Complete resistance to fracture propagation at 0°F was shown by all except one plate which was considered borderline at 0°F. Because of thermal effects of welding, the fracture resistance of HAZ areas of HY-80 plates was shown to decrease progressively as the J/in. were increased from approximately 40,000 to 80,000. Weldments fabricated with very low J/in. (approximately 32,000) on the other hand, developed extensive failures which were uniquely confined to the fusion line of the weldment. At least in part, the fusion line may have proved to be the "weak-link" in these weldments because the weld deposit displayed low-energy-absorption features and welding conditions resulted in little or no degradation of the HAZ.

(3) Test results obtained herein have demonstrated conclusively that the notch-toughness properties of the surface material is the controlling factor concerning the initiation of failure in explosion-bulge tests. Accordingly, the use of notch-tough surface welds to cover otherwise brittle or low-toughness weld deposits can be expected to show increased resistance to fracture initiation in explosion tests of such weldments. However, such techniques provide areas of low resistance to fracture propagation under conditions of forced explosive loadings, and therefore, cannot be considered satisfactory for use in "military-case" structures.

(4) Results obtained for a limited number of samples in one test series corroborate previous data concerning the influence exerted by the weld crown which showed a detrimental effect of the mechanical notch present at the toe of a weld crown. With the weld crown ground off, the samples required 4 shots before failure developed; with the weld crown intact, the samples developed failures on 2 shots. Even in HY-80 welded with Bureau-approved electrodes, the toe of the weld crown is a stress concentration point. Although it would be impractical, if not impossible, to completely grind flush all weld joints in a submarine hull, the influence of the geometry of the weld crown should point out the desirability of training or cautioning the shipyard welders to "blend in" the weld crown as much as possible, and especially to avoid undercuts and highly convex contours.

(5) Test results presented herein for experimental materials have demonstrated the possiblity of producing high-strength submerged-arc weld deposits which are highly notch tough. Providing equivalent results can be obtained consistently with production heats of similar electrode and flux materials, it is believed that the toughness characteristics of weld metal deposited by automatic submerged-arc processes will be equal to those currently obtained with Bureau-approved electrodes.

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Table 1

Materials and Procedures for Explosion Test Samples

Sample Nos.	HY-80 Plate No.	HY-80 Plate NDT (°F)	Amps	Volts	Speed (imp)	No. of Passes	Energy* (Joules/in.)	Weld	Flux	Preheat (°F)	Interpass (°F)
1-3	1	-180	400	27	20	16	32,400	L-61	Axxx16	250	200-250
4-6	2	-170	500	30	20	13	45,000	---	---	None	200
7-8	1	-180	400	27	20	10+6**	32,400	L-61	Axxx16	200-250	200-250
9-10	1	-180	400	--	--	2+4+6**	***	"	"	"	"
11-14	3	-160	540	26-32	20-25	4+8**	41-42,000	0X68	Gr. 50	100	200
15-16	4	--	620	28-32	15-18	12+10**	66-79,000	"	"	"	"
17-18	5	--	"	"	"	"	"	"	"	"	"
19-22	6	-130	540	26-32	20-25	4+4****	41-42,000	"	"	"	"
23-27	7	-130	450-550	24-27	16-1/2-22	10	39-40,500	Dyna. 80S	Gr. 80	None	150
28-30	8	-100	"	"	"	10	"	"	"	"	"
31-32	8	-100	450-475	24-27	15-16.5	7	39-51,300	"	"	"	"
33	9	--	"	"	"	7	"	"	"	"	"
34-35	10	-180	450-575	24-35	"	24	39-80,500	"	"	"	"
36-37	11	-200	"	"	"	24	"	"	"	"	"
38-39	10	-180	450-500	24-30	15-16.5	24	39-60,000	"	"	"	"
40-41	12	-150	425	27	16	8	42,900	M1-88	6C48	150	200
42	13	-140	500	30	17	8	53,000	"	6C48+Acrosite B2	150	150-200
43	13	-140	500	30	17	8	53,000	"	6C48+L860	150	150-200
44	14	--	---	---	---	---	40,500	Dyna. 80S	A	200	200

---Not determined

*Does not consider conditions employed for root passes which varied for all weldments and often consisted of manual stick-electrode "tie-in" passes.

**Final surface layers consisted of manually welded MIL-11018 stick-electrode passes.

***Approximately 60% of weld completed with 1st two passes; first pass at 75,600 J/in.; 2nd pass at 88,000 J/in.; plus 4 passes at 29,500 J/in. followed by 6 manually welded surface layers with Mil-11018 stick electrodes.

****Final surface layers consisted of automatically welded, metallic inert gas (MIL-B-88 electrode) at 52,500 J/in.

Table 2

Explosion-Bulge Test Data for Modified Submerged-Arc Weldments

Sample No.*	Thick (In.)	Sub-Arc Weld	Surface Weld	Charge (lb)	Stand off (In.)	1st Shot	2nd Shot	3rd Shot	4th Shot	Failure Description
7	1	L-61	11018	7	15	N	N	N	F	7" Fusion Line
8	1	"	"	7	15	N	F			10" Fusion Line
9	1	"	"	7	15	N	N	N	F	3" Fusion Line & Transverse Weld tear
10	1	"	"	7	15	N	F			10" Fusion Line & Transverse Weld tear
11	1	0X-68	"	7	15	N	N	N	N	
13	1	"	"	7	15	N	N	N	F	2 Transverse weld tears
14	1	"	11018	7	15	N	N	N	N	
18	2	"	"	28	15	N	N	N	F	5" HAZ & Transverse weld tear
19	1	"	B-88	7	15	N	N	N	F	Transverse weld tear
20	1	"	"	7	15	N	N	N	N	
21	1	"	"	7	15	N	N	N	N	
22	1	"	"	7	15	N	N	N	F	Transverse weld tear

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

N = No visible indication of failure. Testing was discontinued after the 4th shot.

F = Failure as described.

TABLE 3

Explosion-Bulge Test Data for Experimental Submerged-Arc Weldments

Sample No*	Thick (in.)	Sub-Arc Weld	Flux	J/in.	Charge (lb)	Standoff (in.)	1st Shot	2nd Shot	3rd Shot	Failure Description
24	1	Dynawire 80S	Gr. 80	40,500	7	15	N	F		Transverse weld
25	1	"	"	"	"	"	N	N	F	15" HAZ & Transverse weld
26	1	"	"	"	"	"	N	N	F	15" HAZ
28	1	"	"	"	"	"	N	F		Transverse weld
29	1	"	"	"	"	"	N	N	N	
30	1	"	"	"	"	"	N	N	F	15" HAZ transverse weld
32	1	"	"	51,300	"	"	N	F		17" HAZ
33	1	"	"	"	"	"	N	N	N	
35	2	"	"	80,000	28	15	F			30" weld-HAZ separation
36	2	"	"	"	"	"	F			30" weld-HAZ separation
37	2	"	"	"	"	"	F			30" weld-HAZ separation
38	2	"	"	60,000	"	"	F			30" weld-HAZ separation
40	1	M1-88	6C48	42,900	7	"	N	N	F	10" HAZ & transverse weld
41	1	"	"	"	"	"	N	F		8" HAZ
42	1	"	6C48+B2	53,000	"	"	N	F		20" HAZ separation
43	1	"	6C48+860	"	"	"	N	N	F	20" HAZ separation

*Sample Nos. which are omitted were given one shot in the crack-starter-modified bulge test or used for drop-weight and Charpy V tests.

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

F = Failure as described.

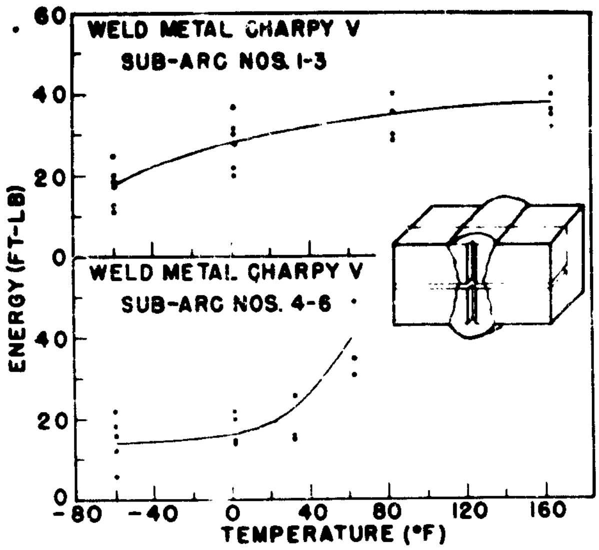

Figure 1 — Charpy V notch test results of welds of commercially-available submerged-arc materials exhibiting low-energy shear (top) and brittle fracture (bottom) at cold water temperatures.

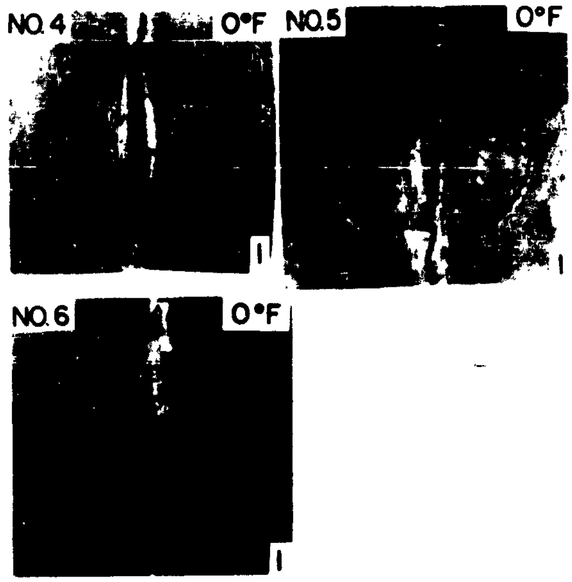

Figure 3 — Explosion-bulge test samples showing poor HAZ toughness and brittle weld performance.

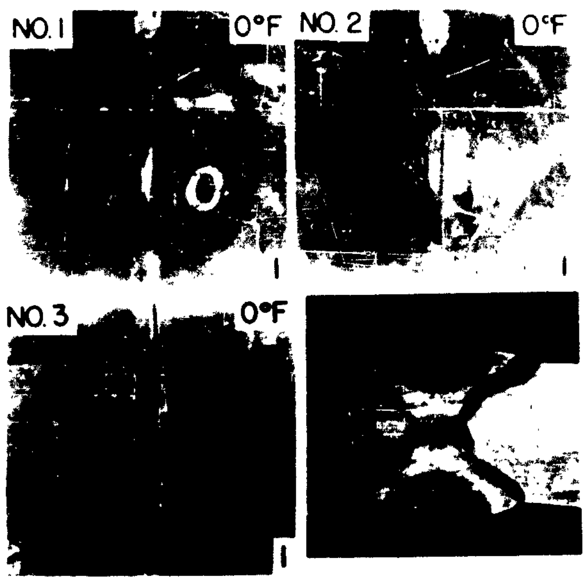

Figure 2 — Explosion-bulge test samples showing fusion-line fracture at low levels of deformation.

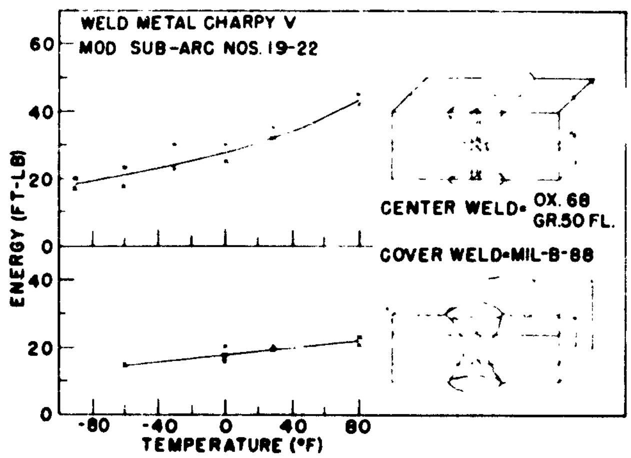

Figure 4 — Charpy V curves of capped submerged-arc welds. Results with duplex specimens machined to include both weld metals (top) and with submerged-arc weld metal only (bottom).

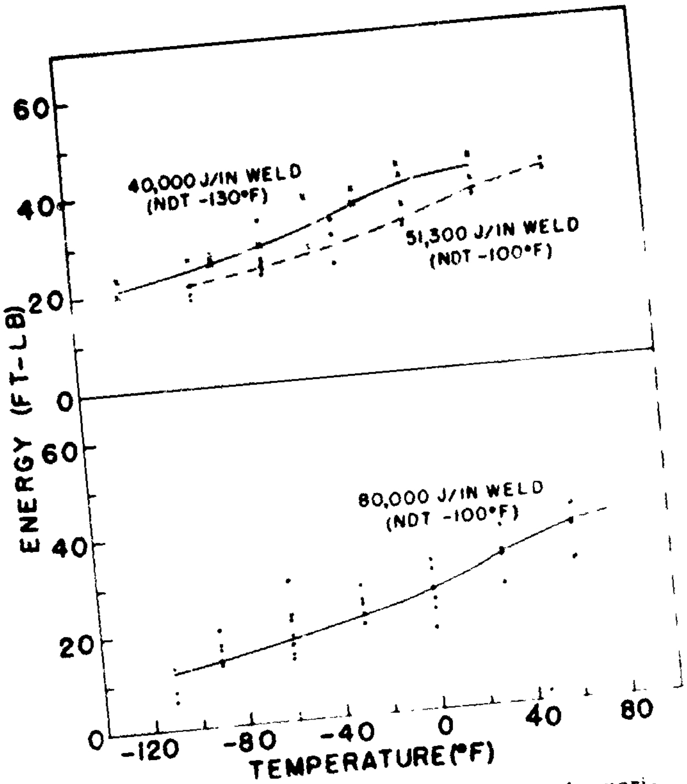

Figure 7 – Charpy V notch test results of experimental sub-arc weld metals deposited at three levels of heat input.

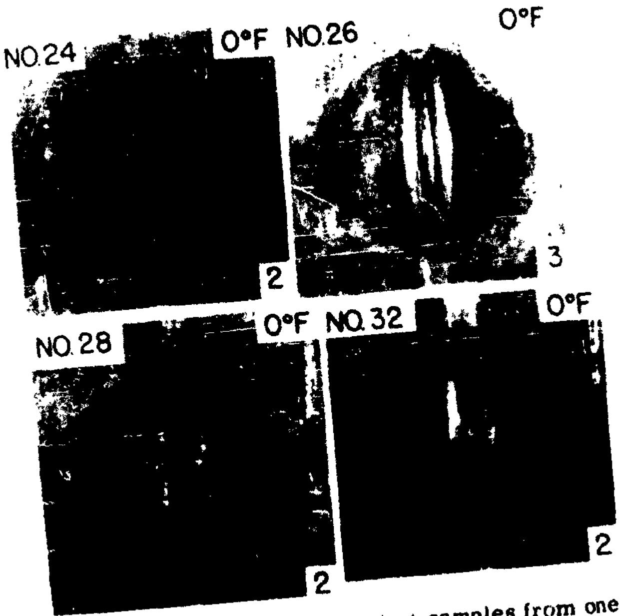

Figure 8 – Explosion-bulge test samples from one source with experimental sub-arc weld metals welded at 40,500 and 51,300 (bottom right) J/in.

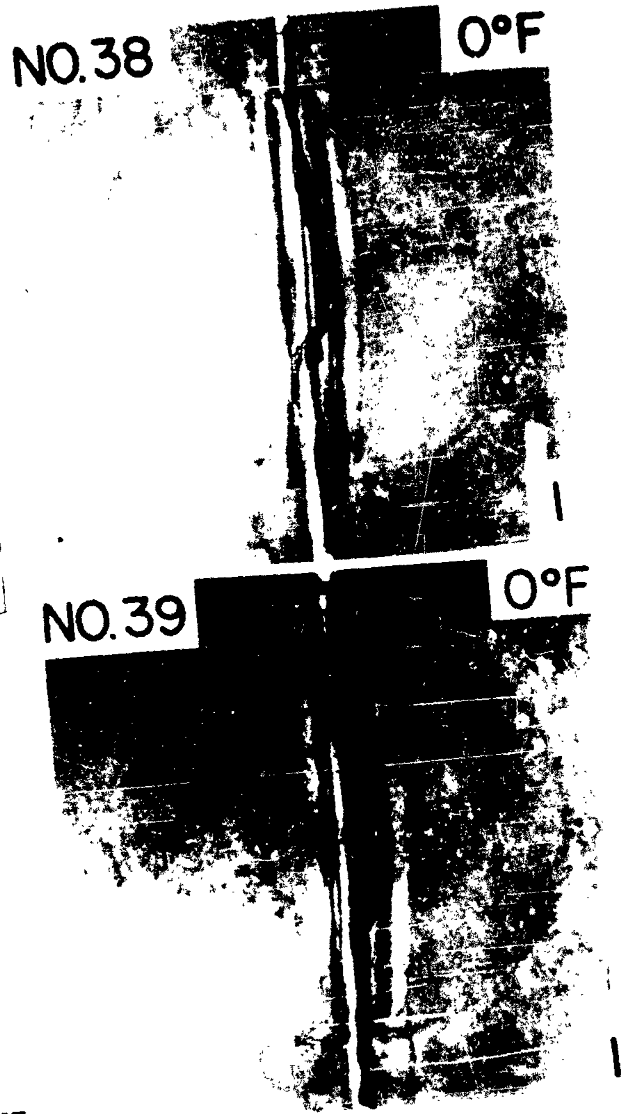

Figure 9 – Explosion-bulge test samples of 2-in. thick experimental sub-arc weldments from one source. Sample No. 39 modified with a crack-starter weld.

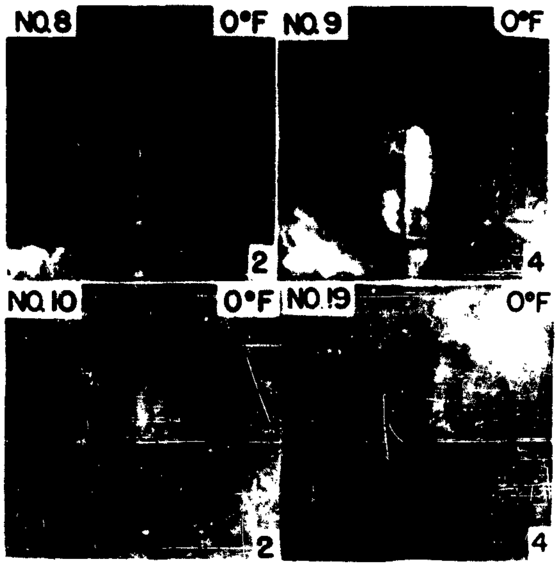

Figure 5 – Explosion-bulge test samples with modified sub-arc welds (capped with Bureau-approved weld metal). Sample No. 9 was tested with weld crown removed.

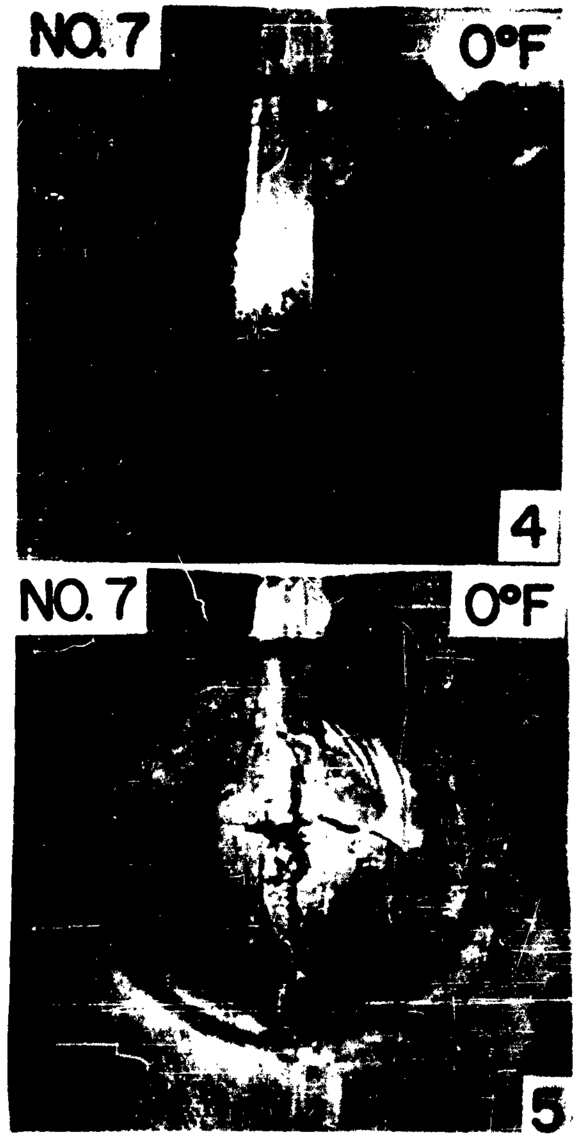

Figure 6 – Explosion-bulge test sample with modified sub-arc weld. Weld crown removed and tested to visible signs of failure (top), and under conditions of forced propagation (bottom).

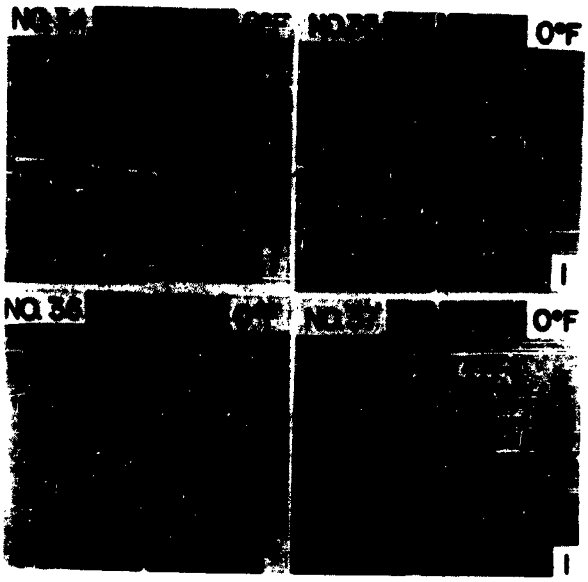

Figure 10 – Explosion-bulge test samples of 2-in thick experimental sub-arc weldments from one source. Sample No. 34 modified with crack-starter weld. Photomacrograph insert on Sample No. 37 shows numerous transverse fissures in HAZ.

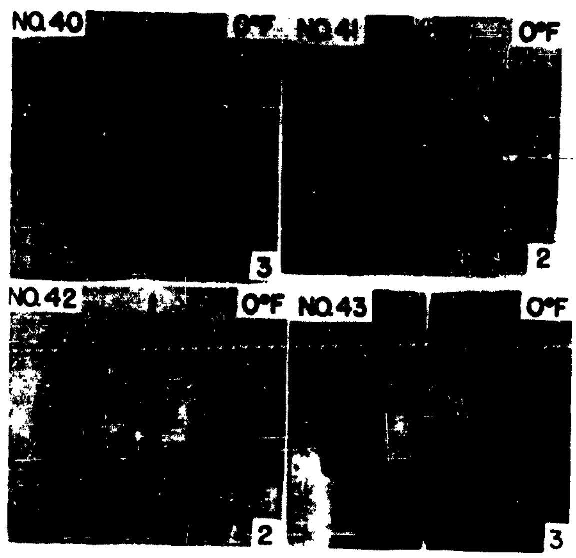

Figure 12 – Explosion-bulge test samples with experimental sub-arc weld metals from MINSY prepared with 43,000 (top) and 53,000 (bottom) J/in.

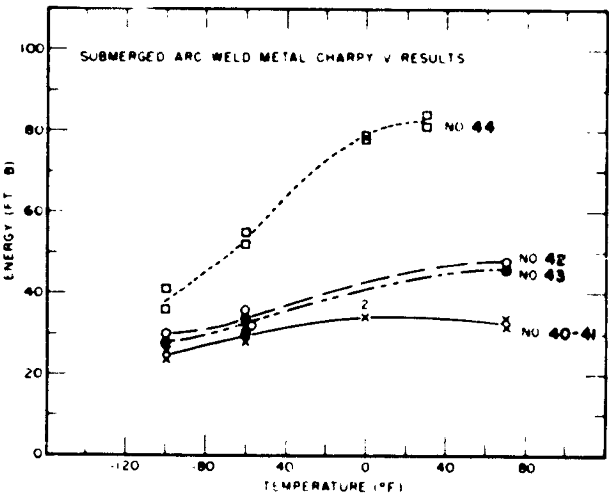

Figure 11 – Charpy V impact test results of experimental sub-arc weld metals received from MINSY (Nos. 40-43) and an industrial shipyard (No. 44).

NOTCH TOUGHNESS EVALUATIONS OF MODIFIED HY-80 STEEL IN HEAVY GAGE PLATES

by

A.J. Babecki and P.P. Puzak

ABSTRACT

Welding fabrication experience with low-alloy HY-80 in plate thicknesses of 1-1/4-in. and under has been good even without strict welding controls. The higher alloy content of heavier gage HY-80 required strict compliance with stipulated welding procedures for trouble-free fabrication. The added expense and production rate reduction resulting from such tighter welding controls prompted a request for special Bureau of Ships permission to specify the low-alloy composition for HY-80 in thicknesses of 2-1/2-in. or more. The request was denied, but it led to a cooperative test program, involving the Naval Research Laboratory, the Naval Proving Ground, and the Philadelphia Naval Shipyard, which was to examine more rigorously the question of low notch toughness in heavy-gage low-alloy HY-80.

Low-alloy HY-80 in plate thicknesses of 1-1/4, 1-3/4, 2-1/2, and 3-in. was procured from two suppliers and was to be given extensive evaluation. However, preliminary drop-weight test results showed that the notch toughness of the low-alloy HY-80 was seriously and progressively impaired as plate thickness increased. This conclusion was unequivocally confirmed by the results of crack-starter explosion bulge tests of full-thickness butt weldments which showed the 2-1/2 and 3-in. plates to be brittle at 0° F and, therefore, unsuitable for submarine application.

INTRODUCTION

Of all high strength structural steels which have been investigated, the low-carbon quenched and tempered Ni-Cr-Mo steel known as HY-80 has exhibited the best optimum combination of weldability, notch toughness and high energy absorption characteristics. Because of these characteristics, HY-80 has found increasing applications in many critical welded structures. In order to provide the hardenability required to develop the desired level of toughness equivalent to that of 1-1/4" thick plates in heavy section plate, the composition limits specified for Ni, Cr, and Mo were increased as specified in Table 1. The composition ranges for what is now commonly referred to as "low-chemistry" HY-80 and "high-chemistry" HY-80 relate specifically to the requirements for plates below 1-1/4-in. and above 1-3/8-in. respectively. The fabrication experience with low-chemistry HY-80 structures has proved to be relatively free of welding difficulties. In many cases where welding fabrication of a given structure with conventional steels was known to have required numerous weld crack repairs, it has been reported that the same structure made with low-chemistry HY-80 was invariably found to be crack-free. Precautions concerning moderate preheat, electrode moisture control, etc. stipulated in the Bureau welding instructions for HY-80 are given in reference (1).

Experience with transition from low-chemistry HY-80 construction to high-chemistry HY-80 construction required by the use of increased thicknesses of material (1-in. and under to 2 to 3 in.) indicated that deviations from stipulated welding procedures resulted in cracking and other difficulties. Time and cost considerations based on fabrication difficulties with 2 and 3-in. thick HY-80 at a major industrial shipyard resulted in a request for special Bureau permission to specify only low-chemistry HY-80 for use in a new construction in which the minimum plate thickness was 2-1/2-in. This request was denied by the Bureau after a review of all available data for light and heavy gage HY-80 indicated that the proposed change was potentially dangerous for submarine service in that notch toughness properties would be sacrificed with no assurances that fabrication would in fact be less difficult with heavy-gage, low-chemistry HY-80 material. In order to examine this question more rigorously BuShips procured material to investigate properties and weldability characteristics of low-chemistry HY-80 in heavy gage plates. A cooperative test program between the Naval Research Laboratory, Naval Proving Ground and Philadelphia Naval Shipyard was established by BuShips (Code 637). NRL was requested to participate in and coordinate this test program.

MATERIALS AND TEST PROGRAM

Mill inspection reports and laboratory check analyses have invariably shown that 1-in. thick HY-80 plates generally conform in chemical composition to the very low side of the composition ranges specified for Ni-Cr-Mo contents. Accordingly, for this investigation, the suppliers were requested to provide low-chemistry HY-80 material into plates of 1-1/4, 1-3/4, 2-1/2, and 3-in. thicknesses. The Ni-Cr-Mo contents for all of these plates were requested to be aimed at the lean side of the specified low-chemistry HY-80 limits for these elements (defined as between the mean and lowest value). One full size plate of each thickness was obtained from each of two steel mills (coded Y-Company and Z-Company). Although described herein as nominally 3-in. thick, the heaviest plate from Y-Co. measured 2-13/16-in. because machining from one side was allowed to remove surface defects and to comply with flatness requirements. As can be seen from the data given in Table 2, only the Mo contents of the Y-Co. plates fell on the low side of the lean analysis range. With the above exception, the Ni-Cr-Mo contents of all plates generally fell near or above the requested maximum aim-value. Thus, test results are considered to be representative of the properties one can expect in heavy section plate for the mean-composition of low-chemistry HY-80.

DROP-WEIGHT AND EXPLOSION BULGE TEST RESULTS

The drop-weight test (2,3) represents a simple, laboratory impact-bend test which determines the highest temperatures at which even minute amounts of deformation in the presence of a sharp crack cannot be tolerated by a given steel without incurring brittle failure. This temperature is defined as the nil-ductility transition (NDT) temperature. The significance of NDT to possible initiation of brittle service failures, and the validation of NDT concepts by correlations with numerous ship and non-ship service failures have been previously described (4,5). The Charpy V-notch test requirements for specification quality HY-80 were established by correlations with NDT and are aimed at insuring that minimum acceptable quality HY-80 displays an NDT of -100° F or lower. Tests of numerous HY-80 plates to date have indicated that the NDT temperatures of normal mill production ranges from -100° to -150°F for low chemistry and from -130°F to -180°F for high chemistry HY-80.

Figure 1 illustrates the severe reduction in notch-ductility properties which occurs in these lean analyses HY-80 materials with increasing thicknesses. The NDT temperatures of the 2-1/2 and 3-inch thick plates are raised approximately 80° to 100° F above the values obtained for 1-1/4-in. thick plates. With the exception of the low Mo content for the Y-Co. plate, the 1-1/4-in. plates conform to low-chemistry HY-80 composition requirements, and NDT determinations of approximately -100° F were developed in these plates. At each thickness level, the moderately lower NDT's of the Z-Co. plates than that for the Y-Co. plates are considered to reflect the differences in chemistry between both materials. In general, the data appear to indicate that 1-1/2-in. and heavier plates which are melted to the low side of Ni, Cr and Mo contents for low chemistry HY-80 could be expected to exhibit NDT temperatures higher than -100°F. It is also suggested that plates with compositions at the high-end of the low-chemistry HY-80 specification ranges for Ni, Cr, and Mo would result in NDT temperatures of -100° F or lower in plate thicknesses of 1-1/2 to 1-3/4-in.

The extensive experience in explosion bulge (6) techniques gained by NRL has generally been limited to plates of approximately 1-in. thickness. In the conduct of these tests, either the explosive charge or the standoff distance is adjusted so that approximately 3 to 4 percent thickness reduction of the plate at the apex of the bulge is developed irrespective of the specimen thickness or yield strength of the material being tested. Prior to this investigation, only one carbon-steel of 1-3/4-in. thickness had ever been tested; 2-1/2 and 3-in. thick plates had never previously been explosion bulge tested. In the absence of established test conditions for these heavy gage specimens it was necessary to resolve questions concerning test conditions by a "best-effort" approach. One of the 2-1/2-in. specimens prepared with steel from each mill was used for initial tests and the data obtained from the two shots given these samples were used to approximate the conditions necessary for all other specimens.

As contrasted with conventional bulge tests which require a repetition of shots until failure is developed, the use of a crack-starter weld reduces the overall time and costs since only one shot is used to complete the test. Such techniques are useful for screening purposes and have proved successful in the past to delineate the possible fracture paths of least resistance in a weldment. Duplicate weldments with steel of each thickness from each mill were prepared by the Philadelphia Naval Shipyard. These were all welded under normal shipyard conditions with the Mil-110-18 stick electrodes that are approved for welding of HY-80. To expedite the test program and to provide the maximum amount of information with the fewest number of full thickness weldments, crack-starter welds were added to the center of each specimen. The bulge tests were conducted by Naval Proving Ground, Dahlgren, Va. Table 3 gives the test conditions employed herein for all samples.

To compare results of these specimens with previous HY-80 bulge tests, it was attempted to conduct all tests at 0° F. However, difficulties involved in the handling of these large specimens, and the time-lapse between removal from the temperature conditioning room and firing of each plate, resulted in some plates being slightly higher than 0° F. Figures 2 and 3 illustrate the appearances of the 1-1/4-in. samples after tests at 10° and 20° F. Complete resistance to fracture with no evidence of HAZ deficiencies were obtained at these test temperatures for these weldments.

Significant differences in notch-ductility between the Y-Co. and Z-Co. plates of 1-3/4-in. thickness were indicated by drop-weight test results. As expected, more extensive plate metal cracking was developed in the Y-Co. plates which were explosion tested at 10° and 20° F, as shown in Figs. 4 and 5. It should be noted, however, that these fractures are only partially brittle with significant surface shear-lips (1/4-in. or more). The smaller amount of cracking developed at the higher (20° F) test temperature indicates that these specimens were tested at temperatures very close to their FTP temperatures where complete resistance to brittle fractures could be expected. In view of the notch-ductility characteristics as determined by the NDT's for these plates, such fracture performance is in complete agreement with expected results.

For the initial tests conducted at 20° F with the 2-1/2-in. thick weldments, the charge weight and offset distance used did not deform the plates adequately to permit proper functioning of the crack-starter weld. Figure 6 illustrates the appearances of these plates upon completion of the second shot given at a 0° F test temperature. Of special significance, it should be noted, is the fact that failure is developed predominantly via plate metal fractures. Essentially all square breaks with no visible shear-lips were developed in sample Y-6, however, small surface shear lips were visible in the plate metal fractures of sample Z-5. Similar observations apply equally as well to the duplicate samples of 2-1/2-in. thickness which were given a single shot at 0° F, Fig. 7; however, the charge-weight used for the latter did not develop the expected thickness reductions. Future tests of 80,000 psi yield strength plates of 2-1/2-in. thickness should be tested with 36 to 40 lb of explosive and a 15-in. standoff distance.

The test conditions used herein for the 3-in. plates also happened to be lighter than that considered standard for bulge tests. However, the inferior notch-ductility properties of 3-in. plates from both mills (NDT of -10° F and +20° F) resulted in extensive failures via brittle plate-metal fractures, as shown in Figs. 8 and 9. In all cases, the fractures were essentially square-breaks with no visible indications of surface shear lips. The proximity of some of the cracks to the HAZ is believed to be only the result of general brittleness of these plates rather than HAZ deficiencies developed by welding.

SUMMARY AND CONCLUSIONS

The principal aim of the investigation was to explore the possibilities of altering HY-80 plate chemical composition in thick sections without materially reducing specification requirements for physical, mechanical, toughness and weldability characteristics. An extensive test evaluation program was originally planned for these materials; in addition to drop-weight tests of surface and centerline thickness specimens to evaluate hardenability characteristics, and explosion bulge tests of full thickness weldments, conventional tensile and Charpy V-notch test evaluations, and explosion crack-starter tests of plate were also planned. However, the results obtained in drop-weight and explosion bulge tests were sufficiently informative as to indicate that extensive testing was not warranted for these particular heavy-section lean analysis plates. These results are summarized briefly as follows:

1. Drop-weight test results indicate that a significant decrease in notch toughness is developed by the low-chemistry HY-80 as plate thickness is increased from 1-1/4 to 3-in. For 2-1/2 and 3-in. thick plates, the loss in toughness is so great that brittle plate fractures would be developed by explosion loadings at water temperatures. Consequently, such material is not suitable for submarine hull structures.

2. Explosion bulge tests of weldments corroborated the results of drop-weight studies. In the bulge test samples which were thicker than 1-1/4-in., failure always occurred via fractures of the plate. Specification quality Mil-110-18 electrodes were employed, and no evidence of weld fracturing was observed for the test temperatures studied (0° to 20° F). The 2-1/2 and 3-in. thick weldments exhibited extensive brittle plate fractures.

3. Test results with the Y-Co. plates which were low only in Mo content suggest that material on the low side of the low-chemistry HY-80 composition range would probably be suspect in thickness of 1-1/2 or 1-3/4-in. because of inferior toughness properties. However, results obtained for 1-3/4-in. thick plates indicate that consideration of a chemistry range intermediate to those presently specified for HY-80 would be warranted for plate thicknesses between 1-3/8 and 2-in. Providing future HY-80 construction involves these thicknesses to such an extent as to warrant an intermediate chemistry HY-80, it is believed that a composition range for Ni, Cr and Mo between the mean-values now specified for light-gage and heavy-gage HY-80 would develop adequate notch toughness in thicknesses up to 2-in. Prior to general acceptance of the above, it is believed necessary to confirm these deductions by tests of material specifically melted to such compositions. It should also be noted that normal mill production of low chemistry HY-80 has generally been found to confirm the low-side of the composition ranges specified for Ni, Cr, and Mo contents. It is believed, therefore, that to obtain plates with composition at the high-end of the chemistry range, a special procurement order such as was necessary to obtain the subject lean-analyses plates will be required.

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5. Puzak, P.P., Babecki, A.J., and Pellini, W.S., "Correlations of Brittle Fracture Service Failures with Laboratory Notch Ductility Tests," Welding J., 37:391-s (1958)

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TABLE I

Chemical Composition of HY-80 Steel (Mil-S-16216C)

Nominal Thickness*	C Max. %	Mn %	P Max. %	S Max. %	Si %	Ni %	Cr %	Mo %
Up to 1-3/8-in. inclusive	0.22	0.10-0.40	0.035	0.040	0.15-0.35	2.00-2.75	0.90-1.40	0.23-0.35
Over 1-1/4-in.	.23	.10-0.40	.035	.040	.15-0.35	2.50-3.25	1.35-1.85	.30-0.60

* For thickness between 1-1/4 and 1-3/8 inches, either composition may be applied.

TABLE 2

Chemical Composition of Lean Analysis HY-80 Plate Materials

Mill	Plate Thickness	C (%)	Mn (%)	P (%)	S (%)	Si (%)	Ni (%)	Cr (%)	Mo (%)
	Requested Aim	0.22 Max.	.10-.40	.035 Max.	.040 Max.	15-.35	2.00-2.38	.90-1.25	.23-.29
Y-Co.	1-1/4"	0.14	0.21	0.014	0.022	0.14	2.32	1.24	0.18
"	1-3/4"	0.16	0.23	0.014	0.025	0.14	2.41	1.46	0.19
"	2-1/2"	0.14	0.19	0.013	0.019	0.13	2.25	1.18	0.16
"	2-3/4	0.19	0.21	0.018	0.020	0.14	2.21	1.03	0.23
Z-Co.	1-1/4"								
"	1-3/4"	0.17	0.18	0.006	0.034	0.17	2.26	1.13	0.30
"	2-1/2"	0.14	0.18	0.004	0.019	0.17	2.24	1.16	0.30
"	2-3/4"	0.18	0.18	0.006	0.028	0.19	2.34	1.17	0.32

TABLE 3

LEAN Analysis HY-80 Explosion Bulge Test Data

Specimen No.	Plate Thickness	Est. Test Temp.	Chge. Size	Stand Off	No. of Shots	Ck. St. Orient.*	Drop-Weight NDT Temperature	
							Surface	Centerline
Y-1	1-1/4"	+10F	12#	19"	1	L	-90	
Y-2	1-1/4"	+20F	12#	19"	1	T	-90	
Y-3	1-3/4"	+10F	24#	17"	1	L	-80	-70
Y-4	1-3/4"	+20F	24#	17"	1	T	-80	-70
Y-5	2-1/2"	0F	32#	15"	1	T	-10	-30
Y-6	2-1/2"	+20F	32#	20"	1	L	-10	-30
		0F	32#	18"	1	L		
Y-7	2-13/16"(3")	0F	36#	15"	1	L	+30	+10
Y-8	2-13/16"(3")	0F	36#	15"	1	T	+30	+10
Z-1	1-1/4"	+20F	12#	19"	1	T	-110	
Z-2	1-1/4"	+10F	12#	19"	1	L	-110	
Z-3	1-3/4"	+20F	24#	17"	1	T	-140	-110
Z-4	1-3/4"	+10F	24#	17"	1	L	-140	-110
Z-5	2-1/2"	+20F	32#	18"	1	L	-50	0
		0F	32#	18"	1	L		
Z-6	2-1/2"	0F	32#	15"	1	T	-50	0
Z-7	3"	0F	36#	15"	1	L	-10	-20
Z-8	3"	0F	36#	15"	1	T	-10	-20

* L - parallel with weld   T - transverse to weld

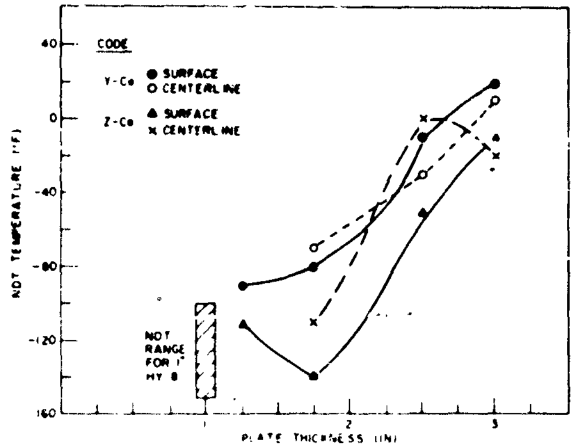

Figure 1 – Variation of drop-weight NDT temperature with plate thickness of low-alloy HY-80 steel procured from two sources. An NDT temperature above -100°F indicates a notch ductility too inferior for submarine applications.

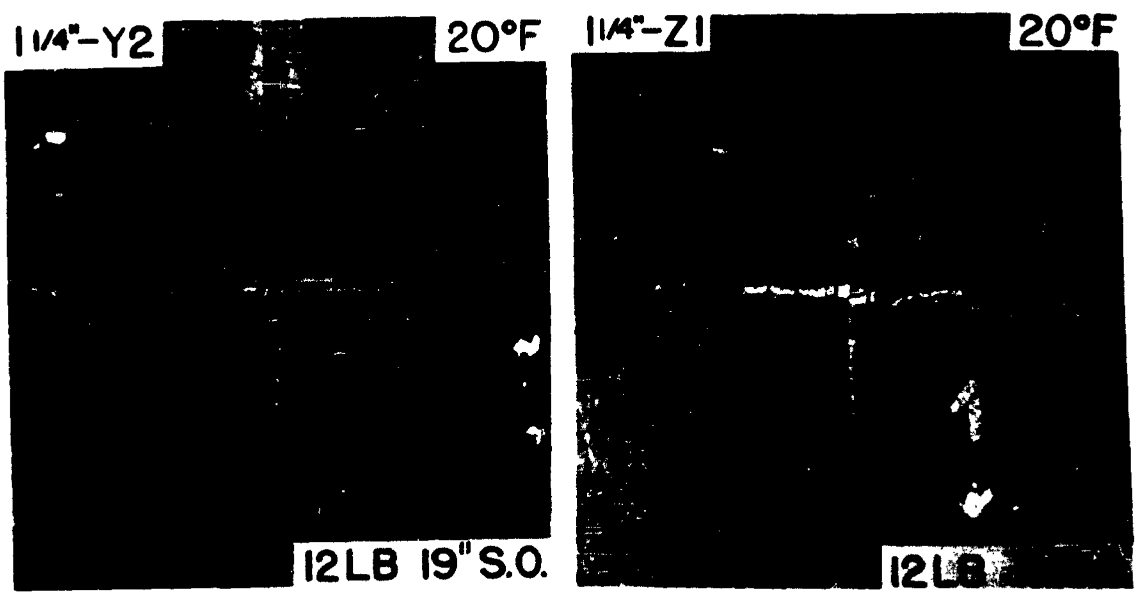

Figure 2 – Crack-starter explosion-bulge test plates of 1-1/4-in. thick low-alloy HY-80 showing good resistance to brittle fracture at 20°F.

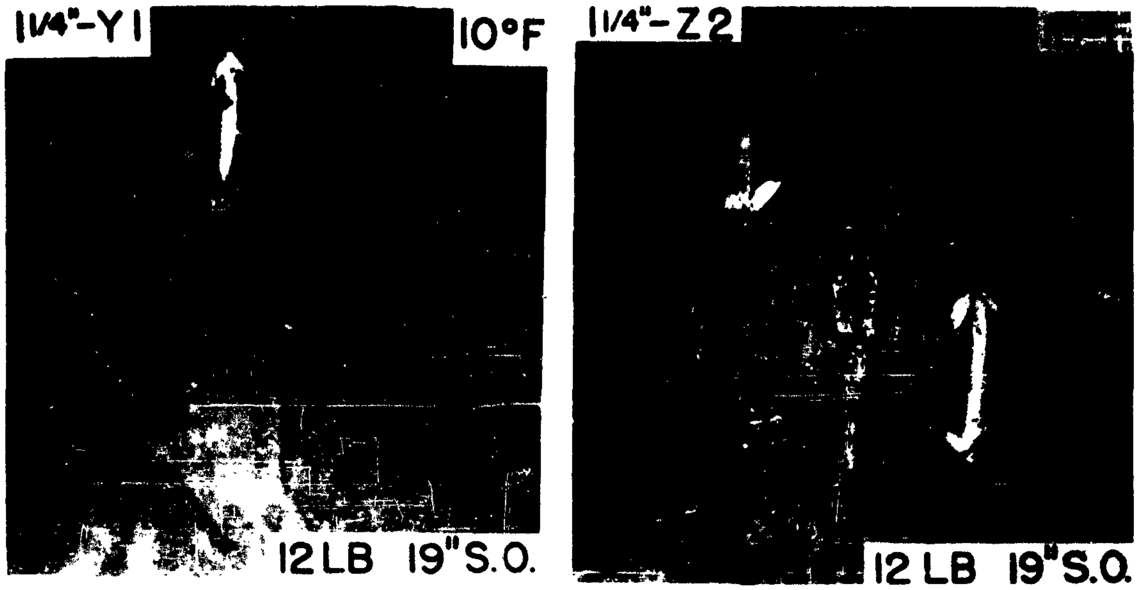

Figure 3 — Duplicate 1-1/4-in. thick crack-starter explosion-bulge test plates.

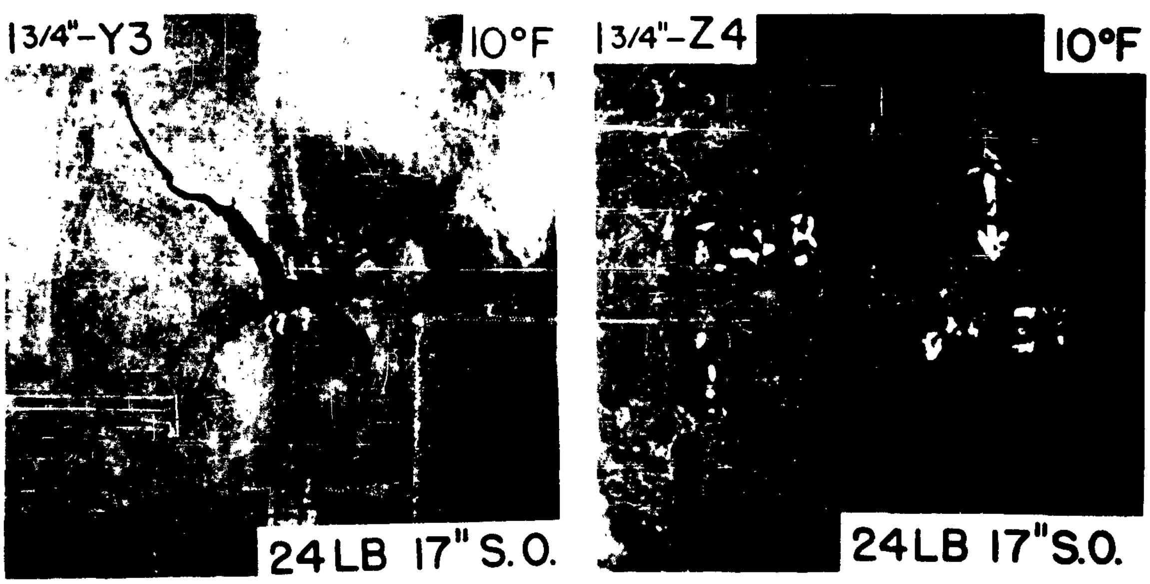

Figure 4 — Crack-starter explosion bulge test plates of 1-3/4-in. thick low-alloy HY-80. Plate on left exhibits extensive brittle fracture at 10°F; plate on right shows superior performance.

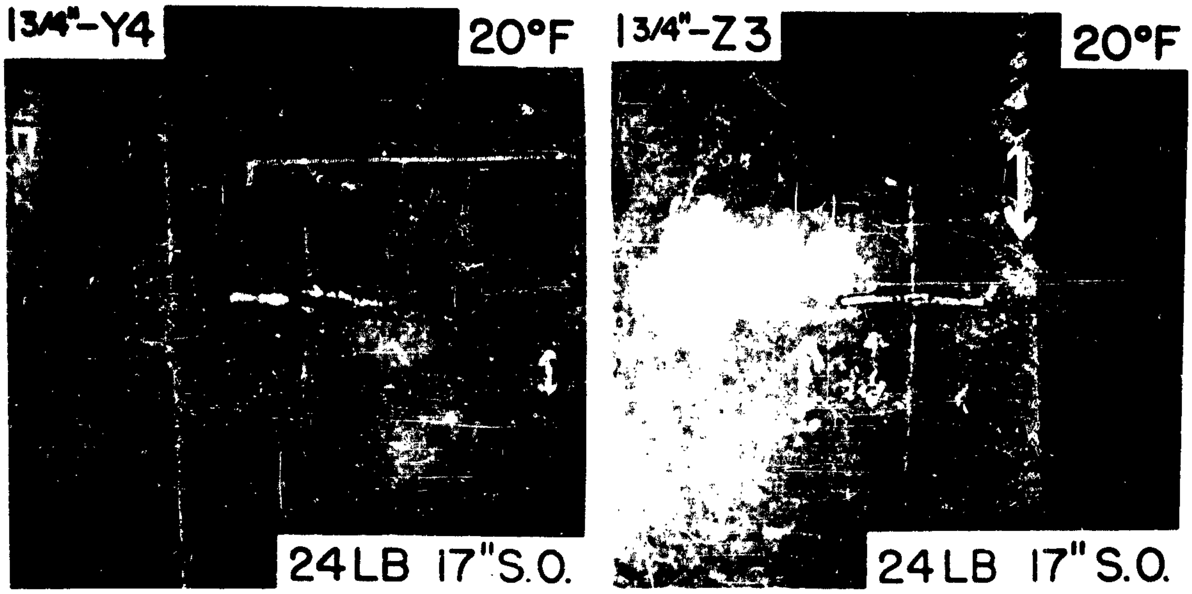

Figure 5 — Duplicate 1-3/4-in. thick crack-starter explosion-bulge test plates. The Z-Company plate again possesses the better notch toughness.

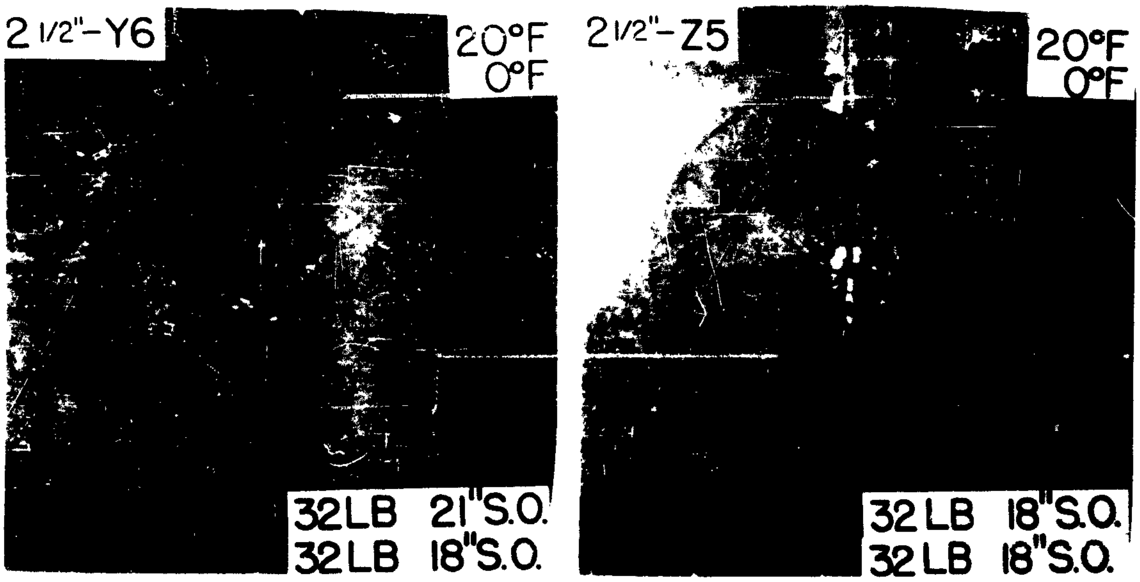

Figure 6 — Crack-starter explosion-bulge test plates of 2-1/2-in. thick low-alloy HY-80 given two test shots. Both plates developed extensive brittle fractures in the plate metal on the second shot.

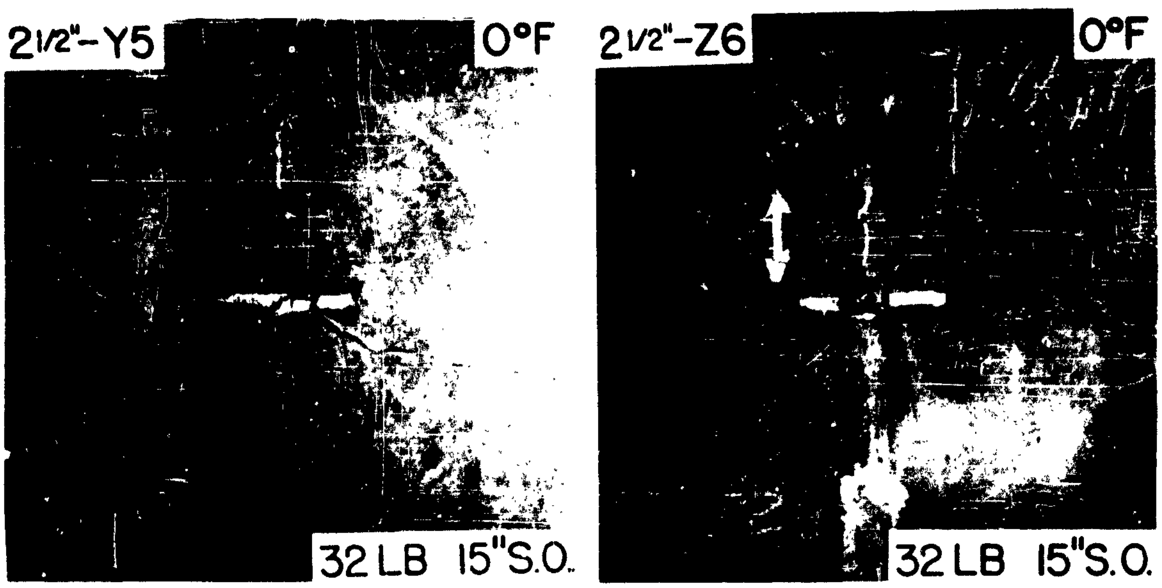

Figure 7 – Duplicate 2-1/2-in. thick crack-starter explosion-bulge test plates exhibiting brittle fracture at 0°F.

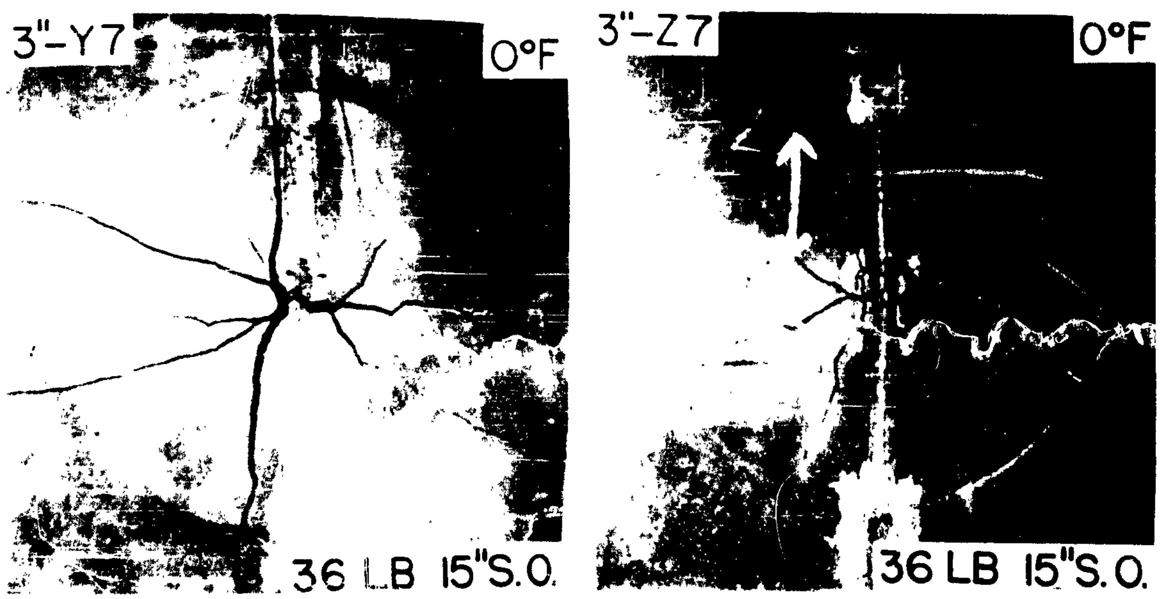

Figure 8 – Crack-starter explosion-bulge test plates of 3-in. thick low-alloy HY-80 which developed extensive brittle fractures at 0°F.

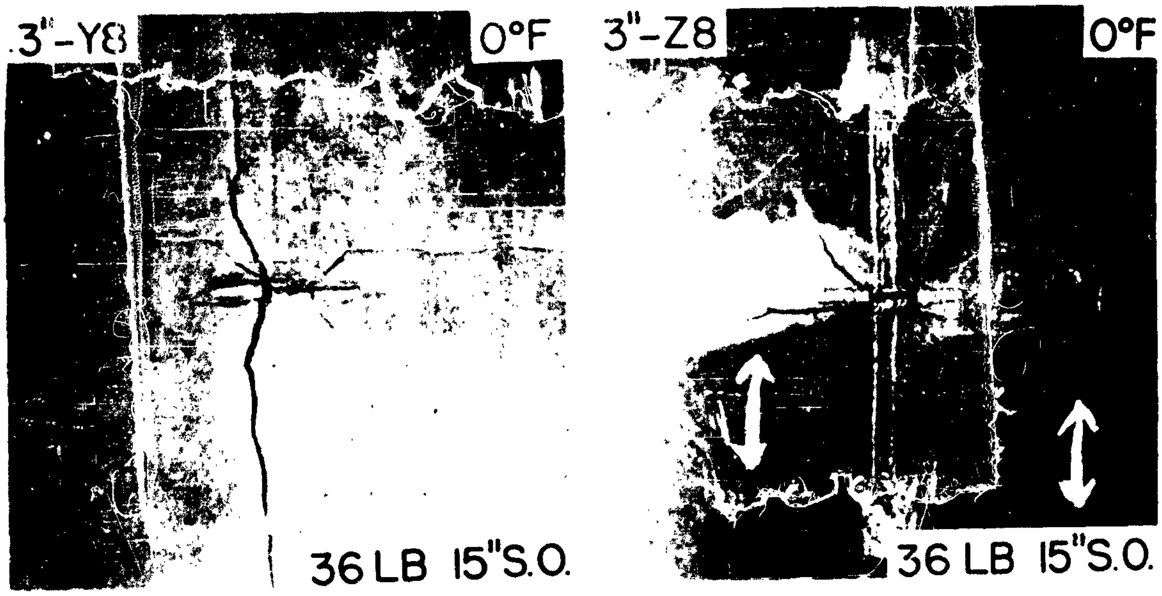

Figure 9 — Duplicate 3-in. thick crack-starter explosion-bulge test plates. Failure again is by brittle fracture.

EFFECT OF WELDING VARIABLES ON THE YIELD STRENGTH OF MIL-9018 WELD METAL

by

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Abstract

The results of this investigation, conducted to determine the causes of yield strength variations between yard acceptance tests and the manufacturer's quality control tests of MIL-9018 electrodes, show the effect of the use of stringer beads and low preheat and interpass temperatures on increasing the strength of the weld metal in both the as-welded and stress relieved conditions.

Introduction

Yield strength values for MIL-9018 weld metal in the as-welded condition have differed by as much as 20,000 psi between yard acceptance tests and the manufacturer's lot inspection tests conducted in accordance with the provisions of the MIL-E-19322A (SHIPS) specification.

It is generally recognized within the welding industry, although sometimes overlooked, that variations in welding conditions and procedures can alter the properties of the resulting weld metal - particularly low alloy steel weld metal. This investigation was conducted in an attempt to determine, on the yield strength of MIL-9018 weld metal, the magnitude of the effects of welding variables within the range of those currently encountered in electrode testing and subsequent fabrication use.

TEST PROCEDURE

Selection of test conditions

Eleven test plates were welded with two different brands of 5/32" MIL-9018 electrodes and one brand of 3/16" MIL-11018 electrodes, using procedures encountered in actual submarine hull construction and those permitted for the lot inspection tests of electrodes required by specification MIL-E-19322A(SHIPS) for quality assurance purposes.

In the present tests all electrodes were used just as they came from their containers without rebaking. Mechanical testing of the weld metal was conducted on .505" tensile bars in both the as-welded and heat treated conditions. Specimens for the "as-Welded" tests were machined and tested immediately upon completion of welding and were not given the benefit of aging. The tensile data reported were obtained in accordance with Federal Test Method Standard No. 151, July 17, 1956.

Selection of electrodes

The particular lots of MIL-9018 electrodes used were selected on the basis of availability and the fact that considerable information about them had been obtained from previously conducted standard quality control tests. This information, shown in Tables I and II, was required to establish the electrode's conformance with the specification and was further useful for correlation with the present test results. Except for nickel, the weld metal chemistry of the two brands of 9018 electrodes tested was strikingly similar. This, however, was not a consideration in their selection.

The MIL-11018 electrodes used were selected also on the basis of availability; they had been recently produced and, again, previous test information was available for comparison purposes. Unfortunately, 5/32" electrodes, with the same comprehensive background information, could not be obtained in time for these tests and it was necessary to substitute the 3/16" diameter.

The weld metal chemistry for each of the lots of electrodes tested is shown below in Table I and the mechanical properties in Table II.

Selection of base metal and joint type

T-Steel was selected as the base metal because of its strength and the fact that it is, for these electrodes, permitted for the inspection plate test in the electrode specification.

The selection of the joint design and dimensions for the test model was based on the desire to provide some restraint and, with a minimum of welding, to obtain, in addition to sufficient weld metal for the required tensile and charpy specimens, some indication of electrode usability. The latter was the initial purpose of the "Inspection Plate Test" in the specification. Each joint was intended to provide two tensile bars and ten charpy specimens from which both as-welded and heat treated mechanical properties could be determined. The test model is shown in Figure I. A cross section through the groove, in a test plate ready for welding, would be

TABLE I

Weld Metal Chemistry

	9018(1)	9018(2)	11018(3)
C	.046	.05	.052
Mn	.88	.96	1.78
Si	.37	.30	.40
S	.015	.012	.010
P	.018	.013	.023
Cr	.12	.12	.16
Ni	2.16	1.67	2.20
Mo	.37	.29	.40
V	.00	.01	.00

(1) Lot #0B11A, Weld Pad
(2) Lot #501, HT 79L432, Outside Report - details unknown to us.
(3) Lot #0A30B, Weld Pad

TABLE II

Weld Metal Mechanical Properties

Material		Y.S., Ksi	T.S., Ksi	Elongation % 2 Inches	Reduction of Area - %
9018(1)	A.W.	83.7	96.6	24.0	63.8
9018(2)	A.W.	91.0	100.5	23.0	59.8
11018(3)	A.W.	108.1	122.7	21.0	63.5
	H.T.	103.0	111.6	24.0	65.8

(1) Lot #0B11A - MIL-E-19322A Restrained Groove
(2) Lot #501, HT 79L432, Outside Report - specific test details unknown to us
(3) Lot #0A30B - MIL-E-19322A Restrained Groove

A.W.: As-welded
H.T.: 1150° F 2 hrs. F.C.

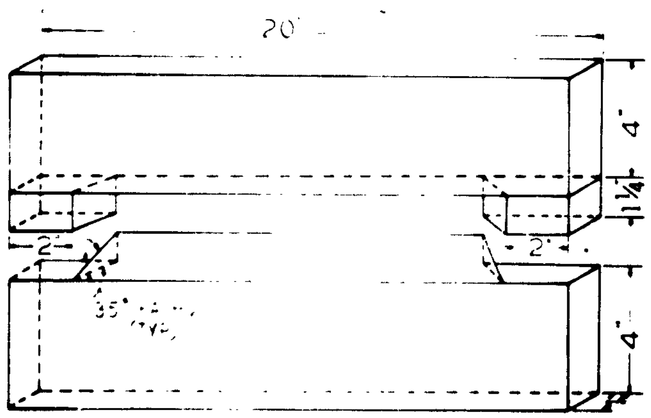

FIGURE I

Combination Restrained Groove-Inspection Plate Test very much like that of the inspection plate in MIL-E-19322A(SHIPS) and would be of proper root dimension, including the back-up strip, for a 7/32" electrode. This cross section and tensile bar location is shown in Figure II.

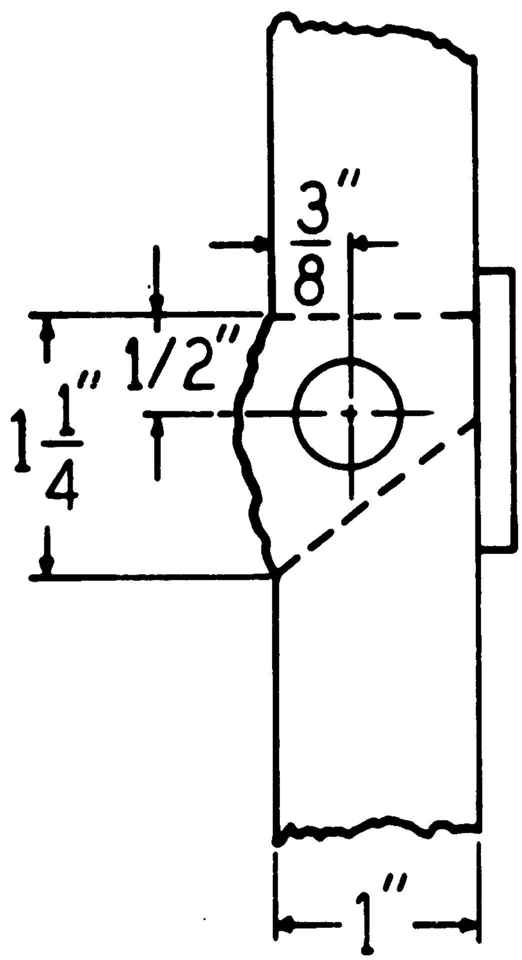

FIGURE II

Cross Section of Test Joint and location of Tensile Bar

Preparation of test joint and weld specimens

Flame cutting and sawing were employed in preparing the various components of the test model. All mating flame cut surfaces and those on which weld metal would be deposited were hand ground to remove the oxide layer prior to fitting and tacking.

Preheat was applied with an oxyacetylene flame and throughout the tests tempil sticks were used as temperature indicators.

D.C. Motor generators and rectifiers with drooping characteristics were used to supply the welding current. Amperages were checked periodically with a tong meter and near the completion of the tests individual voltage and amperage readings were taken for each weldor, on recording Esterline-Angus meters. The selection of the actual welding currents used was based on weldor preference within the requirements of the specifications. Travel speed readings were taken during the tests to form a basis on which to compute heat input.

All plates were allowed to air cool to the required interpass temperature and to room temperature on the completion of welding.

Each joint was saw cut in half to provide the specimens required for testing in the as-welded and heat treated conditions. The heat treatment applied was that specified in MIL-E-19322A(SHIPS). The specimens requiring heat treatment were all treated at the same time in the same oven.

The .505" tensile specimens were prepared from each plate by saw cutting and machining. Yield strength determinations were made in accordance with the extension-under-load procedure of Federal Test Method Standard No. 151.

Test Results

In both the as-welded and heat treated conditions, considerable variation was encountered in weld metal tensile properties as a result of changes in welding position, width of weave and preheat and interpass temperature. The overall range being 17,000 psi in tensile and 21,000 psi in yield strength in the as-welded condition for the MIL-9018 electrodes of Lot #0B11A. In the heat treated condition the range was about 15,000 and 14,000 psi respectively.

A comparison of the results of tests B and C in Table III shows that some reduction in weld strength does accompany the use of higher preheat and interpass temperatures. The trend is continued in test Q4533-D of Table IV. Test B was considered an example of an accepted fabrication procedure whereas C and Q4533-D, in addition to test H represent procedures permitted in welding the "Inspection plate test" in MIL-E-19322A(SHIPS) from which the weld metal charpy values are obtained.

An examination of the results of tests B, D, and F of Table III and C of Table IV with E and G of Table III and A and B of Table IV shows clearly the higher strength of stringer beaded weld metal irrespective of the position of welding and the amperage used.

Tests H and I of Table III, to which lot #501 MIL-9018 electrodes (a different brand from lot #0B11A) were subjected, involved only a difference of 75°F

Table III

TABLE III

SPECIMEN NO. (AS-WELDED)	POSITION OF WELDING	ELECTRODE SIZE	ELECTRODE IDENTIFICATION	BEAD TYPE	PREHEAT AND INTERPASS TEMPERATURE	ARC VOLTS	AMPERAGE D.C. - R.P.	FORWARD TRAVEL SPEED I.P.M.	HEAT INPUT JOULES/IN. x 1000	YIELD STRENGTH P.S.I. x 1000	Tensile Strength P.S.I. x 1000	ELONGATION % 2 INCHES	REDUCTION OF AREA - %
12758													
B	H	5 32"	(2)	S	125 150	21-22	160	6.2,9.0	33.2, 23.0	94.0	101.5	21.0	63.6
Ht.										92.4	98.0	23.5	61.9
C	H	5 32"	(2)	S	200 500	21-22	160	9.6	21.5	88.7	93.7	28.0	69.8
Ht.										85.5	92.5	28.0	68.2
D	V	5 32"	(2)	S	125 150	21-23	120	4.3	36.8	99.7	108.5	19.0	56.4
Ht.										92.9	101.5	23.0	63.5
E	V	5 32"	(2)	W-4D	125 150	22-23	130	1.7	103.0	86.2	101.6	23.5	63.5
Ht.										88.7	98.7	26.0	57.5
F	F	5 32"	(2)	S	125 150	23-25	185	8.4	31.5	91.8	97.2	23.5	65.6
Ht.										89.0	91.0	25.5	65.1
G	F	5 32"	(2)	W-4D	200 250	22-24	175	5.1	47.2	78.3	91.2	24.0	65.7
Ht.										79.6	86.2	28.0	69.8
H	H	5 32"	(3)	S	200 500	21-22	165	7.9	27.0	92.7	100.1	26.0	67.8
Ht.										92.2	99.4	26.0	63.6
I	H	5 32"	(3)	S	125	21-22	160	7.1,6.0	29.1, 33.4	106.2	113.2	20.0	50.7
Ht.										100.2	109.2	24.0	62.1
J	H	3 16"	(4)	S	200	18-20	205	7.7	30.4	126.8	130.3	13.0	55.0
Ht.										116.2	121.8	22.0	57.6
K	F	3 16"	(4)	W2-1 2D	125	19-21	245	6.4	46.0	109.5	126.4	16.5	37.7
Ht.										107.1	114.7	24.0	64.5
L	V	3 16"	(4)	W-4D	200	19-20	155	3.2	56.6	111.9	125.8	4.0	19.8

(1) Base Metal: T-Steel
(2) MIL-9018 Lot #0B11A
(3) MIL-9018 Lot #501 HT #79 L 432
(4) MIL-11018 " #OA30B
(5) Welded without regard for interpass temperature values given indicate actual plate temperature

Table III

TABLE IV

COMPARISON OF WELD PROPERTIES[1]

Specimen No. (As-Welded)	MIL-19322A Joint Type	Preheat Temp. °F	Max. Interpass Temp. °F	Bead Type	Yield Strength K.S.I.	Tensile Strength K.S.I.	Elongation % - 2 Inches	Reduction of Area - %
Q4533								
A	Restrained Groove	125	125	W-2-1/2D	83.7	96.6	24	63.8
B	"	125	125	W-2-1/2D	84.2	96.2	25	66.4
C	Inspection Plate	200	125	S	97.0	103.9	21	61.6
D	"	200	(2)	S	79.0	93.0	27	64.3
12758								
B	(3)	125	150	S	94.0	101.5	21	63.6
D	(3)	125	150	S	99.7	108.5	19	56.4
G	(3)	200	250	W-4D	78.3	91.2	24	65.7

(1) All electrodes 5/32" MIL-9018 Lot No. 0B11A welds are in the as-welded condition.

(2) Unrestricted. Welding progressed without regard for interpass temperature. Much of the time the plate was above 600 F - never below 500 F once reaching that temperature.

(3) Combination plate not in specification.

Test Results (cont'd)

in preheat temperature but as much as 375° F in interpass temperature, produced strength level differences of about 13,000 psi in both tensile and yield in the as-welded condition and 8,000 and 10,000 psi respectively in the heat treated condition.

The purpose of these two tests was to provide a basis for comparison of the properties of two different brands of MIL-9018 electrodes. A comparison of the results of tests B and C with those of I and H respectively, reflect the characteristically higher weld metal strength level produced by the stringer bead technique.

The MIL-11018 tests, J, K, and L, were included only for informational purposes. The weld pad chemistry for these electrodes, as can be seen from Table I, differs from that of lot #0B11A MIL-9018 electrodes only by an addition of approximately 1% of manganese and, except for the adjustment required to produce this alloy difference, the coating composition of the two is identical. A direct comparison between these results and those of the MIL-9018 electrodes cannot be made because of the difference in electrode diameter. However, the significance of these tests can be seen by comparing the results with those reported in Table II (electrode #3) which would appear on a certification of conformance with the military specification for these electrodes.

An examination of the fractured surfaces of the tensile bars indicated sound, ductile fractures for all heat treated bars. As-welded bars D, E, G, H, and I contained small fisheyes. The L bars were both tested in the as-welded condition and produced approximately the same results--premature yielding and fracture resulting from small fisheye-like defects.

Discussion

Width of weave and position of welding (which undoubtedly is related to amperage that can be used) appear to be more influential than preheat and interpass temperature in their effect on the resulting weld metal strength. In all cases, regardless of position of welding, the use of a stringer bead technique resulted in the highest strength weld metal.

The effect of heat input is more difficult to interpret since the highest computed heat input did not result in the lowest strength levels nor, conversely, did the lowest heat input result in the highest weld metal strength. A macro and micro structure study would be in order, for the effect of factors such as bead thickness resulting from position of welding should be considered in addition to heat input.

Heat input is, in itself, difficult to handle since a weldor very often changes his travel speed to suit local conditions, particularly in out of position work. For this reason average heat input computations for a heavy joint based on a few travel speed readings may be considerably in error.

Another factor affecting the accuracy of calculated heat input values is the need to shift to a volume or area basis rather than deal with a linear consideration only, for the width of weave increases as the speed of travel decreases, hence the need to include the lateral dimension.

The decrease in yield strength resulting from heat treatment was surprisingly small in the MIL-9018 weld metal tested. The reduction encountered in test I and J (MIL-11018) was the greatest, 6,000 and 10,000 psi respectively. Even the decrease in tensile strength was not generally substantial.

The tensile bars, by virtue of their location in the joint, (Figure II) contained very little if any base metal dilution or enrichment. In view of this, the magnitude of the variation in yield strength here encountered should generate concern over the actual strength level of weld metal, especially that of MIL-11018 electrodes, and its effect on joint soundness in highly diluted (root passes, for instance) restrained joints in higher carbon, higher alloy base metal such as HY-80.

Conclusions

This study of the effect of welding variables on the yield strength of certain low alloy steel weld metal indicates that:

1. The strength of a welded joint depends, in addition to other factors, on the specific details surrounding the manner in which the weld metal is actually deposited in that joint.

2. A given electrode, classified as MIL-9018 in accordance with the provisions of existing specifications may deposit weld metal during fabrication, which, in the as-welded condition, may have tensile properties of a MIL-9018, a MIL-10018 or possibly even MIL-11018 electrode, depending on how the electrode is actually applied.

   A 11018 electrode, similarly, may deposit weld metal conforming to the strength requirements of a 12018 type and even a 13018 type, should it exist.

3. Specification procedures and techniques governing manufacturing tests of electrodes, users inspection tests, and subsequent fabrication procedures must be identical if reasonable reproduction of results is to be expected.

Recommendations

1. The amount or location of fabrication cracking difficulties when correlated with weld metal mechanical properties must be made on the basis of actual joint weld metal properties and not on the manufacturer's lot inspection test results unless the two are actually made in the same fashion. (see Table V). Moreover, in single pass fillets and root pass work the effect of dilution, in addition to the effect of welding technique, should not be overlooked.

2. Consideration should be given to the use of stringer bead techniques only whenever possible, in fabrication, and lot acceptance test requirements set up on the same basis.

TABLE V

MIL-9018 and MIL-11018 ELECTRODES

	Inspection Tests – Specification MIL-E-19322A(SHIPS): Restrained Groove	Inspection Tests – Specification MIL-E-19322A(SHIPS): Inspection Plate	Use in Fabrication – General Specifications for Ships, Section S9-1
A. Purpose	Soundness Tensile Properties	Useability Soundness Toughness	----
B. Position of Welding	Flat	Horizontal (7 32" - 5 16" flat)	All (according to individual specifications for material)
C. Welding Technique	None specified	None specified but position dictates stringer beads up to 7 32" O electrodes.	None specified
D. Base Metal	None specified	HT, A302 or T-1 Steel	(MIL-9018 for welding base metals with properties similar to those of weld. MIL-11018 - Butt joints* in HY-80 and T-1 Steel)
E. Preheat & Interpass Temperature	100 F maximum	200 F minimum with T-1 Steel. 300 F minimum with HT or A302	70 F & 125 F minimum, depending on plate thickness. 300 F maximum regardless of any condition.
F. Heat Input	None specified	None specified	Maximums stated for certain plate thickness groups.

*MIL-10018 is recommended in MIL-E-19322A(SHIPS) for other joints in HY-80 Steel.

QUALITY CONTROL

IN THE

FABRICATION OF HY-80 STRUCTURES

Delivered by: Thomas J. Dawson
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Pascagoula, Mississippi

Before: Bureau of Ships Symposium
Washington, D. C.
21, 22 March 1960

What is quality control? It has been stated that quality control intentions are all the means by which frequency of difficulties is kept down It---

(a) Minimizes the number of defects

(b) Catches those that do occur as early in production as possible.

(c) Eliminates the cause of those that do occur It will be noted from this that it definitely differs from inspection which is to check an end product to assure its being satisfactory for use

The definition is so simple, it might be misleading "To minimize the number of difficulties" is a far-reaching statement, and intentionally applies far-reaching efforts. These must be from original design through procurement, process, installation, and final testing. This is a large area, so large in fact that in any industry, such a quality control program, to be effective, requires strong managerial interest and control.

Quality control in the fabrication of HY-80 falls into the category of apparently a relatively new material, at least in the thicknesses and uses to which it is now being put in submarine construction. It is a material that appears to require a reasonably strong quality control program in order to have real assurance of a reliable end product. For the past two years, problems in welding HY-80 have been uncovered by very costly experiences, and late in the fabrication schedules causing serious delays.

As in any other phase of work, the question arises--How far should we go? This in the end is governed to a large part by how much it costs. Complete quality control over any operation like complete control in any other area would, of course, give a complete history. Complete quality control in every step involved, every move, proof of quality of every piece of HY-80 material, every welding rod, every weld, every joint, and every phase of a fabrication operation would, of course, cost a great deal more than could be justified. On the other hand, quality control relying solely on the faith of the steel manufacturer, the rod manufacturer, shipfitter, and welder to produce automatically each and every time satisfactorily would result in no expense. All of the shipyards are somewhere between these two extremes.

Traditionally and rightfully so, the quality of any shipyard work has been thought of as the province of the artisan and his immediate supervisor Bureaucratic organizations make this prerogative seem greater in the minds of supervisors. It is an old truism that pride of workmanship differentiates the workman from the journeyman, or we might say the artisan from the helper This is as it should be, as pride of workmanship will produce more quality at less cost than rigid inspection or quality control.

It is unfortunate but quality does not begin and end in the shop or on the ship. It begins long before our workmen have an opportunity to demonstrate their capabilities. Many times they unknowingly face problems, and this is especially true in the HY-80 materials, which require rigid procedural control and material control from the raw material through to the steel fitting to such technical operations as accurate control of the moisture content of the welding electrodes to be used. They are faced with the following problems:

1. Are the plans and the job instructions such that they make the job feasible to perform?

2. Do the drawings and specifications incorporate the required control that must be maintained in order to meet the required quality?

3. Is the base material and the welding rod unmistakably that which is right for the job?

4. Have those actions or processes that have gone on in processing and fitting the material before the

conscientious welder starts his weld helped or prevented him from achieving the quality of weld desired? If we have negative answers to any of these questions, they will cost many dollars and delays in spite of the best welders in the world of which we have many good welders in the shipbuilding industry.

Quality control to be really effective embraces many areas and must start at the beginning of the job to be effective. The following requirements are some ideas of the minimum factors necessary for an economic quality control program for the fabrication of HY-80 which will result in the most economical job and the production of a reliable end product of predictable behavior:

(1) Design: Some of the designs today have much to be desired in order to ease the fabrication problems of HY-80 steel. The numerous geometrical forms described as "cruciforms" are very difficult to weld due to the high restraint they impose on the welded joints. Square corners with welds emanating from 3 or more directions present high restraint and multiaxial stress concentrations Through members and intersecting members welded to shell or tank tops create problems at snipes. By this I refer to the snipe in one member to allow the weld to progress uninterrupted on the other member. These present difficulties when the snipes are welded in materials less sensitive to weld than HY-80 steel. Effective quality control procedures should point up areas such as this which are difficult areas for fabrication. If proper records are kept, they will be effectively shown by comparison

(2) Procurement: All materials should be ordered as specified Positive identification must be maintained with full information on material identification codes disseminated to all the workmen. An effective quality control procedure will, as a minimum, spot check material specifications and material identification to assure that it is being rigidly carried out

(3) Receipt Inspection: Effective quality control will encompass receipt inspection of material. HY-80 material requires a specific receipt inspection by the Bureau specifications from which a great deal of quality control information can be obtained and through which rigid quality control procedures can be employed. Laminar inclusions are a characteristic of the HY-80 material. The effect of these inclusions, which have been identified largely as "alumini", upon weldability has not been definitely established since it is commonly recognized that inclusions normally contain a variety of impurities. They unquestionably exert an influence upon weldability and should be controlled. Many of these are extremely small inclusions but numerous throughout the thickness of the plate in certain areas. These are demonstrable by ultrasonic examination not always by a definite "pip" as the large laminations, but by a definite loss of back reflection. We have established a limit for rejection of 25% loss of back reflection. This has not been expensive and has not resulted in a major percentage rejection of plate material, but has eliminated plates of questionable quality for all of the follow-up operations that must be performed upon them. Records of receipt inspection will serve as an excellent indication of whether or not the specifications are adequate, and good information on the suppliers' reliability if reviewed.

(4) Job Instruction Control: It is in this area that quality control can function effectively by reviewing procedures and supplementing these as necessary. The supplement should define areas of responsibility and disseminate the necessary information to all parties responsible so that they have sufficient information to effectively perform their jobs. As an example, the following areas of responsibility in the welding of HY-80 material should be established with feed back information to the Quality Control Department:

(a) Base Material control.

(b) Electrode control.

(c) Root opening and joint preparation control.

(d) Preheat control

(e) Inprocess inspection control such as

1 Magnaflux
2. X-ray
3. Control and release for other operations.

(5) Inspection of Work in Progress: The earliest detection of errors or faults pays the biggest dividends and results in the shortest delays. Regardless of who performs the inspection, this inspection should report minimal information to the Quality Control Department for assimilation and review, and the development of statistical information that will predict problem areas and a dependable end product.

(6) Human Factors: As in any other area in dealing with people, people are the direct insurers of quality. As stated previously, pride of workmanship will produce more quality at less cost than any of the other means of quality control or rigid inspection. All quality control programs should be arranged so that they point up the good quality of workmanship to encourage the individuals responsible for it.

Quality control can actually be thought of, after obtaining the above information, in 3 stages--diagnosis, remedy, and maintenance. By maintenance, we mean the holding of the remedies once they are developed. The information gathered above is essential for the diagnosis and a rational approach to the development of remedial procedures. The development of statistical data condenses the information to be fed back to managerial personnel relative to problem areas to obtain the proper assistance to develop remedial procedures. The maintenance of the remedial procedures is the biggest problem in quality control. This requires the cooperation of the entire supervision and inspection personnel concerned with operations. Factual data collected as outlined above serves as a positive control over maintenance as it will furnish data not only on problems but furnish information on good quality, and establish confidence in procedures in use.

An example of quality control as outlined above practiced at the Ingalls Shipbuilding Corporation for control of fabrication and welding of HY-80 steel encompasses the following:

(a) The operational procedures are reviewed by the staff engineers of the Quality Control Department for completeness, areas of responsibility, standards of acceptability, and questionable areas are discussed with responsible parties in an attempt to assure full understanding and practicability of their application.

(b) Receipt inspection of plate material is carried out by the Quality Control Department. This consists of the following as a minimum:

1. Surface inspection.
2. Hardness measurements at diagonal corners of the plates as a rough check against chemistry and heat treatment.
3. Micrometer measurements for plate gage
4. Ultrasonic measurements at the corners of a 2' grid for information as to uniformity of thickness.
5. Ultrasonic measurement of plate soundness on the same 2' grid with areas showing indications of discontinuities searched out in their entirety. Attachment 1 shows segregations resulting in 25% or greater loss of back reflection

This information is accumulated by the Quality Control Department, and the plates are assigned for specific locations in the submarines. Defective or questionable plates are positively identified by a different identification system from those plates of quality satisfactory for use.

(c) Moisture control in electrode coatings:

1. The Quality Control Department rebakes all electrodes as received from the manufacturer and distributes them to welding rod distribution rooms.

2. The Welding Department personnel operate the welding rod distribution rooms keeping the electrodes at the prescribed temperature prior to releasing them in small quantities to the welder. It is the welder's responsibility to return all electrodes not used with a 4-hour period of time.

3. The Quality Control Department makes periodic checks of the welding electrode moisture content on incoming electrodes, after rebaking, and from the welder's electrode can on the job site.

4. Records of electrode baking, moisture content, etc. are fed to the Quality Control Department. Discrepancies from established procedures and prescribed limits are taken up with the responsible parties for immediate correction.

Sample Source	Electrode Moisture Content
From electrode can opened at oven prior to baking	0.23%
After baking at 800 F for one (1) hour	0.007%
Electrode from holding oven 72 hours	0.06%
Random samples from welders' cans on the job site	
(1)	0.06%
(2)	0.19%
(3)	0.09%
(4)	0.14%

(d) Preheat control: It is the joint responsibility of the Quality Control Department, Welding Engineering, and Welding Department to see that the proper preheat is maintained on all structures being welded from HY-80 material. The Metallurgical Processing Division of the Quality Control Department installs the preheaters and regulates the temperature on the assemblies. Hourly temperature readings are recorded as well as current weather conditions, and whether or not welding was being performed on the assembly (Attachment 2). This information is fed back to the Quality Control Department. It is the responsibility of the Welding Engineer to establish the preheat levels. It is the responsibility of the Welding Engineering Department to check welding supervisors and welders to see that the correct preheat is maintained and the proper heat imput is being followed for the welding being preformed.

(e) Magnaflux: As magnaflux operations are performed, written records are made by the magnaflux operators on the form enclosed as Attachment 3. This information is fed back to the Quality Control Department where it is accumulated by a statistician on work forms for IBM punch card operations (Attachment 4). At periodic intervals, a recap is made of this information by the IBM system. This recap is then reviewed by the Quality Control Department and Welding Engineer for problem areas. An example of the value, this information can serve as illustrated by the following:

1. From a graph (Attachment 5) which is typical of an HY-80 fabrication, the total cracks discovered by magnaflux are plotted against the man-hours of welding applied to the job. From this it can be seen that the cracks were reasonably proportioned to the man-hours applied to it which varied with the cracks for several months until true control allowed the manpower to continue to increase and the cracking rate to decrease. The latter end of the graph is welding under very high restraint which accounts for the rise in the number of cracks per man-hour.

2. Attachment 6 graphically demonstrates the transverse cracks compared to the longitudinal cracks for a better realization of the basic cracking problem involved in welding HY-80 material under restraint.

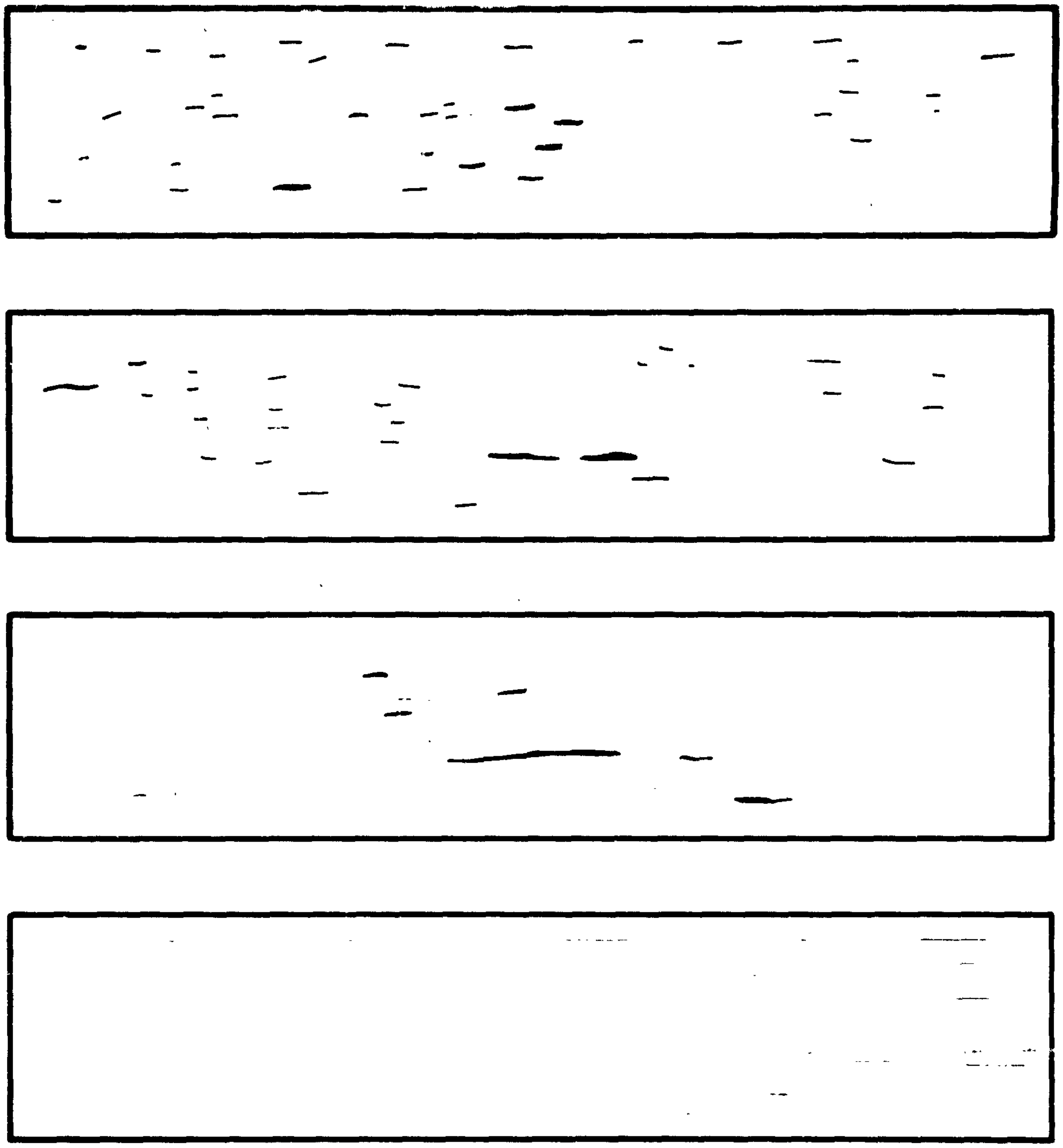
3. Attachment 7 graphically demonstrates the total cracks plotted against the root weld cracks in an attempt to evaluate the source of the cracking problem in HY-80 steel. From this it can be observed that to a very great extent, the cracking problem exists at the root of the weld from our experiences. It is from this information that we, to date, have been unable to develop a procedure that we felt was satisfactory for twin arcing or for welding over tacks. The small difference between the two curves indicates the finished weld cracking that was observed both by delayed cracking and that found immediately upon completion of the weld.

4. In order to differentiate between these two problems and to get a truer picture of the amount of delayed cracking observed, graph (Attachment 8) shows finished weld cracking for comparison with the delayed cracking. It will be observed from these curves that sufficient delayed cracking has been observed to justify the 7-day recheck on all of the primary strength welding performed on HY-80 structures at our plant.

(f) The radiographic results are likewise tabulated.

In summary, those parts of the quality control system which from a mechanism for feed back of information on corrections or anticipated problems, we feel, have proven potential as a cost reducer in our program. We constantly guard, however, against personnel drifting too far into a straight forward inspection group. Inspection by its nature is primarily destructive criticism and we attempt to keep our quality control in the area of constructive criticism. If we can continuously continue our aim of constructive criticism, we will continue to enjoy the cooperation of all of the other departments with quality control services as a focal point from which we can initiate action on our HY-80 welding problems for the control of costs as well as quality.

ATTACHMENT I



LAMINAR PLATE DEFECTS RESULTING IN MORE THAN 25% LOSS OF BACK REFLECTION

TYPICAL MAGNAFLUX --- INDICATION OF SECTION AFTER DETECTED BY ULTRASONIC INDICATIONS

Form No. 125921

ATTACHMENT 2

THE INGALLS SHIPBUILDING CORPORATION
PASCAGOULA, MISSISSIPPI
QUALITY CONTROL DEPARTMENT
METALLURGICAL PROCESSING DIVISION

RECORD OF STRIP HEATING

Hull__________ Date__________

Assembly No. ________ Frame No. ________ Manual Weld________ Aircomatic Weld________

No. Heaters: 800 watts______ 1100 Watts______ 2000 Watts______ Material Heated______

Weather Conditions: 1st Shift________ 2nd Shift________ 3rd Shift________

Ambient Temp. F________

Time	Volts	Temp. F	Time	Volts	Temp. F
7:00 AM			7:00 PM		
8:00 AM			8:00 PM		
9:00 AM			9:00 PM		
10:00 AM			10:00 PM		
11:00 AM			11:00 PM		
12:00 Noon			12:00 Midnite		
1:00 PM			1:00 AM		
2:00 PM			2:00 AM		
3:00 PM			3:00 AM		
4:00 PM			4:00 AM		
5:00 PM			5:00 AM		
6:00 PM			6:00 AM		

All temperature recordings are greater than the degree indicated but below the next 50 Temple Stick.
Reading shall be taken from 8" to 12" ahead of welders.

Remarks:____________________

Observers:

____________ **1st Shift**

____________ **2nd Shift**

____________ **3rd Shift**

Form 11597 **ATTACHMENT 3**

THE INGALLS SHIPBUILDING CORPORATION
PASCAGOULA, MISSISSIPPI
QUALITY CONTROL DEPARTMENT
METALLURGICAL PROCESSING DIVISION

MAGNAFLUX REPORT

Hull ________ Date ________

PART TESTED:

Frame No. ________ Assembly No. ________

Inside Hull ________ Outside Hull ________ Forward of Frame ________ Aft of Fr. ________

Vertical Butt ________ Flange Butt ________ Scars (No.) ________

Horizontal Butt ________ Webb Butt ________ Tie-in ________

Circumferential Butt ________ Webb to Shell ________ Block Ends ________

Frame Butt ________ Webb to Flange ________ X-Ray Repair ________

Miscellaneoud Parts ________
(write out)

____

TYPE OF CHECK: Root Pass ________ Finish Weld ________ Re-Check ________

PROCEDURE: Magnetic Yoke ________ Other ________
(write out)

OBSERVATION:

Number of Blocks ________

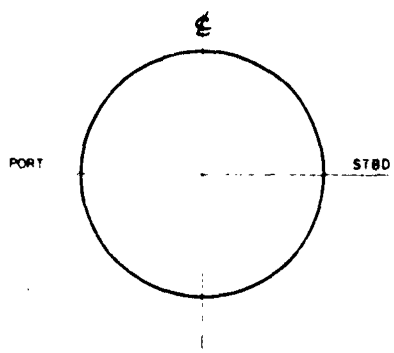
Length of Blocks ________

Number of Cracks:
Longitudinal ________ Transverse ________

Total Distance Magnafluxed:
Ft. ________ In. ________

Total Inches of cracks ________

Note: Location of M/fluxed area indicated on sketch.
Horizontal seams are indicated by symbol



Remarks ________

____

REQUESTED BY:

Welding Dept. ________ Navy ________ NPD ________ Other ________
(write out)

Reported By: ________
Magnaflux Technician

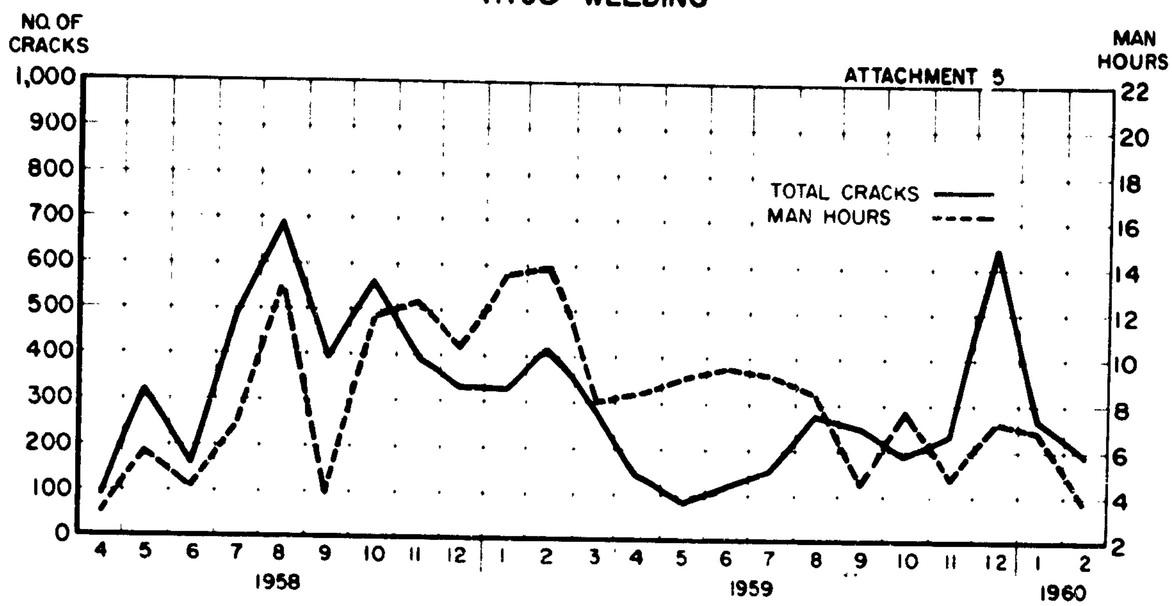
Attachment 4

Month	Year	Hull No.	Frame No. Struct. Code No.	Total No. of Cracks	Transv. Code 1	Long'l Code 2	Root Weids Code 3	Finished Weld Code 4	Inches of Cracks Code 5	Feet M/flux Code 6	Recheck Code 7	Inches of Cracks Code 8	Feet M/flux Code 9

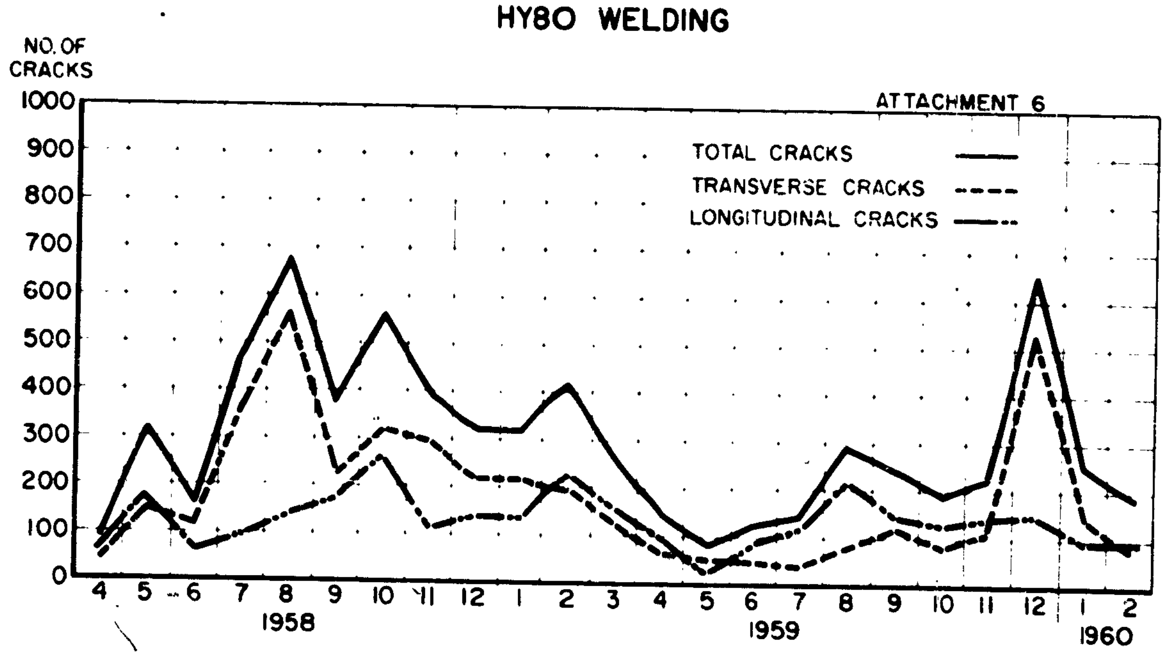
STRUCTURE CODE LIST

CODE NO.	STRUCTURE
1	Web to shell
2	Web to flange
3	Frame butts
4	Bhd. to shell
5	Shell seams & butts
6	Sea Chest
7	Inserts (shell)
8	Misc. Inserts & Penetrations
9	High Pressure Tanks
10	Torp. Impulse Tanks
11 (escape hatehes)	Trunks to shell
12	Shielding tank
13	Lead Shielding
14	Foundations
15	Butt welds in bhds. & tank tops Subject to D.S.P.
16	Scars
17	Misc.

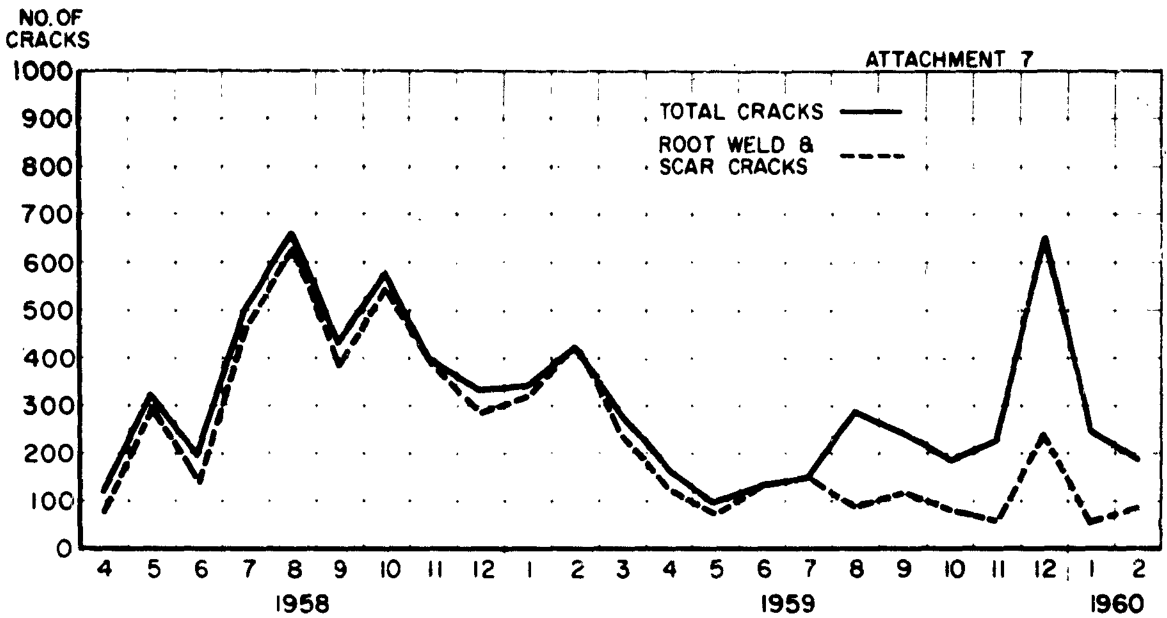
HY80 WELDING



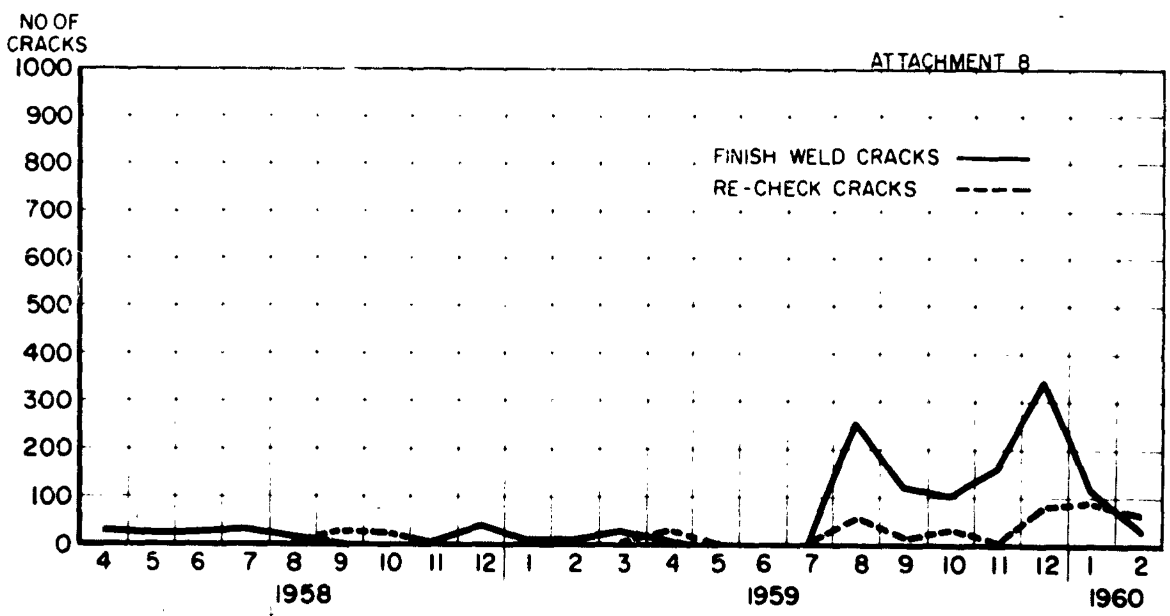
HY80 WELDING



HY80 WELDING



HY80 WELDING



March 22, 1960

HY-80 Symposium

Workmanship Controls in the Fabrication of HY-80 Hulls

E. Franks, Electric Boat Co.

The fabrication and welding of HY-80 steel structural components, of necessity, must be closely controlled operations in order to assure satisfactory performance of the end product. Judicious inspection throughout the various stages of fabrication is the method employed at EBDiv. to control the workmanship and provide this assurance.

It is essential that the quality of the materials entering into the fabrication be combined with workmanship control so that end product deficiencies, if they occur, can be properly evaluated. From receipt inspection of HY-80 plate material to final inspection of the submarine structure, all inspections form a part of workmanship control. Receipt inspection of the HY-80 plate material is conducted by the Inspection Department upon arrival of the plate in the plant. As shown in Figure 1, Brinell Hardness is checked at three points on each plate. The paint is removed from the three areas prior to taking the readings. The edge thickness is checked as shown in Figure 2, at 10 points using a micrometer. For all plates subject to sea pressure as designated on plate schedules, ultrasonic tests are made for detection of laminations as shown in Figure 3. These UT readings are taken along lines of a 24" grid over the entire surface. This inspection is combined with thickness measurements taken by means of Vidigage ultrasonic equipment as shown in Figure 4. The Vidigage thickness readings are taken at the intersecting points of the 24" grid mentioned above. At this time visual surface inspection for scars, scabs or other surface defects is made and such areas marked on the plate surface. All this data is recorded on chits as shown in Figure 5. Two types of forms are used for the receipt inspection operation. The first designated Type A inspection is used for plates which require UT and second designated Type B inspection for plates which do not require ultrasonic inspection. Upon completion of the required tests, the plates are marked satisfactory or unsatisfactory, stored and the records forwarded to the Inspection Department records section.

When plates are drawn from storage for fabrication, they proceed to the Layout Department where the Inspection Department checks layout in accordance with blueprints, makes visual surface inspection for scars, scabs or other surface defects. As shown in Figure 6 burned edges are checked for bevel angles, plate laminations, gouges and uneven burned surfaces. This data is logged into Inspection data books at this point.

The receipt inspection of electrodes used for welding HY-80 steel is based on the manufacturer's certification of compliance with Military Specification together with results of a practical usability test conducted by the Welding Engineer's Office. Release of electrodes for production use is based on satisfactory completion of both requirements and the results of this inspection are recorded by the Welding Engineer's Office. In order to provide and maintain low moisture content in electrode coatings, all Types MIL-11018, MIL-10015 and MIL-260-15 electrodes are baked prior to issue to the welders. As shown in Figure 7, this baking is conducted at a centrally located point by Welding Department personnel. Electrodes are transferred to holding ovens strategically located throughout the plant for direct issue to the welders. The Welding Engineer's Office makes a daily surveillance check of electrodes in the holding ovens as shown in Figure 8. Random samples of electrodes are selected from the holding ovens, the coating removed and the sample tested for moisture content by the R & D Laboratory. Results are reported daily to the Welding Engineer's Office

The fabrication sequence now brings the plate material in the hands of the shipfitter and the welding electrodes in the hands of the welder together to start the erection operation. When the shipfitter supervisor has the structure ready for welding, he requests a "cleared for work" chit from the structural inspector. The structural inspector checks the area for joint preparation, fit-up tolerances and preheat temperature. All fits must be satisfactory with the required preheat on the joint. When the inspector determines that all requirements are satisfied he obtains the signature of the shipfitter supervisor, the welding supervisor and certifies by his signature that the joint is satisfactory to start welding. The welding supervisor's signature on this chit as shown in Figure 9 indicates that he accepts the joint presented by the shipfitter as satisfactory for welding. This chit as shown on Figure 10 is then distributed by the inspector to the various offices for record. It should be noted that this chit may also be used for other operations which will be described later.

During the course of all welding, the structural inspector makes surveillance checks for compliance with established welding procedures, techniques and preheat and interpass temperature. Figure 11 shows an inspector checking preheat during progress of welding an insert. If at any time the inspector considers the work is not completely satisfactory, it is his prerogative to obtain corrective action through the cognizant supervisor.

When, in the course of erection, the welding supervisor determines an application is suitable for twin arc welding as shown in Figure 12 he presents a twin arc chit to the Inspection Department who check to their satisfaction that all applicable requirements are met. The Inspection Department then obtains approval from the Navy Inspection Office and distributes copies of the chit which is shown on Figure 13.

For full penetration welds, arc air gouging is used for preparation of the back weld. After gouging, the back weld area is ground and an MT inspection of the backgouged surface conducted by the structural inspector. The results of this inspection are entered on a chit similar to the final MT chit and copies distributed.

When the welding supervisor has completed the fabrication to his satisfaction he notifies the structural inspector, who visually inspects the work while still hot for weld contour, size or undercut. At this point the Inspector makes certain that in the preheated area all temporary erection clips and brackets not required for subsequent fabrication are removed, all surface scars are repaired and the surface in the weld area is properly prepared for final magnetic particle inspection. When considered satisfactory by the inspector he prepares a chit for final MT inspection, which the welding supervisor signs, certifying that the weld quality is in accordance with all requirements. At this point the welding supervisor authorizes the preheat to be turned off. Final MT inspection is then made by the structural inspector 24 hours or more after cooldown. Figure 14 shows a structural inspector making the final MT inspection of a butt weld. Upon satisfactory MT results, the chit is so marked and signed by the inspector and duplicate chits distributed. This chit is same as that used for fit up.

When unsatisfactory MT results are obtained the chit is so marked, and a repair weld certification procedure follows. A complete description of the unsatisfactory area is prepared by the inspector and immediately forwarded to the main inspection office. The structural inspector then gives verbal authority to the Welding Department to procede with removal of the defective area. When the inspector ascertains by MT inspection that the defect has been completely removed he signs the chit noting that the crack was removed and the area is ready for repair welding. This chit is now completed and duplicates are distributed. After repair welding is completed to the satisfaction of the welding supervisor he requests the structural inspector to initiate a new chit marked "repair weld" for final MT inspection as with an unrepaired weld. Final MT inspection of a repair weld is made at least 10 days after cooldown.

Upon completion of all butts and seams, the structural inspector initiates a request to the X-Ray Department to radiograph the required area. When the X-Ray Department radiographic inspector ascertains that the X-Ray quality meets all requirements he presents the radiographs to the Inspection Department. As shown in Figure 15 the Inspection Department reviews the radiographs and presents them to the Navy Inspection Office for certification. At each review a radiography report, which accompanies the radiographs, is initialled by the reviewer signifying certification and the chits returned to the X-Ray Department for file.

The data obtained from the final MT chits is transferred to master plans by the Inspection Office as shown on Figure 16. By this method an up-to-date record is available for ready reference on the status of completed work. After entry on the master plans the chits are filed in the Inspection Office as shown in Figure 17. This file is available to all inspectors for review and reference at any time.

The use of this chit system at Electric Boat Division for workmanship control in the fabrication of HY-80 hulls provides a constant check and record throughout the production sequence. A flow chart as shown on Figure 18 indicates the sequence of major operations throughout construction. When the various inspection operations discussed above are factored into this flow chart we see that an inspection is performed between essentially all major operations. By this method quality is assured throughout the fabrication operation. The continuous surveillance by inspection personnel and their contact with trade personnel increases the trade cognizance of quality. In this manner, workmanship is used to build quality into rather than inspect quality into the end product.

FIGURE 1

FIGURE 2

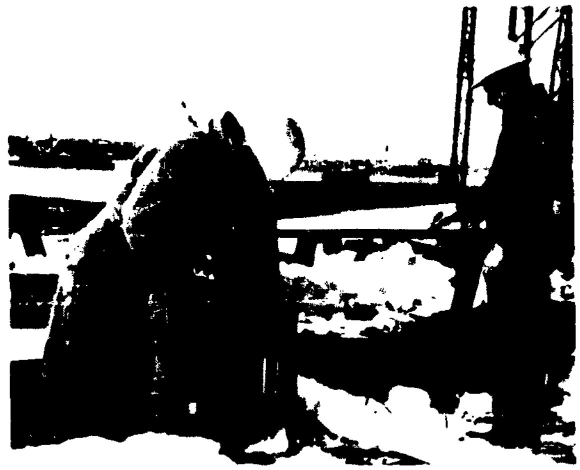


FIGURE 3

FIGURE 4

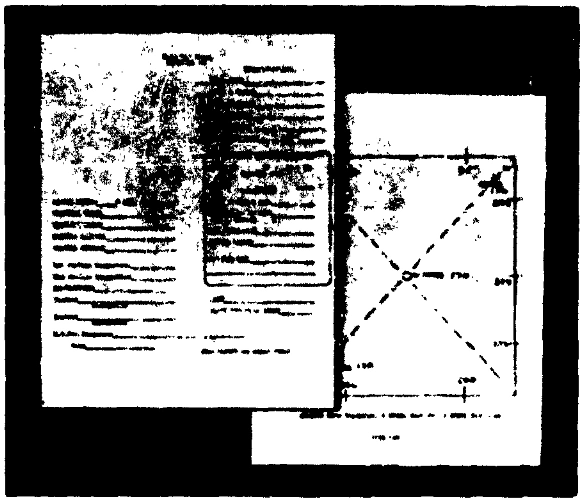


FIGURE 5

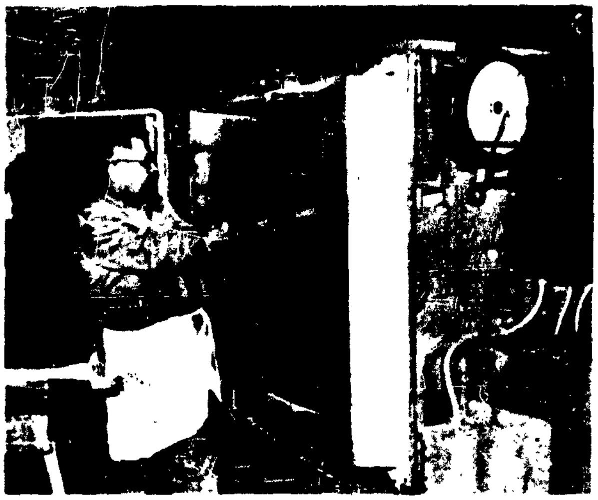
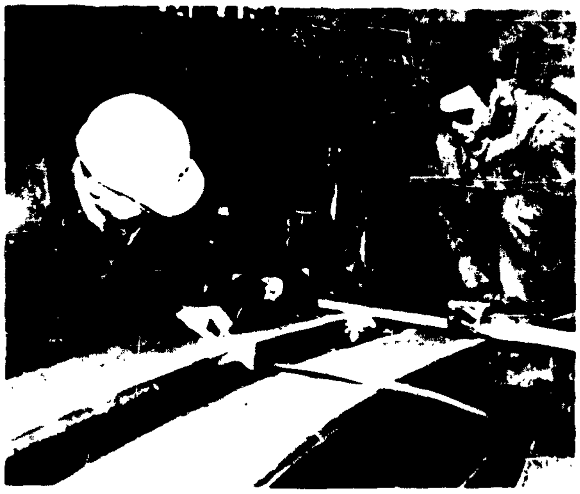


FIGURE 7



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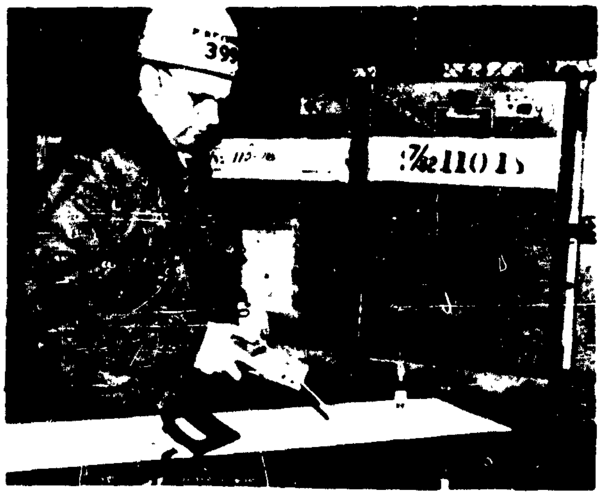

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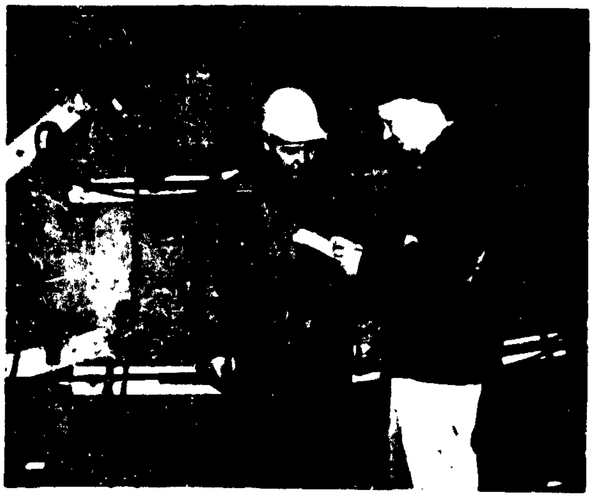

FIGURE 9

FIGURE 11

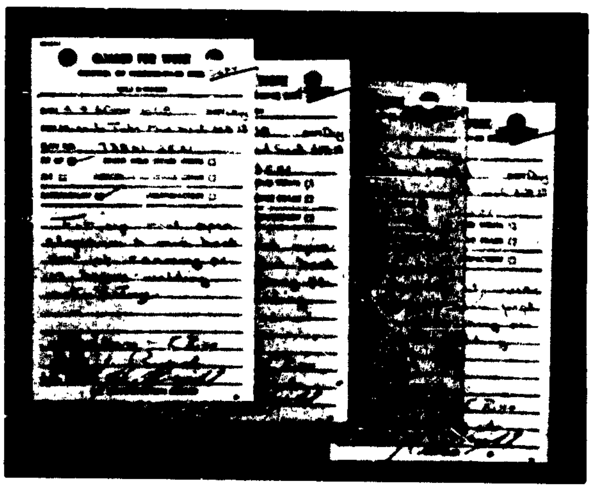

FIGURE 10

FIGURE 12

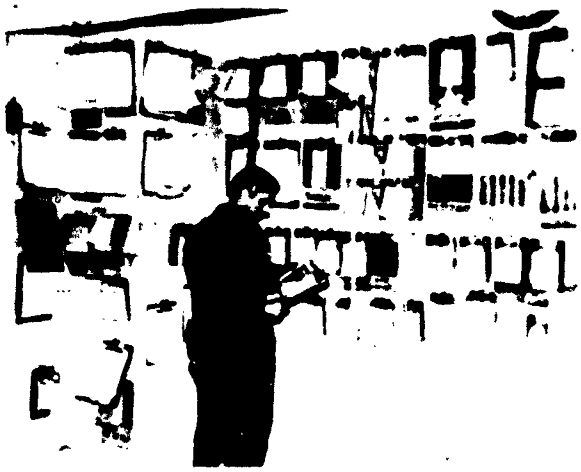

FIGURE 7

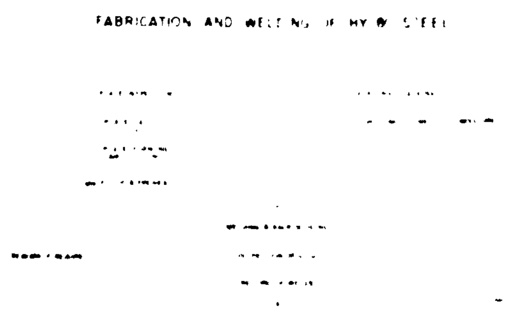

FIGURE 18