

Tensile Properties of HY80 Steel Welds Containing Defects Correlated With Ultrasonic And Radiographic Evaluation

Defects intentionally induced in submarine hull welds were evaluated ultrasonically and by radiography. Class I and II welds had a high degree of reliability

BY ROBERT A. YOUSHAU

ABSTRACT. Tensile testing was performed on HY80 welds containing these specific defects: slag, lack of fusion and incomplete penetration. Tensile properties were correlated with ultrasonic and radiographic evaluation in terms of acceptance criteria of the Naval Ship Systems Command. Results of this work indicate a high degree of confidence for static application for welds evaluated by this criteria.

Introduction

Hull welds on U. S. Naval vessels are inspected by ultrasonics or radiography and acceptance criteria have been devised for each method. Acceptance standards for radiography are based on defect identification and also on length and proximity to other flaws; however, with ultrasonics defect identification is not considered. Instead, evaluation is based on *signal amplitude* length and proximity to other flaws.

Using these parameters, three classes of acceptable weld quality have been devised for radiography and for ultrasonics. In practice the acceptance criteria has worked very well but it

was not known to what extent weld quality might be degraded by permissible amounts of certain type flaws.

The primary purpose of this work was to obtain tensile test data for weld joints containing specific flaws and to correlate these data with the ultrasonic inspection results. Tensile data were also correlated with radiography and a comparison was made between the two inspection methods relative to the evaluation of discontinuities in terms of acceptance criteria of the Naval Ship Systems Command.

Selection of Defects

U. S. Navy procedures for ultrasonically evaluating weld flaws is based on signal amplitude, and entrapped slag represents the largest potential cross-sectional loss for any type defect likely to be permitted in a hull weld. This is because the reflection from bonded slag is substantially less than that from an air gap type defect (estimated ratio of 6:1). Accordingly, entrapped slag was selected for study.

If the slag is not bonded, then the ultrasonic response closely resembles that obtained from lack of fusion, a welding condition where the void has been filled with metal without the metal fusing to the adjacent surface, an air gap defect. Since there is no

obvious way to distinguish between the two conditions ultrasonically, slag and lack of fusion are grouped together. The grouping of slag and lack of fusion is further suggested by their mechanical similarity and the fact that in weld fabrication they frequently occur together. This is substantiated by radiographic analysis.

Selection of Filler Material

HY80 was chosen as the base material and 11018 welding rod was selected as the filler material. This low hydrogen iron powder electrode is suited to all position welding for all applications and is extensively used in submarine hull construction.

Since this study is concerned specifically with weld defects, it is the filler material and not the base metal which is of interest. It is emphasized that the HY80 base metal has only two functions: it is a handle for holding the weld joint during test and it is a standard against which properties of the weld joint are compared. Specifically, if the failure is in the HY80 base metal, then it can be said that the properties of the weld joint were superior to HY80. If the failure is in the weld joint then it can be said that the properties of the weld joint were degraded to the numerical values obtained in the test.

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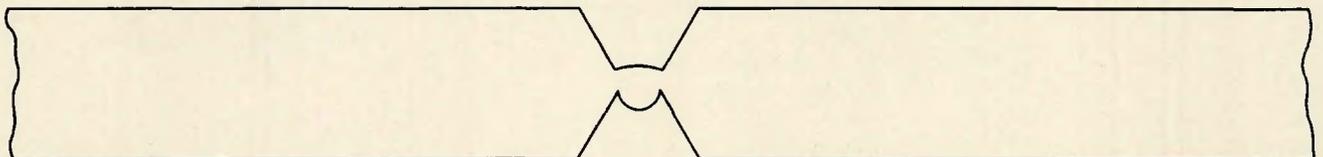


Fig. 1—Cross-sectional sketch of root pass bead for inducing entrapped slag

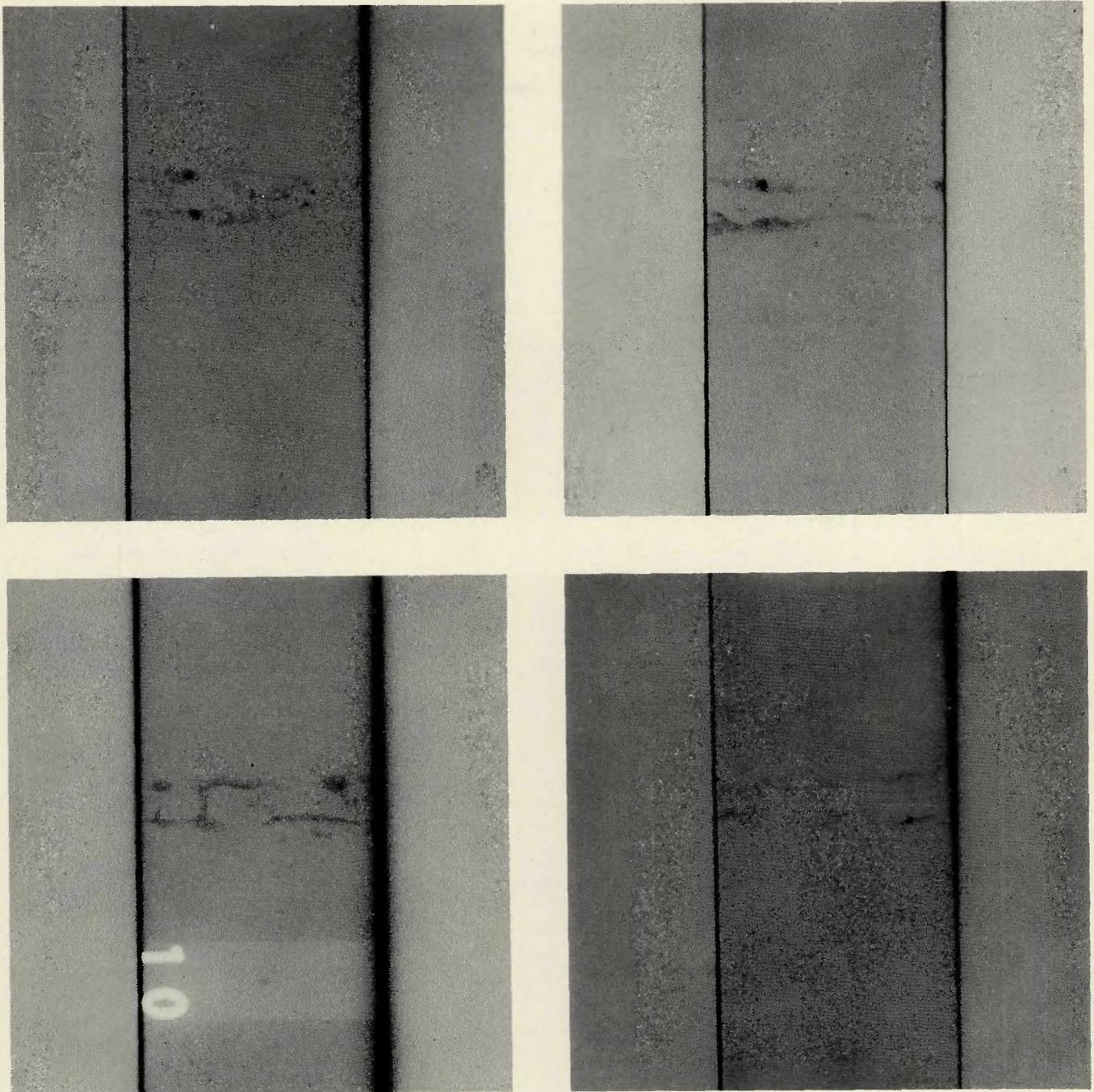


Fig. 2—Radiographs of typical weld flaws slag and/or lack of fusion

Weld Fabrication and Weld Inducement

HY80 steel for submarine construction must be welded in accordance with NAVSHIPS 0900-006-9010.² Insofar as this work is concerned, three technical aspects apply:

1. HY80 base metal must be preheated above 125F but not in excess of 300F
2. Heat input during welding is limited to a maximum of 55,000 joules/inch. (In practice this is complied with by

welding so that there is a bead length of at least 6 in. for a $\frac{3}{16}$ in. rod and 5 in. for a $\frac{5}{32}$ in. rod.)

3. The weld bead adjacent to the HY80 must have a temper bead placed on it.

One-inch thick HY80 plates were prepared in 5 ft lengths by 1 ft wide. The edges were chamfered to provide a double V-joint (60 deg.).

The two plates were positioned to maintain a $\frac{3}{16}$ in. root gap and in applying the first pass some filler material was permitted to drop into the

root opening (Fig. 1). In good welding practice this irregular filler material would be ground smooth before welding from the other side; however, in this work the grinding was not performed. Consequently, in the course of welding over the root pass some slag is entrapped in the space between the chamfer and the root pass bead. This technique can also result in lack of fusion, verified by radiographic analysis.

Figure 2 shows radiographs of typical flaws produced by this technique.

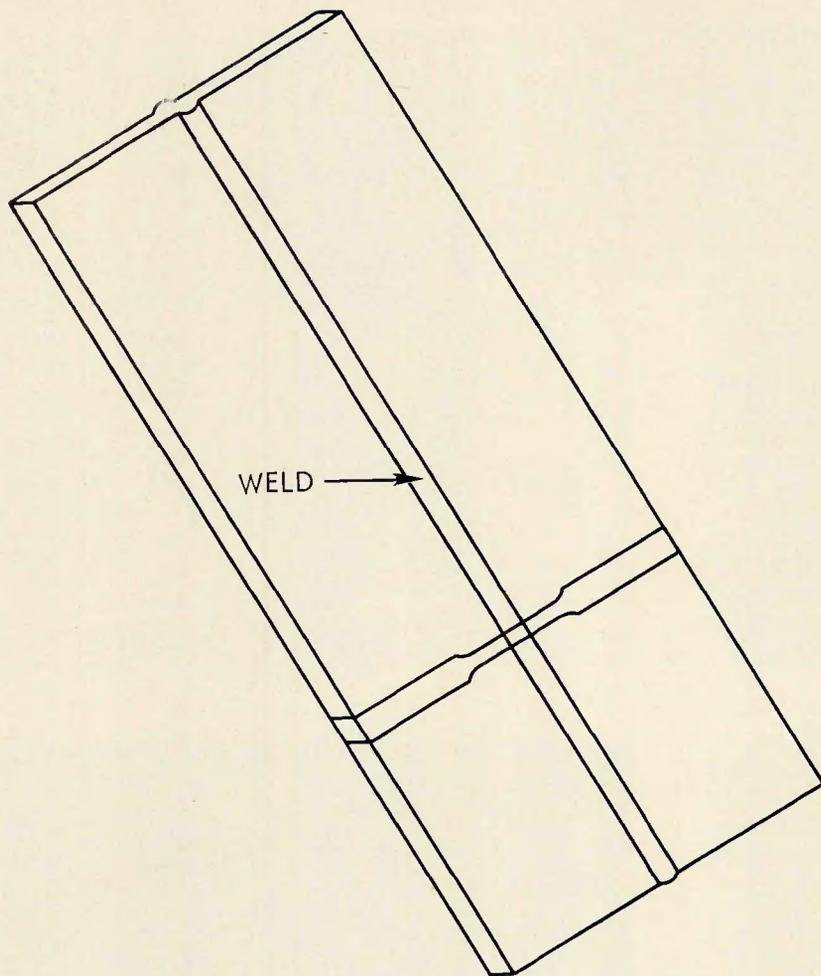


Fig. 3—Tensile coupon location relative to welded plate

Experimental Procedures

The following sequential steps were employed:

1. After welding, the weld bead was machined reasonably smooth
2. Five foot welded sections were radiographed with location markers included
3. Tensile coupon locations were selected by ultrasonics and radiographic analysis
4. Ultrasonic signal amplitude and discontinuity lengths were determined. In cases where signal amplitude exceeded the amplitude reject level, a determination was made of the number of decibels above this level
5. Tensile coupon blanks were removed from the welded plate at selected locations
6. Finished tensile coupons were radiographed
7. Specimens were tensile tested.

The Tensile Test

Tensile blanks for use in this work were removed from the welded plates as illustrated in Fig. 3. The dimensions of the tensile coupons are shown in Fig. 4.

Three types of primary information were obtained from the tensile test:³

Yield Strength—The strength at which a material exhibits a specified limiting set. In this study the yield was obtained using two different methods which produced equivalent results—the 0.2% offset method and the 0.5% extension under load method.

Ultimate Strength—The maximum stress that can be developed in the tensile test referred to the original cross-sectional area.

Percent Elongation—The increase in gage length after rupture referred to the original gage length. A gage length of 8 in. was used in this work.

Ultrasonic Procedure and Acceptance Criteria

Ultrasonic inspection and flaw evaluation were performed in accordance with Navships 0900-006-3010.¹ Since the procedure and acceptance criteria of this document are germane to this work, a brief review of the pertinent aspects are presented.

Recommended procedures for the ultrasonic inspection of steel 1 in. thick are: a transducer with an active element not in excess of 1 in., a nominal frequency not less than 2.0 MHz and a resultant shear wave angle of 60-70 deg. The transducer used in this work was 1/2 in. by 1 in. with a nominal frequency of 2.25 MHz and a resultant angle of 70 deg in steel.

Two signal amplitude levels, ARL (amplitude reject level) and DRL (disregard level) are defined in conjunction with a calibration procedure involving the reflection from the wall of a 3/64 in. diam drilled hole. Distance-amplitude correction controls are required. The sensitivity is set either to obtain a signal amplitude 80% of full screen height for the case

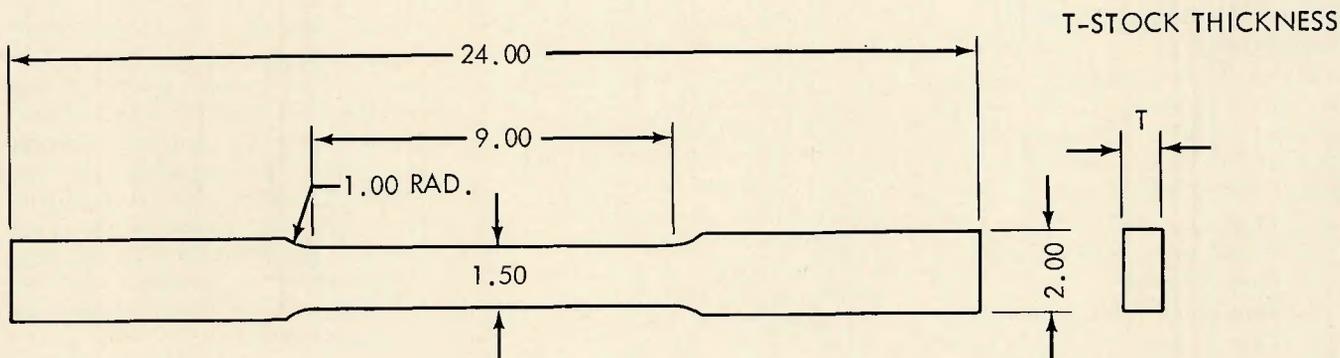


Fig. 4—Tensile coupon

where a decibel attenuator is not available or to obtain a signal amplitude 20% of full screen height for the case where a decibel attenuator is available. For the latter situation, after calibration, the signal amplitude is increased by 12 decibels. In either case the 20% level is the DRL (Class I) and the ARL is either the 80% level or 12 decibels above the DRL.

Figures 5a and 5b illustrate these two cases.

The calibration procedure involving the decibel attenuator averts the problem of instrument non linearity and is preferred.

Defect lengths and separation distances between defects are determined by establishing the end points by the method of half amplitude.

With the instrument thus calibrated, three classes of weld quality are defined. A description of these classes is given in Table 1.

The ultrasonic acceptance limits also contain rules regarding the evaluation of multiple discontinuities and limits for cumulative flaw length in specified lengths of weld.

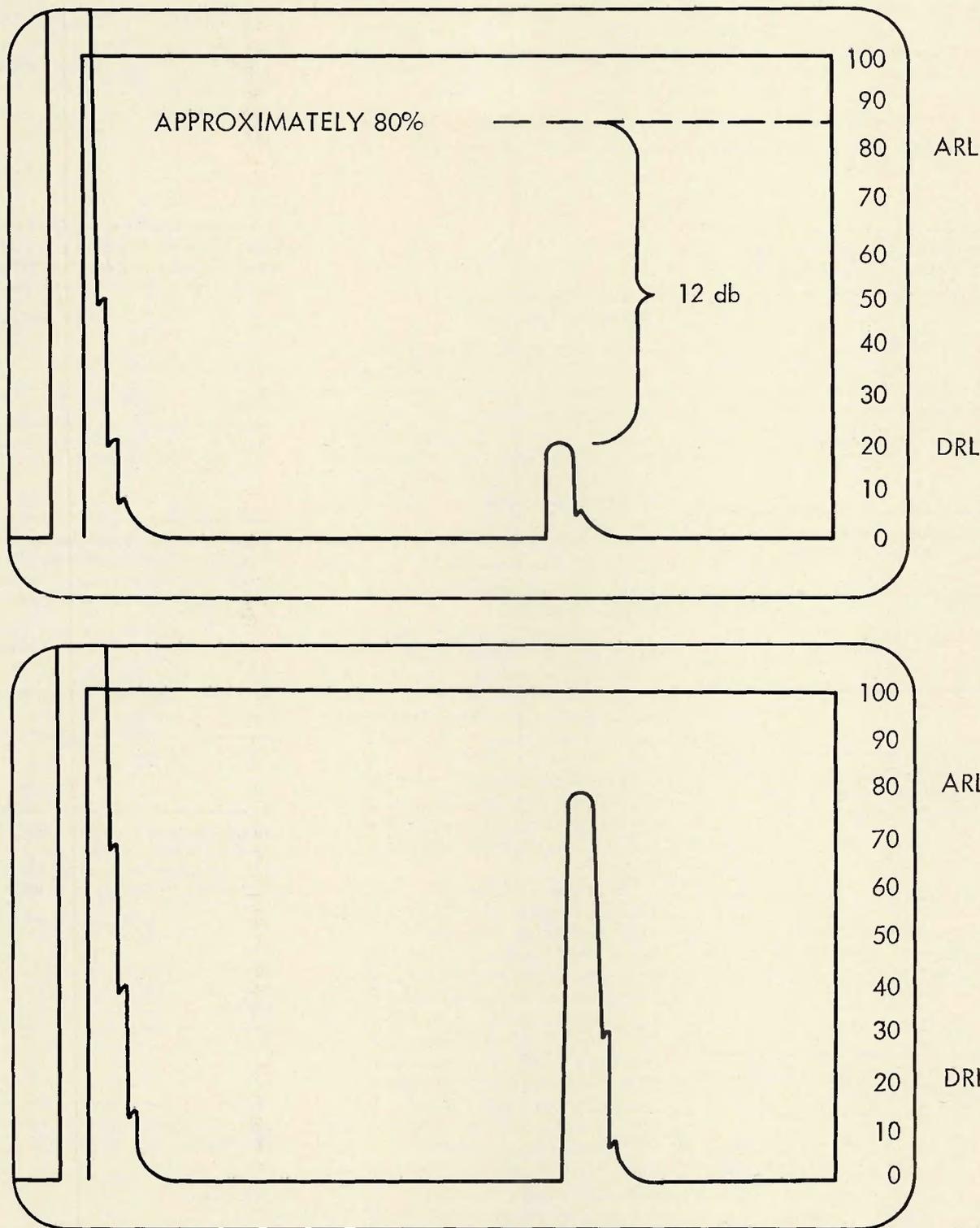


Fig. 5—Typical viewing screen calibration for instruments with (top) and without (bottom) decibel attenuation control. Calibration is performed with reflection from wall of a 3/64 in. drilled hole using distance-amplitude corrections

Table 1—Acceptance Limits for Ultrasonically Inspected Hull Structure Production and Repair Welds¹

Class	Indications in excess of ARL	Indications equal to DRL or greater*	Indications less than DRL
I	Rejectable regardless of length	Length must not exceed 1/2 T	Acceptable
II	Length must not exceed 1/4 in.	DRL is increased from 20% to 40% of full screen height Length must not exceed 1T	DRL is increased from 20% to 40% of full screen height Acceptable
III	Length must not exceed 1/2 in.	DRL is increased from 20% to 40% of full screen height Length must not exceed 1 in. or 1T whichever is greater	DRL is increased from 20% to 40% of full screen height Acceptable

* Up to and including ARL

Table 2—Tensile Properties of Ultrasonically Evaluated Welds, Class I

	Yield psi	Ultimate, psi	Elongation, %
High	84,200	101,500	18.6
Low	80,600	98,000	16.5
Average	82,800	100,000	17.2

Note: In all cases, failure occurred in the HY80 base metal, 17 specimens

Table 3—Specified Mechanical Properties for HY80 (1 in. thick)

Yield, psi	Ultimate, psi	Elongation, %
80,000-95,000	Record for information only	20

Table 4—Tensile Properties of Ultrasonically Evaluated Class II Welds, Slag and/or Lack of Fusion Flaws

	Yield, psi	Ultimate, psi	Elongation, %
High	84,300	100,800	18.0
Low	79,200	98,600	16.0
Average	82,500	99,600	17.2

Note: In all cases failure occurred in the HY80 base metal; 11 specimens

Table 5—Tensile Properties for Welds Unacceptable for Class III, DRL Slag and/or Lack of Fusion Type Flaws

	Yield, psi	Ultimate, psi	Elongation, %
High	84,200	100,500	17.9
Low	82,300	99,500	15.0
Average	83,600	99,800	16.8

Note: In all cases failure occurred in the HY80 base metal; 4 specimens

Tensile Properties vs. Ultrasonic Results

Seventeen tensile coupons were selected from locations in several different plates where the ultrasonic test did not reveal any flaws. All seventeen specimens, which represent Class I, broke in the HY80 base metal outside the heat affected zone. The spread of the tensile properties and the averages are presented in Table 2.

Since failure occurred in the base metal, these values are to be compared with the specified values for HY80, Table 3.⁴

The specification for elongation refers to a 2 in. gage length. In this work, the specimen size required an 8 in. gage length and since the calculation of elongation is based on the gage length, lower values are to be expected.

From the comparison of Tables 2 and 3 it was concluded that the HY80 met the specification for this material and that the welding procedure was proper.

Ultrasonic evaluation produced eleven examples of Class II from welds containing slag and/or lack of fusion. ARL indications less than 1/4 in. length did not occur, consequently all of these examples pertain to DRL flaws not in excess of the specified limits. All eleven of these specimens broke in the HY80 base metal outside of the heat affected zone. The tensile data are presented in Table 4.

This study did not produce any examples of ultrasonically evaluated Class III welds, which is not surprising considering that ARL flaws within the size restrictions of Class III did not occur and that DRL flaws acceptable for Class III are also acceptable for Class II and were so categorized.

A total of 52 slag and/or lack of fusion specimens were ultrasonically evaluated as unacceptable for Class III. Twenty-nine of these failed in the base metal with properties almost identical to those of Tables 2 and 4. The tensile values for these welds are presented in Table 5 for DRL flaws and Table 6 for ARL flaws.

For the remaining 23 specimens ultrasonically evaluated as unacceptable for Class III, with slag and/or lack of fusion flaws, failure occurred in the weld, in each case at a flaw location. Table 7 lists the tensile values for DRL flaws and Table 8 lists the values for ARL flaws.

Table 6—Tensile Properties for Welds Unacceptable for Class III ARL Slag and/or Lack of Fusion Type Flaws

	Yield, psi	Ultimate, psi	Elongation, %
High	84,900	102,300	19.0
Low	75,600	99,500	15.0
Average	83,600	99,800	16.8

Note: In all cases failure occurred in the HY80 base metal; 25 specimens

Table 7—Tensile Properties for Ultrasonically Evaluated DRL Slag and/or Lack of Fusion Flaws, Unacceptable for Class III, Failure in the Weld

	Yield, psi	Ultimate, psi	Elongation, %
High	82,400	94,500	5.3
Low	80,900	87,300	3.0
Average	81,500	91,600	4.0

Note: 3 specimens

Table 8—Tensile Properties for Ultrasonically Evaluated ARL Slag and/or Lack of Fusion Flaws, Unacceptable for Class III, Failure in the Weld

	Yield, psi	Ultimate, psi	Elongation, %
High	84,500	101,400	11.0
Low	77,100	82,300	2.0
Average	82,100	93,900	5.6

Note: 20 specimens

Table 9—Mechanical Properties of 11018 Welding Rod, As Welded

Yield, psi	Ultimate, psi	Elongation, %
98,000 to 110,000	110,000	20*

* 2 in. gage length

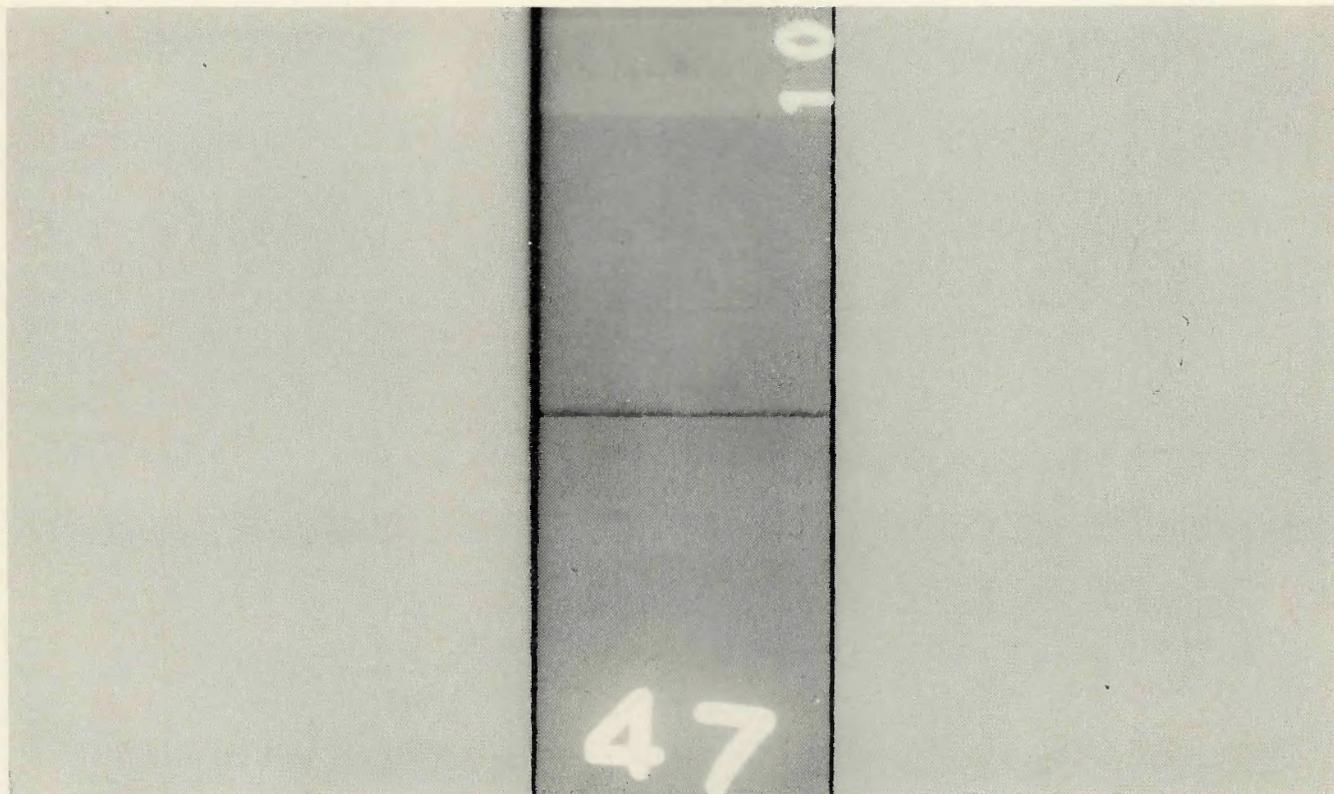


Fig. 6—Radiograph of incomplete penetration

The comparison of Tables 7 and 8 with Table 9 shows that for the case of failure in the weld the yield and ultimate strengths have been noticeably degraded while elongation is markedly reduced. It is considered coincidence that the degraded yield strength of the filler material is approximately equivalent to the yield strength of the HY80 base metal.

A decibel attenuator was used to numerically evaluate amplitude for specific slag and/or lack of fusion flaws where the ultrasonic signal was in excess of the ARL. Table 10 presents tensile properties for those specimens from this group for which failure occurred in the weld. For the cases where failure occurred in the base metal the tensile properties are almost identical with previously presented data. The number of specimens involved and the incidence of failure is indicated for each decibel level.

The comparison of these data with Table 9 indicates a degradation of yield and ultimate strengths and a considerable reduction in elongation. There does not however appear to be any correlation between the signal amplitude and the extent of the degradation of properties. The high incidence of failure in the weld (12 of 18) is significant.

Tensile testing was also performed

on a group of eight specimens containing incomplete penetration. These welds were ultrasonically evaluated as unacceptable for Class III with signal amplitude uniformly three decibels above the ARL. All eight of these specimens failed in the base metal. The size and severity of the incomplete penetration is illustrated in the radiographic reproduction of Fig. 6 and the macrograph of Fig. 7. Table 11 lists the data.

Acceptance Criteria for Radiographic Inspection

The acceptance criteria for welds inspected by radiography is set forth in NAVSHIPS 0900-003-9000.⁸ Flaw identification is required and limits for each type flaw are defined in terms of

the weld thickness for three classes of weld quality.

All of the welds used in this work were 1 in. thick and the acceptance criteria for the defect types pertinent to this study are as follows:

Slag

- Class I Max single length, $\frac{3}{16}$ in.
- Class II Max single length, $\frac{3}{8}$ in.
- Class III Max single length, $\frac{1}{2}$ in.

Incomplete Penetration and Lack of Fusion

- Class I Max length, individual indication, $\frac{3}{32}$ in.
- Class II Max length, individual indication, $\frac{3}{16}$ in.
- Class III Max length, individual indication, $\frac{3}{16}$ in.

Table 10—Tensile Properties for Welds Ultrasonically Evaluated at Specific Decibel Values for Signal Amplitude in Excess of ARL, Slag and/or Lack of Fusion Flaws, Failure in the Weld

No. of Decibels	Yield, psi	Ultimate, psi	Elongation, %	Broke in Weld
2	83,700	99,400	8.0	1 of 1
3	82,500	89,700	4.0	1 of 3
4	81,300	89,400	4.0	5 of 6
6	80,400	95,000	6.0	4 of 5
8	—	—	—	0 of 2
10	81,700	99,100	8.0	1 of 1

Note: Average values

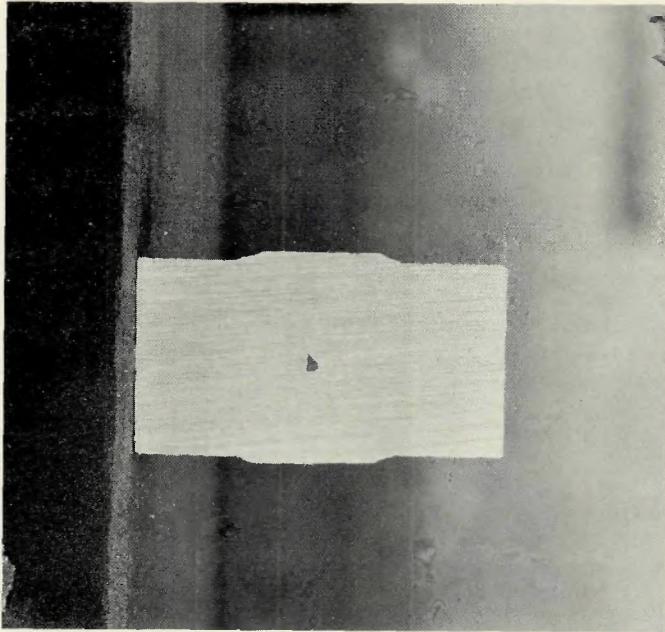


Fig. 7—Macrograph of incomplete penetration

When more than one indication is present a distinction is made between aligned and unaligned distribution. For the aligned case, a separation distance of $4L$ is required between indications, where L is the length of the longer of two indications. For the unaligned case, permissible individual indications must be separated in any direction from adjacent groups or other individual indications by L or $1/2$ in. whichever is lower.

There are also cumulative limits in specified lengths of weld which do not apply to this work.

Tensile Properties vs. Radiographic Analysis

Radiographic analysis of the welds is presented in Table 12. In the tensile test, all of the welds in Class I, II and III experienced failure in the base metal. These data, which are not presented here, are consistent with the previously detailed mechanical properties for HY80.

For the welds which were radiographically analyzed as unacceptable for Class III, 38 specimens failed in the base metal, again with properties consistent for HY80. Twenty-three specimens failed in the weld. Table 13 details the types of flaws involved and the number of failures for each type.

There are no significant differences between the data of Tables 14 and 15 and it is concluded that slag mixed with lack of fusion affects weld quality much the same as isolated slag. It is noted though that in either case the

yield and ultimate strengths are degraded in comparison with the values specified in Table 9 and that the reduction in elongation is considerable.

Conclusions

Generalizations based on statistical analysis demand random sampling and it is recognized that the selection of specimens for this work was not random. Nevertheless, the weld flaws were in each case typical of what might be encountered in production and both the inspection procedure and classification into categories were strictly in accordance with naval specifications. Similarly, although the welds were made by a particular welder working under a given set of ambient conditions, the welding procedure was as specified for HY80 hull fabrication. For these reasons, these data are considered suitable for statistical analysis with the results generally applicable to similar welds.

The problem is: Having tested a certain size and having obtained a

certain ratio of success to failure for that sample, what statement can be made regarding similar items not tested? Problems of this type are handled by determining at a particular level of confidence a bracket within which the untested specimens can be expected to perform. In this particular case, the performance characteristic of interest is that the weld should be stronger than the base metal. In statistics this is a one-sided confidence interval and tables based on cumulative binomial probability distribution have been compiled for rapid processing for this type problem.⁷ Separate tables are presented for different confidence levels.

In regard to the level of confidence it is important to recognize that a 100% confidence level can be attained only by testing all of the specimens in a population. For confidence levels less than 100%, finite sample sizes can be used but at very high confidence levels, the sample size must be large or the statement that is to be made concerning the untested specimens will be weak. Most of the sample sizes of this work were considered adequate for analysis at a 90% confidence level. Table 16 lists the confidence intervals for each category tested.

The confidence interval of 87% for the group ultrasonically evaluated as Class I is used to illustrate the meaning which can be attached to the values presented in Table 16. The following statement applies: It is calculated that any group of like specimens, randomly selected, will test at least 87% satisfactory 90% of the time the test is made. If the actual test

Table 11—Tensile Properties for Welds Containing Incomplete Penetration, Ultrasonically Evaluated as Unacceptable for Class III, Failure in Base Metal

	Yield, psi	Ultimate, psi	Elongation, %
High	83,700	101,500	18.0
Low	82,400	100,000	17.2
Average	83,100	100,800	17.7

Note: 8 specimens

Table 12—Radiographic Analysis and Classification of Weld Defects

	Class I	Class II	Class III	Class III Unacceptable
Clean	13	—	—	—
Slag	4	5	2	35
Slag mixed with lack of fusion	—	—	—	9
Lack of fusion	1	2	—	9
Incomplete penetration	—	—	—	8
Totals	18	7	2	61

Table 13—Radiographic Identification of Weld Flaws Unacceptable for Class III, Failure in Weld

Flaw Type	No. of Specimens
Slag	19
Lack of fusion	0
Slag mixed with lack of fusion	4

were to be made the percentage for satisfactory performance might be higher (or lower) but the sample size limits the prediction to 87%.

From Table 15 it is concluded that the acceptance criteria for Class I and Class II welds is well placed both for ultrasonic and radiographic evaluation. The number of specimens for Class III radiographic evaluation was considered insufficient and no conclusions are made for this category. Considering the high degree of reliability required in submarine construction and the number of incidences of failure in the weld (23) for slag and/or lack of fusion flaws unacceptable for Class III, the limits of acceptance for Class III also seem to be well placed.

A confidence interval of 75% was calculated for the specific weld flaw incomplete penetration. This value suggests that for static application incomplete penetration might be tolerated in larger amounts than presently permitted.

All specimens involved in this study were evaluated by both ultrasonics and radiography. The comparison in Table 17 is presented in terms of the weld classes previously described.

In the table, 75 of 88 specimens were evaluated to the same class by both methods. Four other specimens were closely evaluated. This comparison indicates good equivalency.

In the analysis of specific cases where classification was radically different, there were five examples of slag and four of lack of fusion. Regarding the inspection methods, when the classification was radically different ultrasonics indicated more gross severity in four cases while radiography indicated more gross severity in five cases.

Flaw Examination

All 23 of the specimens which failed in the weld broke at a flaw location. Approximate losses in cross-section area were determined for each specimen. These data which pertain to a specimen cross-section of 1½ in. square are graphically plotted in Fig. 8 while the spread of values is presented below.

Cross-section Area of Flaw

High	0.340 sq in.
Low	0.110 sq in.
Average	0.210 sq in.

No conclusions are made regarding these data other than that there seems to be a general trend toward lower ultimate strength for larger flaws.

Figure 9 is a photograph illustrating typical flaws in broken tensile specimens.

Discussion

This work was restricted to static tensile testing and the conclusions drawn are accordingly restricted to static applications. Further, these data are not considered translatable to applications involving dynamic loading.

As stated previously, the ultrasonic procedure for inspecting naval vessels does not consider defect identification. Although this work has shown that welds ultrasonically evaluated by this procedure exhibit a high degree of reliability, there are indications that for static applications specific defect types could be tolerated in larger amounts than currently permitted. This is substantiated by the consistency of the tensile testing results obtained for incomplete penetration. The importance of defect identification is further supported by the high incidence of failure in the weld for slag type defects. Further work involving defect identification and mechanical correlation with specific flaw types might usefully enlarge upon this knowledge.

Summary

Hull structure welds on naval vessels are inspected either by ultrasonics or radiography. For each of these inspection methods the Naval Ship Systems Command has defined three classes of weld quality, Table 1. These weld quality classification categories were used in this study which was primarily concerned with the specific weld flaws slag and lack of fusion. These defects were intentionally induced in submarine hull welds which were then inspected and evaluated with ultrasonics and radiography. Tensile coupons were removed from select locations and stressed to failure. Welds evaluated as Class I and II were of a high degree of reliability for static applications. Not enough specimens were obtained for Class III to form conclusions for that category; however, the high incidence of failure in the weld for those specimens judged unacceptable for Class III suggest the upper limits of Class III to be well placed.

Table 14—Tensile Properties for Welds Radiographically Evaluated as Unacceptable for Class III, Weld Flaw Identified as Slag, Failure in Weld

	Yield, psi	Ultimate, psi	Elongation, %
High	84,400	101,400	11.0
Low	77,100	84,500	2.0
Average	81,900	93,700	5.5

Note: 19 specimens

Table 15—Tensile Properties for Welds Radiographically Evaluated as Unacceptable for Class III, Weld Flaws Identified as Slag mixed with Lack of Fusion, Failure in Weld

	Yield, psi	Ultimate, psi	Elongation, %
High	84,500	99,400	8.0
Low	79,800	82,300	2.0
Average	82,900	92,700	5.0

Note: 4 specimens

Table 16—Confidence Intervals for Satisfactory Weld Performance Calculated at a 90% Confidence Level

	No. of Specimens	No. of Failures	Confidence Interval, %
Ultrasonic Evaluation			
Class I	17	0	87
Class II	11	0	81
Radiographic Evaluation			
Class I	18	0	88
Class II	7	0	72
Class III	2	0	32
Incomplete Penetration			
Unacceptable for Class III	8	0	75

Table 17—Comparison of Ultrasonic and Radiographic Flaw Evaluation in Terms of Acceptance Criteria of Naval Ship Systems Command

Ultrasonics	No. of Specimens	Radiography
Class I	15	Class I
Class I	1	Class II
Class I	1	Class III*
Class II	2	Class I
Class II	4	Class II
Class II	1	Class III
Class II	4	Class III*
Class III*	1	Class I
Class III*	2	Class II
Class III*	1	Class III
Class III*	56	Class III*

* Unacceptable for Class III

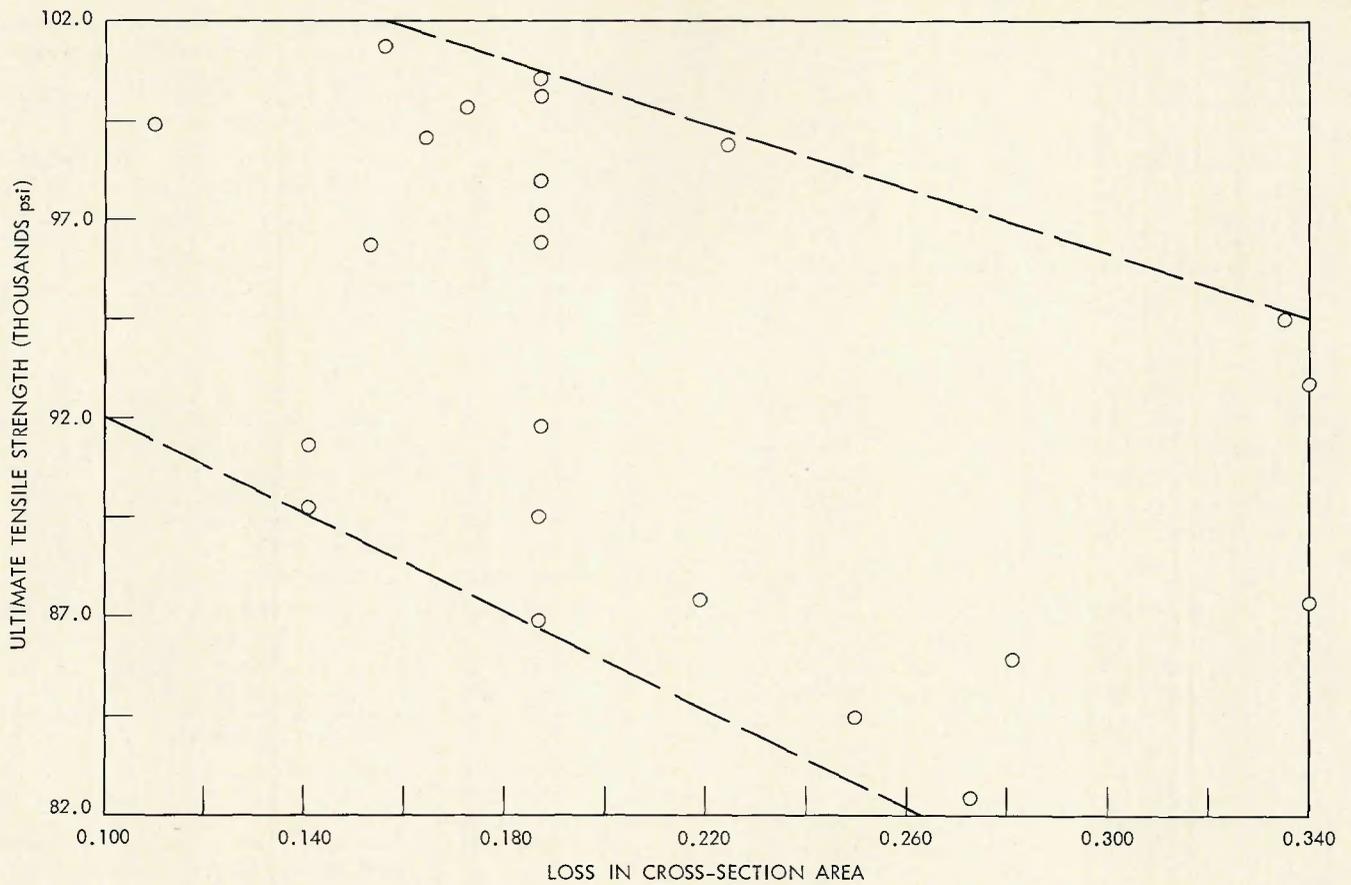


Fig. 8—Ultimate tensile strength vs. flaw area for specimens failing in weld

A comparison was made between the evaluations by ultrasonics and radiography which demonstrated good equivalency.

Acknowledgment

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References

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Fig. 9—Typical flaws in broken tensile specimens



Technical Papers Sponsored by WRC at Detroit

Special committees of the Welding Research Council sponsored four symposiums at the 53rd Annual Meeting of AWS in Detroit, Cobo Hall, April 10-14.

University Research Conference, Session 9. Wednesday, April 12, 9:30 AM

Chairman: Paul W. Ramsey, A. O. Smith Corp.; Co-Chairman: Prof. R. G. Gilliland, Univ. of Wisc.

"Activities of Pressure Vessel Research Committee" Prof. Alan Pense, Lehigh Univ.

"Mid-Range Ductility Minimum in Nickel Alloy Weldments" Prof. N. F. Fiore, Notre Dame Univ.

"A New Weldability Problem—Hot Cracking Induced by Weld Tooling" Prof. Warren F. Savage, R.P.I.

"Magnetic Control of Stud Welding" Prof. Clarence Jackson, Ohio State University

"Effect of Porosity on Tensile Strength of Aluminum Alloy Weldments" T. F. Leahey, Esso Res. and Eng. Co.

"Welded Continuous Frames and Welded Plate Girders" Prof. Lynn Beedle, Lehigh Univ.

Schedule: 9:30—Opening Remarks; 9:35—Paper 1 (30 min); balance of papers 20 min each.

Time for each presentation includes 5 min for discussion.

Strength and Design of Aluminum Alloy Weldments, Session 13. Thursday, April 13, 9:30 AM

Chairman: R. A. Kelsey

"Effects of Defects on Properties of Aluminum Weldments" A. W. Pense and Prof. R. D. Stout, Lehigh Univ.

"Distortion and Residual Stresses" Prof. K. Masubuchi, M.I.T.

"Fatigue Strength of Weldments" Prof. W. W. Sanders, Jr., Iowa State University

"Design Considerations in Welded Aluminum Structures" Dr. J. W. Clark, Alcoa Research Labs.

Reactive and Refractory Metals Symposium, Sessions 17 and 19. Friday, April 14

Morning Session: Chairman: G. M. Slaughter, Oak Ridge National Laboratory

"Automatic Pulsed Arc Welding of Titanium Tubing" R. H. Witt, Grumman Aerospace Corp.

"Fabrication of Titanium Tee Sections by High Frequency Resistance Welding" F. A. DeSaw, H. W. Mishler and R. E. Monroe, Battelle Memorial Institute

"Diffusion Welding of Beryllium—Role of Microalloying Elements" T. J. Bosworth, Boeing Co.

"Interaction of High Temperature Strength and Weldability" R. E. Gold, R. T. Begley and G. G. Lessmann, Westinghouse

Afternoon Session, Chairman: J. R. Condra, DuPont

"Instrumentation for Detecting Purge Gas Contamination" H. Moore, Westinghouse

"Practical Aspects of Tantalum Alloy Development" D. Sandstrom, Los Alamos Scientific Lab.

"Design Considerations in Tantalum Fabrication" F. Waters, Fansteel Metals

"Heavy Section Titanium Welding" H. Nagler, Naval Ship R&D Center

"Arc Spot and GMA Welding of Titanium" G. Cotter, Linde Div.