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FINAL REPORT

ON

EVALUATION OF NOTCH SENSITIVITY OF MILD STEEL SHIP PLATE BY DIRECT EXPLOSION TEST

BY

G. S. MIKHALAPOV

METALLURGICAL RESEARCH AND DEVELOPMENT COMPANY, INC.

Under Bureau of Ships Contract NObs-50464

(Index No. NS-011-067)

Transmitted through

NATIONAL RESEARCH COUNCIL'S

COMMITTEE ON SHIP STEEL

Advisory to

SHIP STRUCTURE COMMITTEE

under

Bureau of Ships, Navy Department

Contract NObs-50148

Division of Engineering and Industrial Research

National Research Council

Washington, D. C.

March 15, 1951

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2101 CONSTITUTION AVENUE, WASHINGTON 25, D. C.

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OF THE
DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH

March 15, 1951

Chief, Bureau of Ships
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Washington 25, D. C.

Dear Sir:

Attached is Report No. SSC-43 entitled "Evaluation of Notch Sensitivity of Mild Steel Ship Plate by Direct Explosion Test." This report has been submitted by the contractor as a Final Report of the work done on Research Project SR-120 under Contract NObs-50464, Index No. NS-011-067, between the Bureau of Ships, Navy Department and Metallurgical Research and Development Company, Inc.

The report has been reviewed and acceptance recommended by representatives of the Committee on Ship Steel, Division of Engineering and Industrial Research, NRC, in accordance with the terms of the contract between the Bureau of Ships, Navy Department and the National Academy of Sciences.

Very truly yours,

Robert F. Mehl

R. F. Mehl, Chairman
Committee on Ship Steel

RFM:ga

PREFACE

The Navy Department through the Bureau of Ships is distributing this report for the SHIP STRUCTURE COMMITTEE to those agencies and individuals who were actively associated with the research work. This report represents results of part of the research program conducted under the Ship Structure Committee's directive to "investigate the design and methods of construction of welded steel merchant vessels."

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FINAL REPORT

ON

EVALUATION OF NOTCH SENSITIVITY

OF

MILD STEEL SHIP PLATE

BY

DIRECT EXPLOSION TEST

COVERING WORK PERFORMED

UNDER

NAVY DEPARTMENT-BUREAU OF SHIPS

CONTRACT NObs-50464

WITH

METALLURGICAL RESEARCH & DEVELOPMENT
COMPANY, INC.

21 DECEMBER 1950

(INDEX NO. NS-011-067)

FOREWORD

The research described in this report was sponsored and financed by the Ship Structure Committee and carried out under Contract NObs-50464 with the Bureau of Ships, Department of the Navy. The work was conducted under the general supervision of the Ship Structure Subcommittee.

The author wishes to express his appreciation to Dr. Finn Jonassen, Technical Director, Committee on Ship Steel; Comdr. R. H. Lambert, USN, Messrs. C. A. Loomis and E. M. MacCutcheon of the Bureau of Ships for their assistance and advice.

The views and opinions expressed in this report are those of the author and do not necessarily represent the views of either the Ship Structure Committee, the Committee on Ship Steel, or of the Department of the Navy.

G. S. Mikhalapov

EVALUATION OF NOTCH SENSITIVITY

OF

MILD STEEL SHIP PLATE

BY

DIRECT EXPLOSION TEST

INTRODUCTION

It will be remembered that the Board to Investigate the Design and Construction of Welded Steel Merchant Vessels placed a major share of blame for the brittle fractures which occurred in service in a number of ships on the excessive notch sensitivity of the steel plate used.[1] This conclusion emphasizes the importance of the phenomenon of notch sensitivity and suggests a need for a thorough evaluation of the notch sensitivity of structural materials. It has, indeed, stimulated an extensive program of research in this field and considerable light has been shed on the notch sensitivity of steel plate as a function of its chemistry, heat treatment, and service temperature. Unfortunately, much less information is available on the notch sensitivity of welded joints.

It is generally conceded that notch sensitivity is essentially poor ductility under triaxial tensile stress such as is usually present at points of severe stress concentration and severe stress gradients, of which a notch is a typical, but not necessarily the only, example. While it is comparatively simple to determine the notch sensitivity of a homogeneous material by using notched specimens, in non-homogeneous materials the task is considerably complicated by the difficulty of predicting the proper location and orientation of a notch to impose the triaxial stress system on the most vulnerable component. In the case of a welded joint the problem is further aggravated by the geometrical complexity of the dissimilar regions and by the fact that the difference in their mechanical properties, particularly yield strength, produces a strain gradient of its own which is destroyed or modified by the introduction of a notch. While a systematic study of the weld region with notch location and orientation covering every conceivable region and plane of weakness within a welded joint is possible, the volume of work required makes such a study impractical as a means of determining probable relative performance of specific welded structures and welding procedures. Furthermore, there is no assurance that the integrated performace of all the regions would be the same as that of the weakest region tested. Yet adequate knowledge of the notch sensitivity of the welded joint is of even greater importance than the knowledge of the notch sensitivity of the plate itself, since welding is usually present at all structural points where multiaxial stresses can be expected to occur.

It is significant that although in welded ships the path of fracture does not usually follow the line of welding but runs through prime plate, the origin of fracture in virtually every observed instance is in or at a weld. Though this in itself does not necessarily constitute a proof that the weld has a greater notch sensitivity than the prime plate, it does point out that since welds are invariably present at structural points where triaxial tension occurs, the maximum load carrying capacity of a structure is a direct function of the notch sensitivity of its welded joints. It may be argued, of course, that refinement of design can eliminate or at least reduce to a vanishing point, both the number and severity of instances of triaxial tension. This argument, although plausible in theory, is hardly tenable in practice since even if a super-design did succeed in reconciling on paper the two opposites of perfect stress streamlining and functional requirements, flaws in, and limitations of, fabrication techniques are almost sure to reintroduce points of stress concentration, and hence of triaxial tension, into the finished structure.

The direct explosion test has been developed to permit the evaluation of notch sensitivity of materials without the use of geometrical notches or other geometrical stress raisers. Sufficient correlation between behavior of prime steel plate under the explosive test and tests employing notches and other stress raisers exists to warrant the assumption that the performance of weld joints under the explosion test is closely indicative of their notch sensitivity. This assumption is further substantiated by a good correlation between performance of welded joints under the explosive test and performance of similar joints in prototypes of ship components, such as hatch corners, subjected to static loading to destruction.[3,4,5,7,8]

The method of conducting a direct explosion test has been described a number of times and it is believed that only a brief review of the testing procedure is warranted.[2,6,7,8] It will be remembered that the test consists of subjecting a number of identical specimens to a blow produced by an explosion of a cylindrical charge of an explosive powder packed to a desired density. The magnitude of each charge is progressively increased until an energy value is reached which just fractures a specimen. The extent of deformation of the specimen subjected to the explosion of a charge just below the minimum charge to fracture, is noted and provides an indication of the maximum deformation the material tested can sustain under the test. Specimen failure is said to have occurred when the length of fracture exceeds 9 inches.

<u>OBJECTIVE</u>

During preceding investigations[8], of the notch sensitivity of alloy steels in both prime and as-welded condition, it was noted that considerable improvement in performance was effected by the substitution of low hydrogen welding electrodes of E-10015 class, in place of E-7016 electrodes, even though the manner and path of fracture appeared identical in both cases, the fracture being confined almost entirely to the prime plate.[8] This in turn suggested the possibility that improvement could be effected in the performance of welded mild carbon steel, through the use of more notch tough electrodes. Indeed, it appeared possible that the notch sensitivity of the welded joint may be as much a function of the welding procedure used as of the notch sensitivity of the prime plate.

Accordingly, a brief investigation was carried out to determine whether variation in welding procedure, primarily welding electrodes, had an appreciable effect on the notch sensitivity of the finished joint and whether this effect was comparable to that produced by a difference in the quality of the prime plate.

METHOD OF INVESTIGATION

Two types of ship plate were selected, ABS Class B and ABS Class C. The Class C Steel was rolled to 1" plate especially for this project instead of to its normal over-1" thickness because the majority of the data thus far obtained with the direct explosion test has been on 1" plate. It will be seen from their respective compositions and mechanical properties, given in Table I, that the two types are closely similar except for the fact that Class B is a semi-killed steel, while Class C is silicon-killed with aluminum added for fine grain. Two types of manual electrodes were used, Class E-6010 and an alloy electrode containing approximately 1.75%Ni and .50%Mo, shielded with lime type, low hydrogen coating and falling within AWS Class E-10016. In addition, a submerged arc process using a standard 2%M electrode was used. The joint preparation was as follows:

TABLE I

Composition and mechanical properties of the 1" thick ship plate used.

Ladle Analysis	ABS Class B*	ABS Class C**
C	.16%	.16%
Mn	.71	.72
Si	.05	.22
P	.010	.015
S	.030	.033
Average Mechanical Properties		
Y.P., psi	35,200	40,200
T.S., psi	60,900	69,800
El., % in 8"	27.6	24.0

* Lukens

** Bethlehem Steel Co.

1. Manual weld 60° double V, 5/32" root opening, 0 root face, root pass made with 5/32" dia. electrode, chipped out to sound metal and welded with three passes on each side, using 1/4" dia. electrode. A total of seven passes.
2. Submerged arc weld: 90° double V, 5/16" root face, 0 root opening welded with three passes of 1/8" dia. electrode from each side for a total of six passes.
3. Submerged arc weld - Front - single U 11/16" deep, 7/16" radius, 1/8" root face, 0 root opening, submerged arc welded with ten passes of 1/8" electrode. Back - 3/16" radius, U groove welded with two passes of 1/4" Class E-6010 electrode.

No preheat was used and the interpass temperature was held at approximately $200^{\circ}F$. All welds were radiographed and with three exceptions, were radiographically sound, though a few cases of considerable porosity were notched. The exceptions consisted of three submerged arc welded specimens, joint No. 2, which exhibited incomplete penetration for about 4" in the center of the joint. The submerged arc joints were welded four at a time and flame cut to final dimension.

Joint No. 3 of the submerged arc welded joints was tested with the face of the submerged arc weld in tension and the explosive charge in contact with the back of the weld. A total of eight sets of specimens was prepared, three using fully-killed steel and five using semi-killed steel. Submerged arc welded specimens were made on semi-killed steel only.

DISCUSSION OF RESULTS

Results of the tests are given in Table II in tabular form and are summarized graphically in Figure 1. Fig. 2 shows the relation between applied energy and deformation produced at room temperature. These results confirm similar relations developed previously.[8] Typical fractures obtained during direct explosion testing are shown in Figures 3, 4, and 5.

Referring to Table II, all fractures observed were of the cleavage type. However, unwelded plates of fully-killed steel C. exhibited a range of partial fracture - that is, a range of energies wherein fracture did not extend from edge to edge of the specimen - nor in some cases through the entire thickness of the plate. At room temperature this range was quite wide (nearly 200 gms., or roughly 25% of total energy to fracture.) Therefore, insofar as resistance to fracture propagation is concerned, steel C ranks by far the best performer of the straight carbon manganese steel plate tested to date, at least at above zero temperature. At lower temperatures, however, there appears to be little difference between steel C and steel B, or between steel C and any other carbon manganese steel tested to date, as the energy to fracture of all drops to nearly zero at -80°F, while at -40°F the performance of B and C steel is quite similar. Some inconsistency appeared at -90°F in performance of steel B, since partial fracture occurred in one specimen at 90 gms., while no fracture took place in two specimens at 110 and 130 gms. This inconsistency may be due to the fact that the fractured specimen was kept at -90°F considerably longer after it apparently reached this temperature, than were the two specimens exhibiting apparently greater strength. As a result, the original procedure of maintaining a specimen at the desired temperature for at least four hours after it has apparently reached the surrounding temperature, was followed in all subsequent tests.

In examining the performance of steels B and C when welded with E-6010 electrode, one is immediately impressed with the startling reduction in the

TABLE II - SUMMARY OF PERFORMANCE OF 1" THICK STEEL PLATE

(All energies are for complete fracture unless followed by * which denotes incomplete fracture.)

Steel			Electrode	70°F 1)	70°F 2)	70°F 3)	32°F 1)	32°F 2)	32°F 3)	10°F 1)	10°F 2)	10°F 3)	-40°F 1)	-40°F 2)	-40°F 3)	-90°F 1)	-90°F 2)	-90°F 3)
AQ -	ABS Gr. B.	Semi-killed,	None	700	42"	3.69"							440	92"	2.48"	80	39"	.05"
AQ-1	" " "	"	AWS 6010	240	24"	1.52"	100*	17"F,24"B	42"	80*	17"B	.18"						
AQ-2	" " "	"	" 10016	420	46"	2.36"	180	44"	90"	100*	17"B	.13"						
AQ-3	" " "	"	Subm.arc,6 passes	620	48"	2.95"				320**	72"	1.54"	140	78"	.77"			
AQ-4	" " "	"	" " 10 " AWS 6010 2 "	460	51"	2.68"				120	53"	.72"	60	39"	.12"			
AP	ABS Gr. C.	Killed	None	740	30"	3.24"							460	44"	2.42"	170"	14"F-47"B	.59"
AP-1	" " "	"	AWS 6010	180	20"	.80"xx				120	38"	.05	60*	4"F,29"B	.01"			
AP-2	" " "	"	" 10016	540	25"	2.54"				400	46"	2.03"	110	45"	.34"			

** On basis of fracture of one specimen radiographically unsound. Higher energy limit with sound specimen probable.

xx at 120 gms. Probable max. deformation 1.00"

1) Energy expressed as weight of charge in grams.
2) Length of fracture, if of different length on front of plate than back, followed by letter F & B (see page 3)
3) Maximum deformation prior to failure given as depth of cup 15" dia. at rim.

plate deformation prior to fracture - and hence a reduction in energy to fracture - which takes place even at room temperature as the result of welding. Furthermore, this increase in notch sensitivity is roughly the same for both steels, (from 3.69" depth of cup and 700 gms. energy to fracture, to 1.52" and 240 gms. for steel B and from 3.24" and 740 gms. to .80" and 180 gms. for steel C), suggesting that the use of fully-killed steel does little to improve the load carrying capacity of structures as long as conventional welding procedure is used.

It is also interesting to note that plates welded with E-6010 electrodes become nearly completely brittle, fracturing with virtually no plastic deformation at temperatures as high as +32°F, as compared to between -70° and -80°F in cases of unwelded plate. A typical fracture of a plate welded with E-6010 electrodes and tested at 32°F is shown in Fig. 5.

By comparison with the relatively poor performance of plates welded with E-6010 electrodes, the performance of the same plates welded with E-10016 electrodes is very much superior as shown in Fig. 1. Furthermore, the use of this alloy welding electrode brings out a difference between the two steels, particularly at low temperatures. Thus at room temperature alloy electrodes raised the performance of steel B joints from 1.52" depth of cup and 240 gms. to fracture, to 2.36" and 420 gms. respectively, an improvement of nearly 100%, while steel C joints were improved from 0.80" and 180 gms. to 2.54" and 54°gms., a 200% improvement. The difference between the two steels becomes even more pronounced at 10°F where in the case of semi-killed steel the improvement produced by the low hydrogen low alloy electrodes is lost; whereas performance of joints of fully-killed fine grain steel shows comparatively little deterioration. As a result, the energy absorption at 10°F of fully-killed steel joints welded with low hydrogen low alloy electrodes is four times that of the semi-killed joints, while the difference in plate deformation is even greater (2.03" deep cup as compared to .13" deep cup). It will be remembered that the performance of these steels is indistinguishable when welded with E-6010 electrodes.

As mentioned above, in semi-killed steel improvement in performance produced by the use of E-10016 electrodes decreases rapidly with lowering temperatures and is completely lost by the time 10°F is reached. It is, therefore, particularly gratifying to observe that in this same steel the improvement produced by the submerged arc process is not only greater at room temperature but extends down to as low as -40°F. In fact, at -10°F the performance of submerged arc welds is, in general, comparable to that of E-6010 welds at 70°F, and at -40°F is superior to the performance of fully-killed fine grain steel welded with E-10016 electrodes. It is important to note that the benefit of the submerged arc weld was largely lost when it was made from one side only and the root of the joint sealed with two passes of E-6010 electrode, even though in testing the root of the weld was predominantly in compression. Examination of the fractures in this type of joint reveals that the fracture started in all cases in or at the two root passes made with E-6010 weld metal.

In examining the path of fracture in welded joints it will be seen that unlike alloy steel joints, the mild steel joint appears at the first glance to be stronger than the parent plate, since with the exception of one, or occasionally two, transverse fractures across the weld, the entire path of fracture is confined to metal unaffected by welding as shown in Figs. 4 and 5. This is hard to reconcile with the apparent influence of weld procedure on performance reported above. Furthermore, it is difficult to understand why, if one of the weld components fails first, the failure does not follow the zone of its origin, but propagates into what appears to be a tougher region of parent metal. Indeed, there are plenty of instances of the former behavior in alloy steel joints, where fracture starts in either the weld metal or in the heat affected zone, and then propagates through one or both of these regions.

Whatever the explanation, the fracture in mild steel specimens almost invariably takes place transversely across the axis of the weld and then travels either at 90^{o} or 45^{o} to the axis of the weld. Of course, if it could be demonstrated that the weld possesses some directional property which makes weld metal fracture transversely at a lower stress than longitudinally, this behavior would be more readily understandable. Or, if the fracture were not preceded by appreciable plastic deformation, it could be argued that the locked up residual stresses were responsible for the predominance of transverse fractures. However, since in the majority of fractures appreciable plastic flow does take place, and since the transverse fractures occur only where the weld metal joins notch sensitive material, the correct understanding of the mechanism of fracture must await procurement of more data.

It may be interesting to speculate on the relative importance of the factors responsible for the difference in performance observed between welding procedures investigated. The major differences between the two steels used were in silicon and oxygen content, and probably in grain size, while the major differences between the processes were in the amounts of hydrogen present in the arc atmosphere and in the alloying elements in the weld metal. In general, it could be expected that the lower the gas and the higher the alloy content of the weld, the better would be its performance, and the results obtained appear to be consistent with these expectations. The relative importance of the different factors is not, however, clear. It is probably true that the improved performance of E-10016 joints is caused both by the reduction of hydrogen content and the introduction of nickel and molybdenum into the weld. It also seems probable that with these two factors present, reduction of oxygen content produces further benefits. It appears, however, that the lower oxygen content of fully-killed steel is not sufficient to compensate for the high hydrogen content of E-6010 electrodes. On the other hand, the reduction of hydrogen to nearly zero by the use of fritted flux in the submerged arc process, appears to be more effective than either the reduction of the oxygen content of the parent plate or the addition of alloying elements. These conclusions, however, must remain tentative, at least until additional data is obtained, such as performance of fully-killed steel welded with the submerged arc process, and the performance of both killed and semi-killed steels when welded with the submerged arc process using electrode wire of alloy content equivalent to E-10016 electrodes.

CONCLUSIONS

On the basis of the data obtained during this investigation the following tentative conclusions appear to be pertinent:

1. Performance of prime plate of both killed fine grain, and semi-killed steels tested appears to be closely comparable to other carbon-manganese steels tested in the past.

2. Performance of prime plate of the killed fine grain steel appears to be slightly but not significantly better than that of semi-killed steel.

3. Performance of both killed fine grain and semi-killed steels when welded with E-6010 electrodes is approximately 30% that of the

unwelded plate at room temperature.

4. All fractures were of the cleavage type.

5. Both the killed fine grain and semi-killed steels, when welded with E-6010 electrodes, fail essentially in a brittle manner with virtually no plastic flow at temperatures as high as 10°F as compared to -80°F for brittle failures of unwelded plate.

6. Performance of both killed and semi-killed steels when welded with the low hydrogen low alloy electrode of the E-10016 type is greatly superior to the performance of these steels when welded with E-6010 electrode. However, performance of fully-killed fine grain steel in this case is considerably better than that of semi-killed steel, particularly at lower temperatures. Performance at room temperature of semi-killed and killed steels are approximately 60% and 75% of the prime plate respectively (100% improvement over E-6010 electrode), and at 10°F, 15% and 65% respectively (300% improvement over E-6010 electrode for the fully-killed fine grain steel and none for the semi-killed steel).

7. Performance of semi-killed steel welded with six passes of standard 2% manganese electrode with submerged arc process is generally comparable to that of fully-killed steel welded with low hydrogen low alloy electrodes, and is greatly superior to the performance of semi-killed steel welded with either E-6010 or E-10016 electrodes.

8. The presence of two back passes of 1/4" E-6010 electrode on a ten-pass submerged arc welded joint greatly reduced the performance of the joint even though the E-6010 electrodes were on the compression side of the specimen during testing.

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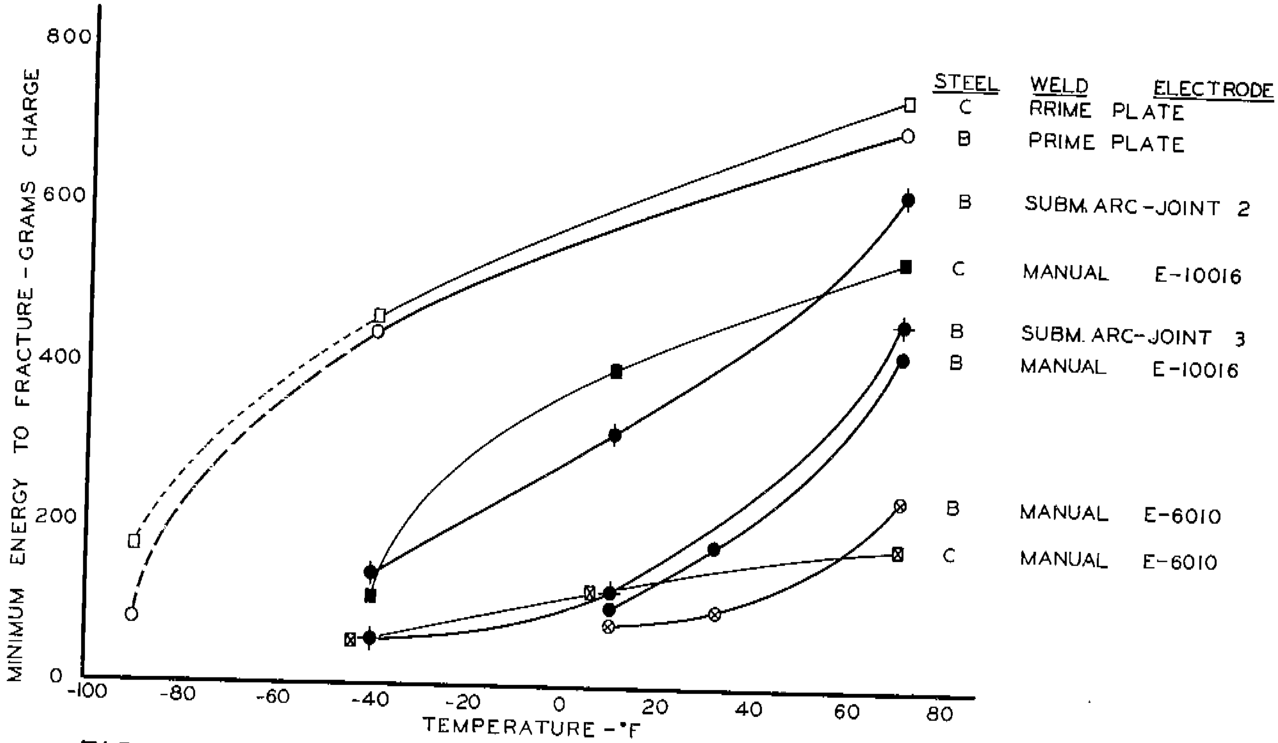

FIG. I. EFFECT OF TEMPERATURE ON MINIMUM ENERGY TO FRACTURE WELDED AND UNWELDED SHIP PLATE ONE INCH THICK

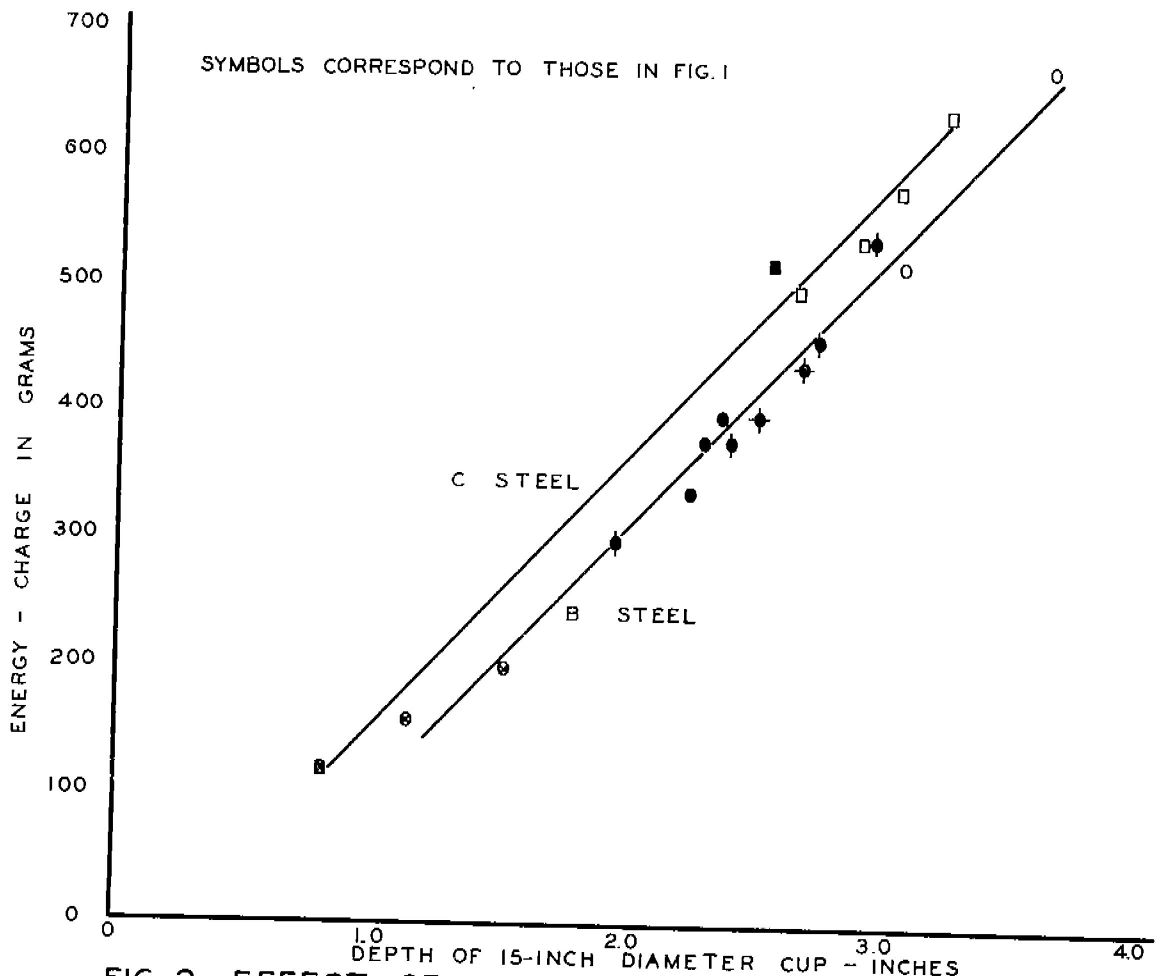

FIG. 2. EFFECT OF APPLIED ENERGY ON SPECIMEN DEFORMATION - ROOM TEMPERATURE TESTS

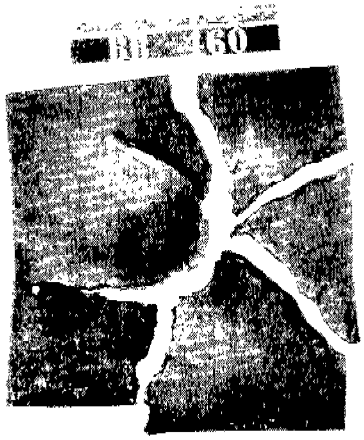

Fig. 3

Fig. 4

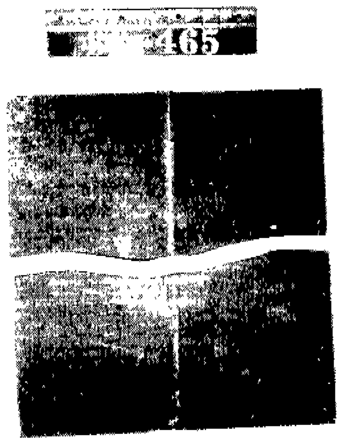

Fig. 5

APPENDIX

PERFORMANCE OF 1" THICK SHIP PLATE

No.	Steel	Electrode	Temp. °F	Charge Grams	Depth of Dish, Ins.	Extent of Fracture
Q-9	Semi-killed	None	70	520	3.07	None
15	"	"	70	600	3.56	Incomp.3" Fr., 6" B.
Q-14	"	"	69	680	3.64	None
10	"	"	69	700	-	Comp. - 2 pcs. - Cl.
4	"	"	70	740	-	Comp. - 2 pcs. - Cl.
12	"	"	-43	400	2.38	None
13	"	"	-39	440	2.52	None
6	"	"	-38	440	-	Comp. - 14 pcs, .92" Cl.
7	"	"	-40	460	-	Comp. - 12 pcs., 104" Cl.
8	"	"	-42	480	"	Comp. - 13 pcs., 112" Cl.
11	"	"	-88	60	.00	None
2	"	"	-91	70	.13	Incomp. -14"Fr., 37" Bk.
3	"	"	-88	80	-	Comp. - 4 pcs., 39" Cl.
1	"	"	-90	80	-	Comp. - 3 pcs., 32" Cl.
Q-1-2	"	AWS 6010	70	160	1.13	None
4	"	" "	70	200	1.52	None
11	"	" "	70	240	-	Incompl. 24" Cl.
10	"	" "	69	320	-	Comp. 6 pcs., 58" tot. Cl.
7	"	" "	68	400	-	Comp. 2 pcs., 40" tot.Cl.
13	"	" "	32	80	.31	None
3	"	" "	33	90	.42	1/2" TW* - back
5	"	" "	31	100	-	Incompl. 17" Fr., 24" Bk.
12	"	" "	32	100	-	Incompl. 10" Fr., 19" Bk.
6	"	" "	30	140	-	Compl., 4 pcs. - 46" Cl.
15	"	" "	10	40	.04	8" crack, back only
1	"	" "	10	60	.18	12" " " "
8	"	" "	10	80	.50	17" " " "
14	"	" "	10	120	-	Compl.,- 4 pcs., 46" tot.C.
9	"	" "	10	200	-	Compl. 6 pcs, 64" tot. Cl.
Q-2-13	"	AWS 10016	70	340	2.24	None
15	"	" "	69	380	2.28	"
2	"	" "	70	400	2.36	"
6	"	" "	70	420	-	Compl. - 4 pcs., 46" Cl.
7	"	" "	68	500	-	Compl. - 3 pcs, 52" Cl.
14	"	" "	31	160	1.06	None
11	"	" "	33	160	1.02	"
9	"	" "	34	170	.90	"
1	"	" "	33	180	-	Comp. - 2 pcs., 44" Cl.
4	"	" "	30	200	-	Comp. - 2 pcs., 35" Cl.

* Transverse to weld

No.	Steel	Electrode	Temp. °F	Charge Grams	Depth of Dish, Ins.	Extent of Fracture
10	Semi-killed	AWS 10016	10	60	.13	None
5	" "	" "	10	100	.83	17" crack, back only
8	" "	" "	10	140	-	Comp. - 3 pcs. 28" Cl.
12	" "	" "	10	220	-	Comp. - 4 pcs. 36" Cl.
3	" "	" "	9	300	-	Comp. - 6 pcs. 68" Cl.
Q-3-14	"	Subm.arc, 6 passes	69	300	1.95	None
7	"	"	70	380	2.40	"
2	"	"	70	460	2.74	"
13	"	"	70	540	2.95	"
10	"	"	70	620	-	Incomp. - 48" Cl.
1	"	"	10	80	.42	None
9	"	"	9	160	1.07	"
8	"	"	9	240	1.54	"
12	"	"	10	320	-	Comp. - 6 pcs. 72" total Cl.
15	"	"	-42	140	.77	None
4	"	"	-38	140	-	Comp. - 7 pcs., 78" Cl.
6	"	"	-39	160	-	Comp. - 9 pcs., 85" Cl.
11	"	"	-40	180	-	Comp. - 8 pcs., 90" Cl.
3	"	"	-42	220	-	Comp. -11 pcs., 90" Cl.
Q-4-12	"	" 10 passes	68	400	2.51	None
4	"	"+6010, 2 passes	70	440	2.68	"
3	"	"	71	440	2.68	"
2	"	"	71	460	-	Comp. - 2 pcs, 51" total Cl.
1	"	"	68	480	-	Comp. - 5 pcs. 62" total Cl.
13	"	"	10	120	.69	None
5	"	"	10	120	-	Comp. - 5 pcs, 53" Cl.
11	"	"	10	140	-	Incomp. 3 pcs. 58"Fr.,46"Bk.
14	"	"	9	160	-	Incomp. 15" Cl.
10	"	"	9	200	-	Incomp. 34" Fr., 28" Bk.
Q-4-8	"	" 10 passes + 2 - 6010 passes	-40	40	.12	None
9	"	"	-39	50	.45	Incompl.-2" Fr., 20" Bk.
6	"	"	-39	60	.58	Incompl.-8" Fr.,10" Bk.
7	"	"	-40	60	-	Comp. - 4 pcs., 39" Cl.
15	"	"	-40	80	-	Comp. - 6 pcs., 75" Cl.
P-5	Killed, Prime	None	70	500	2.66	None
10	"	"	70	540	2.91	"
12	"	"	70	580	3.05	Incomp. -2½" Bk. only
4	"	"	70	640	3.24	Incomp. -5½" Bk. only
14	"	"	70	740	-	Incomp. -30"
1	"	"	-40	380	2.04	None
8	"	"	-40	420	2.20	"
11	"	"	-40	440	2.33	"
9	"	"	-40	460	2.45	"
13	"	"	-39	460	-	Comp. - 2 pcs., 44" Cl.

No.	Steel	Electrode	Temp. °F	Charge Grams	Depth of Dish, ins.	Extent of Fracture
7	Killed, Prime	None	-92	80	-	Incompl. 8" Fr., 40" Bk.
6	"	"	-89	90	.12	None
15	"	"	-90	110	.46	"
2	"	"	-90	130	.59	"
3	"	"	-91	170	1.05	Incomp. - 14" Fr., 47" Bk.
P-1-5	"	AWS 6010	70	120	.81	None
15	"	"	68	180	-	Incompl.- 20" Cl.
11	"	"	68	260	-	Incompl.-26" Cl.
2	"	"	70	340	-	Comp. - 2 pcs., 43" Cl.
12	"	"	70	420	-	Comp. - 2 pcs., 50" Cl.
10	"	"	10	60	.05	None
8	"	"	10	100	.41	½" TW* - back only
9	"	"	10	100	.49	12" crack, back only
1	"	"	10	120	-	Comp. - 3 pcs., 38" Cl.
7	"	"	10	140	-	Comp. - 4 pcs., 45" Cl.
6	"	"	-39	40	.00	None
4	"	"	-41	50	.14	Incomp. - 20" Bk.
14	"	"	-38	60	.22	Incomp. - 4" Fr., 29" Bk.
13	"	"	-40	60	.09	Incomp. - 17" Bk.
3	"	"	-40	140	-	Comp. - 5 pcs., 61" Cl.
P-2-8	"	AWS 10016	69	520	2.55	None
14	"	"	69	540	-	Comp. - 2 pcs., 25" Cl.
7	"	"	70	560	-	Incomp. - 13" Cl.
15	"	"	70	580	-	Comp. - 5 pcs., 64" Cl.
1	"	"	70	600	-	Comp. - 2 pcs. 48" Cl.
P-2-2	Killed	"	10	320	1.79	None
11	"	"	10	360	1.81	"
12	"	"	10	380	1.91	"
5	"	"	10	390	2.02	"
3	"	"	10	400	-	Comp. - 5 pcs., 46" Cl.
6	"	"	-39	80	.26	None
13	"	"	-39	100	.34	"
10	"	"	-42	110	-	Comp. - 4 pcs., 45" Cl.
4	"	"	-39	120	-	Comp. - 4 pcs., 45" Cl.
9	"	"	-41	160	-	Comp. - 5 pcs., 50" Cl.

*Transverse to Weld