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of

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

WAR METALLURGY DIVISION

Progress Report

on

DEVELOPMENT OF ARMOR WELDING ELECTRODES: RELATION OF THE COMPOSITION OF AUSTENITIC (20 Cr-10 Ni) ELECTRODES TO THE PHYSICAL AND BALLISTIC PROPERTIES OF ARMOR WELDMENTS

(OD-36-2)

by

A. L. FEILD, F. K. BLOOM, and G. E. LINNERT
RUSTLESS IRON AND STEEL CORPORATION

OSRD No. 1636

Serial No. M-101

Copy No. 75

July 20, 1943

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July 20, 1943

To: Dr. James B. Conant, Chairman
National Defense Research Committee of the
Office of Scientific Research and Development

From: War Metallurgy Division (Div. 18), NDRC

Subject: Progress Report on "Development of Armor Welding Electrodes: Relation of the Composition of Austenitic (20 CR-10 Ni) Electrodes to the Physical and Ballistic Properties of Armor Weldments" (OD-36-2)

The attached progress report submitted by A. L. Feild, Technical Representative on NDRC Research Project NRC-2R, has been approved by representatives of the War Metallurgy Committee in charge of the work. This report covers investigations on restrained double bevel armor joints welded with electrodes having variations in manganese content combined with variations in molybdenum content. Testing included determination of sensitivity to center root bead cracking, interface cracking, as well as X-ray, macro etch, and metallographic examination. Physical and ballistic properties were determined by tensile tests and a special explosion test.

This project is financed by Rustless Iron and Steel Corporation and is being carried out as a correlation project under the supervision and direction of the War Metallurgy Committee.

Acceptance as a satisfactory progress report is recommended.

Respectfully submitted,

Clyde Williams

Clyde Williams, Chief
War Metallurgy Division, NDRC

Enclosure

PREFACE

This report is pertinent to the problems designated by the War Department Liaison Officer with NDRC as OD-36-2, and to the project designated by the War Metallurgy Committee as NDRC Research Project NRC-2R.

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PROGRESS REPORT

on

Relation of the Composition of Austenitic (20 Cr-10 Ni) Electrodes to the Physical and Ballistic Properties of Armor Weldments.

I. The Effect of Variations in Manganese and Molybdenum Contents.

From: Rustless Iron and Steel Corporation-Research Laboratory.

Report by: A. L. Feild, F. K. Bloom and G. E. Linnert

Date: June 15, 1943.

* * * * *

ACKNOWLEDGEMENTS

The work described in this report, prepared under the supervision of A. L. Feild, Official Investigator, was largely carried out at the Research Laboratory of the Rustless Iron and Steel Corporation by F. K. Bloom and G. E. Linnert with the full time collaboration of W. H. Donoho. L. F. Weitzenkorn and H. Tanczyn assisted in the preparation of the induction heats and experimental core wire. M.Clegg,Jr., G. N. Goller and Mary S. Hatter collaborated on microhardness and microscopic studies as well as in the preparation of photographs.

R. L. Henry of the Physics Department of Johns Hopkins University conducted the X-ray examination of the test plates. Dr. W. O. Snelling, Director of Research, and his associates carried out the explosion tests at the Trojan Powder Company in Allentown, Pennsylvania.

G. S. Mikhalapov, Supervisor of Welding Research, assisted in preparing the outline for the original project and offered many helpful suggestions during the investigation.

* * * * *

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ABSTRACT

Restrained double bevel armor joints were welded with 20-10 electrodes having variations in manganese content of 1.5, 2.0 and 4.3% combined with variations in molybdenum content of 0.0, 1.5 and 3.0%. A comparison was also made between molybdenum added through the electrode coating and through the core wire and between an experimental induction melted and a commercial electric-arc furnace heat. Testing included determination of sensitivity to center root bead cracking, interface cracking, as well as X-ray, macro etch and metallographic examination. Physical and ballistic properties were determined by tensile tests and a special explosion test. Significant features disclosed were:

(1) Variations in manganese and molybdenum content

a) affected sensitivity to root cracking,
b) possibly affected susceptibility to interface cracking,
c) appeared related to tendency to transformation to martensitic structures on heavy dilution.

High manganese contents combined with the use of some molybdenum are believed to represent the best combination.

(2) Ballistic properties could not be related to composition. The initiation and propagation, in the armor, of cracks produced in the ballistic test may explain this and suggest that the ballistic values secured in these tests were associated more directly to the properties of the armor than to those of the weld metal.

(3) No indication could be found that molybdenum added through the electrode coating produced any different properties than when added through the core wire.

(4) Induction melted experimental heats gave comparable results to a commercial electric-arc furnace heat.

* * * * *

SUMMARY

The preliminary work undertaken in this investigation must be verified by similar tests with commercially prepared electrodes and with several other types of armor as well as with conventional ballistic tests, before any final conclusions can be drawn. Nevertheless, several features believed to be significant have been revealed in these tests which have been summarized below. The similarity in results obtained with a commercially melted heat when compared with an induction melted heat of similar analysis justifies the belief that these observations are not limited to induction melted material alone.

(1) The composition of 20 Cr-10 Ni type electrodes appears to govern the ease with which crack free deposits can be made in the root pass of restrained double bevel armor joints. Additions of molybdenum appear desirable. Manganese alone is not helpful.

(2) Some evidence was found that interface cracking in the root pass may also be related to electrode composition. The indication is again that molybdenum is helpful in overcoming this defect. The complicating factor of heavy root deposits required with compositions without molybdenum however prevented drawing any direct comparisons. Deposits from the lowest alloy containing electrode (1.5 Mn-0.0 Mo) used in the investigation were unusually susceptible to this defect.

(3) The tendency for weld deposits to transform to hard brittle martensitic structures in passes where heavy dilution is present appears to be related to the total alloy content. Electrodes, where the sum of the manganese plus molybdenum content was less than about 4.0%, were found to be transformed in the shoulder passes.

(4) No indication could be found that molybdenum added indirectly to the deposit through the flux produced any different properties than when added directly through the core wire.

(5) No appreciable variation in the shock resistance of the specimens exposed to the explosive tests was found to exist with variations of the manganese-molybdenum content of the weld metal.

(6) The failure to find any direct correlation between electrode composition and ballistic strength values secured in the explosion test may be traceable to the apparent tendency for fractures to originate and propagate largely on the armor side of the weld interface. This preliminary evidence that ballistic properties may be related more to the properties of the armor than of the weld recommends itself for further investigation.

(7) From the standpoint of the ease of welding restrained armor joints, electrodes containing sufficiently high manganese contents to insure freedom from dilution transformation and also with molybdenum contents adequate to minimize center root cracking are believed to represent the most desirable combination.

PROGRESS REPORT

on

Relation of the Composition of Austenitic (20 Cr-10 Ni) Electrodes to the Physical and Ballistic Properties of Armor Weldments.

I. The Effect of Variations in Manganese and Molybdenum Contents.

INTRODUCTION

The general aim of this project was to study the effect of variations in the composition of austenitic 20 Cr-10 Ni type electrodes on the properties of restrained armor weldments.

Two types of 20-10 electrodes have been used in tank-armor fabrication; one modified by additions of manganese, one by additions of molybdenum. Various combinations of the two elements have also been considered. Very little fundamental information has been available, however, to indicate what effect variations in the per cent of these elements have on weld properties. This first progress report describes an investigation undertaken to provide such data as could be secured by carefully controlled tests on a laboratory scale.

The specific aims of this first investigation were to:

(1) Determine the effect of variations in manganese and molybdenum content on the welding properties, particularly sensitivity to root cracking, the physical properties and microstructure of restrained welds in armor.

(2) Estimate the effect of variations in the per cent of these elements in the weld deposit on the ballistic properties by means of a special explosion test.

(3) Compare the effect of molybdenum alloyed in the weld deposit through the core wire with molybdenum added through the electrode coating.

Various steps taken in this investigation included:

(1) Preparation of electrodes from nine experimental induction melted heats and one commercial electric-arc furnace heat. The heats were of 20 Cr-10 Ni type representing seven different levels of manganese and molybdenum contents. The approximate analyses are listed on the following page

Series No.	Composition Identity *	Melting Practice	C	Cr	Ni	Mn	Mo
I	1.5 Mn-0.0 Mo	Induction	.10	20.0	10.0	1.50	--
	2.0 Mn-0.0 Mo	Induction	.10	20.0	10.0	2.00	--
	2.0 Mn-0.0 Mo-E	Electric	.10	20.0	10.0	2.00	--
	4.3 Mn-0.0 Mo	Induction	.10	20.0	10.0	4.25	--
II	2.0 Mn-1.5 Mo	Induction	.10	20.0	10.0	2.00	1.50
	2.0 Mn-(1.5 Mo)	Induction	.10	20.0	10.0	2.00	(1.50)*
	2.0 Mn-(1.5 Mo)-E	Electric	.10	20.0	10.0	2.00	(1.50)*
	2.0 Mn-3.0 Mo	Induction	.10	20.0	10.0	2.00	3.00
III	4.3 Mn-1.5 Mo	Induction	.10	20.0	10.0	4.25	1.50
	4.3 Mn-(1.5 Mo)	Induction	.10	20.0	10.0	4.25	(1.50)*
	4.3 Mn-3.0 Mo	Induction	.10	20.0	10.0	4.25	3.00

* Throughout the balance of the report the various compositions will be identified by the symbols shown in this table. (1.5 Mo) indicates molybdenum added through the flux; the suffix E indicates material melted commercially in the electric-arc furnace.

Series I was designed to compare the effect of three levels of manganese 1.50, 2.00 and 4.25% alone. Series II was included to compare the effect of 1.5% and 3.0% molybdenum with manganese fixed at 2.00%; Series III to compare the same levels of molybdenum with manganese fixed at 4.25%. Compositions 2.0 Mn - (1.5 Mo) and 4.3 Mn - (1.5 Mo) were included in the latter two series to compare molybdenum introduced into the weld deposit through the flux with molybdenum added through the core wire.

During the course of the investigation, a commercially melted electric-arc furnace heat of analysis similar to composition 2.0 Mn - 0.0 Mo became available and was included in Series I and Series II for comparison with the induction melted heats.

(2) Welding of duplicate restrained joints from each composition, noting sensitivity of each type of electrode to (a) root bead cracking, and (b) interface cracking.

(3) Examination of welded joints including:

a) X-ray examination of "as welded" plates
b) Macro etch for quality of welds
c) Transverse tensile properties of welds
d) Metallographic examination of welds and microhardness traverses
e) Ballistic properties by explosion testing

(4) Examination of explosion tested samples.

MATERIALS USED AND PROCEDURE

1. Preparation of Experimental Electrodes

Nine, twenty-five pound experimental induction melted heats were prepared in an Ajax high frequency furnace. The small ingots (together with one billet from the commercial electric-arc furnace heat) were forged and hot rolled to rods. The hot rolled rods were annealed, pickled and cold drawn by the usual commercial methods to core wire of 1/4" and 3/16" diameter. Straightened and cut wire in 14" lengths was then flux coated in an experimental laboratory extrusion press. In all cases, a lime base flux of composition similar to those found to be employed on commercial rods of this type was used. The same formula was used throughout except for small variations in the content of ferromanganese from heat to heat necessary to maintain the level of this element the same in the weld deposit as the core wire. Ferromolybdenum was employed where it was desired to alloy molybdenum with the weld deposit.

The efficiency of the flux was gauged by conducting a complete analysis of a weld pad prepared from each lot of coated 1/4" diameter electrodes. The procedure used was similar to that now required by the Bureau of Ships Specification 46E4(INT) April 1, 1943. These analyses are listed for comparison with the core wire analyses in Table I*-Appendix I.

2. Welding of Restrained Joints

2a) Preparation of Test Plate

Figure 1**-Appendix II shows the details of design and welding sequence employed in preparing the restrained joint. The intent was to secure a test plate containing a highly restrained double bevel butt weld. For additional restraint, the test plates were rigidly clamped in a heavy jig throughout the entire welding procedure and for a period thereafter of twenty-four hours. Figures 2 and 3 show, respectively, the appearance of a test plate clamped in the jig ready for welding and a final welded plate.

All test plates were torch cut and beveled to size from four, 1½" thick plates of Great Lakes homogeneous heat treated armor, representing one heat of the following composition:

Heat 9-00474	C	Mn	P	S	Si	Cr	Mo	Zr
Mill Analysis	.29	.94	.018	.025	.67	.59	.18	.09

This armor was chosen because of its wide use and because it was generally believed to be somewhat more critical in its demands on the performance of the electrodes.

In all cases, the test plates were assembled with the rolling direction of the armor at right angles to the weld axis as indicated in Figure 1. After each pass across the weld, the test plate was allowed to cool to a maximum of 200°F. before proceeding.

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* All tables are assembled in Appendix I.

** All drawings and photographs are assembled in Appendix II.

2b) Determination of Sensitivity to Root Cracking

Work done previous to this investigation disclosed that the 20 Cr-10 Ni composition exhibits a marked tendency to crack down the center of the first or root pass under certain conditions. Preliminary tests disclosed that the degree of cracking was apparently chiefly related to the thickness of the deposit, i.e., the thicker the root pass the less the likelihood of cracking.

Root beads of various thicknesses were deposited with several different types of electrodes and the degree of cracking noted. In each case there appeared to be a characteristic critical root thickness above which cracking no longer occurred. This observation suggested a possible method of rating each of the compositions included in the investigation for sensitivity to root cracking.

As each of the three segments across the root was deposited in each test plate, the thickness of the weld was measured and recorded together with the appearance of the bead. Figures 4, 5 and 6 illustrate the technique employed. Figures 4 and 5 show the appearance of the face and back of a root pass deposited with three, 3/16" diameter, electrodes of composition 2.0 Mn-0.0 Mo-E. Figure 6 shows the appearance of cross-sections through the three different locations indicated in Figures 4 and 5. It is of interest to note that in the root passes slightly thicker than required to prevent complete cracking, the crack appears only on the back side of the weld.

The data secured in these tests are recorded in detail in Table II. In most cases, it was possible to estimate within fairly narrow limits, the critical root thickness required for each composition. In one case, the root beads were all deposited without exhibiting cracking. Here, it is assumed, the critical root thickness was less than that deposited.

2c) Observations During Completion of Test Welds, Interface Cracking

After determining the critical root thickness, all cracked root beads were chipped out and new beads of sufficient thickness to avoid center cracking were deposited. With certain compositions no further difficulties were experienced and welding proceeded as indicated in Figure 1. However, others exhibited a marked tendency to develop cracks at the interface between the root bead and the armor. This type of crack was quite distinct in appearance and location from the center root cracks described above. They were very narrow in width and extended from as little as 1/8" to the full 8" length of the root pass. In many cases, they were detectable only by examining the junction of the weld metal and armor with a small hand magnifying glass. They occurred almost without exception in the root pass. In several cases it was necessary to weld several plates before two were secured free from this defect. Table III summarizes these experiences and indicates the frequency of interface cracking in various compositions.

3. Examination of Welded Joints

After completion of welding (See Figure 3) and removal from the restraining jig, each test plate was ground on both sides on a Blanchard Grinder to bring the top of the weld flush with surface of the armor.

After X-ray examination, the plates were sectioned by cold sawing in the manner illustrated in Figure 7. One of each of the duplicate test plates, after discarding the outer 2", provided two macro etch test specimens, two explosion test specimens, one specimen for microscopic examination and three tensile test specimens from the face, root and back of the weld. The second plate provided two macro etch specimens and three explosion test samples.

3a) X-ray Examination

The plates were radiographed at Johns Hopkins University by Mr. R. L. Henry. A 200 KV General Electric machine employing a tungsten target was used. The following exposure conditions, after trial, were applied:

Voltage - 170 KV
Amperage - 10 m.a.
Filter - filter cassette
Exposure time - 25 to 30 minutes
Focal distance - 64 inches
Film - Eastman Type K
Penetrameter - 2%, visible

3b) Macro Etch Examination

Macro etch specimens were ground flat on a 320 grit belt, etched in cold dilute aqua-regia for 1 to 3 minutes and examination at 15 X magnification for the presence of defects. Figure 8 illustrates the appearance of three typical etched specimens.

3c) Tensile Tests

Rectangular shaped tensile test specimens cut transversely across the weld, representing the face, root and back of the weld, as shown in Figure 7, were ground with a 320 grit finish to final dimensions of 9/32" by 1". Tensile tests were conducted on a 120,000# hydraulic machine. An attempt was made to maintain a constant headspeed by employing fixed valve openings in all tests. The headspeed from the yield point to breaking load was approximately 0.3" per minute. Per cent elongation was measured across the welds using three gauge lengths. Standard two inch gauge marks were made in the armor with the weld at the center. In addition, punch marks were made at the interface between the weld metal and armor, both at the widest point across the weld and at the narrowest point across the weld. Table IV, Appendix I contains the data secured in these tests and noted the location of the fracture of each specimen. The yield strength was determined from autographic stress-strain curves with the extensometer attached over a 2" gauge including weld metal and some armor. The offset used in calculating the values was taken as .2% of the average width of the weld metal.

It will be noted in Table IV that a number of the tensile test samples cut from the face and back of the plates were found to have broken across the weld metal in the shoulder. These fractures were brittle in appearance and resulted in generally lower per cent elongations. Rockwell hardness tests made on the samples selected for microscopic examination showed that these brittle fractures were associated with transformation of the weld metal in the shoulder pass to a hard martensitic structure. The hardness values secured on the shoulder passes are recorded with the tensile test results for comparison.

3d) Metallographic Examination and Microhardness Survey

Samples prepared from the middle of one weld of each type were examined. Photomicrographs, Figures 9 to 11, were prepared illustrating the appearance of the weld structure at a point near the center of each root bead. Microhardness traverses were made with an Eberbach tester (28.4 gm. load) across the fusion line of samples from plates representing each of the seven compositions studied. Impressions across the interface, spaced approximately .0015" apart, were made with a Standard Vickers pyramid diamond penetrator. The area tested in each case was approximately at the middle of #4 bead on the back side of the root pass. This location was chosen because as it will be seen later, it was apparently near this point that fractures originated in the explosion test. Figure 12 is a photomicrograph of this area showing the hardness impressions. The hardness values indicated are believed correct for comparison among themselves, but their relation to Standard Vickers or Brinell values has not been established.

3e) Ballistic Properties by Explosion Testing

Explosion test samples were ground flat on side, top and bottom faces in the Blanchard Grinder to the following dimensions:

Height - 1-7/16" ± 1/64"   Width - 1-7/8" ± 1/64"   Length - 8" ± 1/4"

In addition to the welded test samples, samples were also prepared of similar dimensions from the virgin armor plate. One set was selected with the direction of rolling parallel to the long axis of the specimen, i.e., longitudinal; one set with the rolling direction at right angles to the long axis, or transverse.

All tests were conducted under the direction of Dr. W. O. Snelling at the Trojan Powder Company, Allentown, Pennsylvania. Details of the set-up used are shown in Figurd 13.

The test samples were rested on steel blocks with the face of the weld upwards. Charges of nitrostarch in the form of 2" diameter flat discs of different gram weights were exploded on top of the weld. Varying total amounts of explosives were used on each specimen to establish the amount required to just completely break the sample. Different weights of powder were obtained by combining discs of 20, 25, 30, 35 and 50 grams. The force applied by the explosive is not believed to be linearly proportional to the weight especially with large charges. It has been pointed out that as the height of pile of explosives increases, the downward force exerted by the powder at the top of the charge diminishes rapidly. An approximate relationship between explosive charge and impact energy expressed in terms of ball-pendulum displacement as tentatively determined by Dr. Snelling (NR C-25 Project - Explosive Tests) is attached (Figure 14).

The charges applied, the angle of bend and the appearance of the tested samples are recorded in Table V. Figure 15 shows the appearance of a typical set of specimens after testing.

4. Examination of Explosion Tested Samples

Samples which were partially cracked externally by the explosive charge as well as those which showed no external cracks were sectioned transversely through the center of the weld and subjected to metallographic examination to establish the origin and mode of fracture from the ballistic impact. Several were found containing only internal cracks varying from microscopic dimensions up to large fissures extending almost to the surface as noted in Table V. Figures 16, 17 and 18 illustrate the initiation of the cracks and the mode of progression in typical samples.

DISCUSSION

1. Preparation of Electrodes

(a) The analyses of the induction melted heats and weld deposits fell within reasonably narrow ranges. Small variations in carbon, phosphorus, sulphur, silicon, chromium and nickel contents present throughout the series were not considered to have influenced the comparison of the effect of variations in manganese and molybdenum contents. The chromium to nickel ratios of all heats fell within the range of 2.01:1.00 to 2.06:1.00.

2. Welding of Restrained Joints

(a) Sensitivity to Root Bead Cracking

(1) The effect of molybdenum in reducing the thickness of the root pass required to prevent center cracks is clearly shown in comparing the data for Series I heats without molybdenum with Series II and III heats containing 1.5% and 3.0% of this element.

(2) Variations in manganese either without molybdenum present or with 1.5% or 3.0% of this element caused no marked trend in the results; if anything, Series II heats with a level of 2.0% Mn were slightly better than Series III with a level of 4.3% Mn.

(3) Increasing the molybdenum from 1.5% to 3.0% showed no marked additional benefit nor was there any difference apparent between adding this element through the core wire or through the flux.

(4) The results secured on induction melted heats compare closely with those obtained from the commercial electric-arc furnace heat.

(b) Susceptibility to Interface Cracking

(1) Series I heats with increasing manganese and no molybdenum were susceptible to the development of interface cracks.

(2) Composition 1.5 Mn-0.0 Mo in this series produced frequent interface cracking which was only slightly alleviated by preheating the test plates before welding.

(3) With increasing manganese content up to 4.3%, but with no molybdenum, this defect was still present but in a lesser degree.

(4) Welds from compositions with 2.0 and 4.3% manganese and 1.5 and 3.0% molybdenum appeared relatively free from this defect.

(5) Difficulties experienced with Series I heats appeared to coincide with the much heavier root deposits required to prevent center cracking. Such heavy beads were more prone to results in incomplete coverage of the root joints in the back of the pass introducing, in some cases, a notch effect. This notch condition, however, was not wholly responsible for interface cracking since the defect occurred in several instances even with satisfactory root point coverage.

3. Examination of Welded Joints

(a) X-ray Examination

Examination of the radiographs indicated that all plates were sound, free from porosity, large slag inclusions or cracks. It is of interest to note that the small interface crack later discovered in one end of a plate welded with the 2.0 Mn-0.0 Mo-E rod was not disclosed under the particular conditions of this test.

(b) Macro Etch Tests

In all cases except one, the macro etched samples disclosed no defects of significance. One plate welded with rod 2.0 Mn-0.0 Mo-E possessed a small interface crack in the root pass. This crack was later found to have progressed about 3/4 of an inch into the tensile test specimens cut adjacent to the macro etch sample, but is not believed to have extended beyond this point.

(c) Transverse Tensile Tests

(1) Tensile and yield strength values of root samples are generally higher and elongation values lower than those of samples from the face and back, probably because of greater dilution of the weld metal in these areas.

(2) No consistent trends are discernable between tensile and yield strength values with variations in manganese or molybdenum content, different methods of introducing the latter elemnt or between induction and electric-furnace heats. Some indication is present that the welds containing the highest manganese and molybdenum contents possessed slightly higher values.

(3) Comparison of elongation values with variations in composition is largely voided by the erratic and generally low values obtained where face and back samples fractured through shoulder passes. Even excluding these values no clear trends seem to be present.

(4) The presence of partial interface crack in samples from composition 2.0 Mn-0.0 Mo-E sharply reduced the tensile and elongation values.

(5) The tendency of some compositions to transform to martensite in the highly diluted shoulder passes appears to be related to the total alloy content of the electrodes. It will be noted in Table IV that those compositions possessing over approximately 4.0% total manganese plus molybdenum possesed relatively soft shoulders while those having less than this amount were either partially or completely hardened.

(d) Microstructure and Microhardness Traverses

(1) Microstructures in the root pass were similar in all samples, consisting of an austenitic matrix with delta ferrite containing carbides dispersed throughout.

(2) The amount of the delta ferrite constituent varied over wide limits throughout the weld and even within the same bead. It was clear, how-

ever, that the total amount of this constituent was related to the composition. Increasing molybdenum content increased the amount of this constituent. Increasing manganese content decreased the amount. On a percentage basis molybdenum appeared to be more effective in increasing delta ferrite than manganese was in decreasing the amount of this constituent. Some inconsistencies in this rule which may appear to be present in the photomicrographs are largely traceable to the difficulty of selecting a field representative of the average structure of the weld. In addition, small variations in chromium-nickel ratio and carbon content are known to affect the per cent of this phase and their effect should be borne in mind.

(3) Microstructures at the weld interface presented no consistent picture, but varied widely in the same sample at various locations in the weld. For this reason the structures shown in the photomicrograph of this area should not be interpreted as representative of the entire interface structure throughout the samples. Attempts to correlate variations in these structures with variations in the composition have so far failed.

(4) One consistent feature in all cases was the presence of a narrow hard band at the interface about .0015 inches in width as shown by the microhardness values. In this band hardnesses were found ranging from 302 V.P.N. to the highest value of 712 V.P.N. found in the weld prepared from composition 1.5 Mn-0.0 Mo.

(e) Ballistic Properties by Explosion Testing

(1) Some variations were found in the charges required to break the various welds, but no clear cut trend could be found between these values nor the angle at fracture with variations in manganese or molybdenum content.

(2) No definite trend was present to show whether molybdenum alloyed through the core wire produced any different results than when alloyed through the flux. One set with the commercially melted rod gave slightly poorer results than its induction melted counterpart; the other set gave superior results.

(3) Tests on the virgin armor indicated superior ballistic resistance to any of the welded samples. Tests taken with the specimen axis transverse to the rolling direction were decidedly inferior to those taken parallel.

4. Nature of Failure in Explosion Tested Samples

The progress of cracks in the explosion tested samples were traced as follows:

(1) Initiation as minute fissures in the armor just at the interface about one-half way between the root and the back face.

(2) Extension in both directions, towards the root and towards the back face, travelling mostly in the armor, but occasionally in the weld metal.

(3) At a point beyond the root generally at the base of the shoulder pass on the face side, the crack turned out into the weld-metal and continued to the face. Travelling in the other direction, the crack also passed out

into the weld metal generally in the vicinity of the pass just below the shoulder bead.

(4) Where the crack extended in the weld in some instances, it travelled for short distances along the hard interface zone which was found just on the fusion line. In general, however, the tendency appeared for the cracks to cross over, well into the softer weld metal.

(5) These observations were consistent throughout the series and the nature of the failures could not be related to variations in the composition of the electrodes.

FUTURE WORK

While the preliminary results of this first investigation indicate the desirability of molybdenum additions to the austenitic 20 Cr-10 Ni type electrode, the present critical shortage of this element militates against its use in any substantial amounts. The establishment of some other method of minimizing sensitivity to root cracking therefore must be seriously considered.

One possibility appears to be the use of electrodes with high chromium to nickel ratios. Preliminary tests suggest that increasing the Cr/Ni ratio tends to lessen the degree of center root cracking.

In addition it appears essential to establish whether the type of ballistic failure encountered in this investigation is characteristic of armor weldments or is traceable to the particular type of armor employed.

The following further work has therefore been planned:

(1) Investigation of the effect of variations in Cr/Ni ratio of electrodes combined with variations in molybdenum content. Testing procedures similar throughout to those described in this report will be employed excepting that tensile test samples will be selected in such a way as to avoid including weld metal from the shoulder beads of the test plates. In addition all-weld-metal tensile tests will be included to determine the effect on the physical properties of the weld metal alone.

(2) Repetition of the first investigation by selecting at least two of the electrode compositions originally employed and preparing test plates from several other makes of homogeneous armor. Testing procedures similar to (1) above would be employed.

APPENDIX I

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APPENDIX I - I

TABLE I

ANALYSIS OF CORE WIRE(1) AND WELD METAL(2)

SERIES NO.	COMPOSITION IDENTITY	HEAT NO	MELTING PRACTICE	MATERIAL(3)	C	MN	P	S	SI	CR	NI	MO	CR-NI RATIO
I	1.5 MN-0.0 MO	E 801	INDUCTION	CW	.087	1.45	.028	.016	.33	20.07	10.01	—	2.01
				WM	.100	1.54	.036	.009	.21	19.67	10.17	.07	1.93
	2.0 MN-0.0 MO	E 803	INDUCTION	CW	.089	1.90	.035	.012	.36	20.22	9.99	—	2.02
				WM	.102	2.15	.034	.019	.33	19.79	10.10	.07	1.96
	2.0 MN-0.0 MO-E	33005	ELECTRIC	CW	.071	1.82	.038	.015	.33	20.48	9.96	—	2.06
				WM	.077	1.90	.042	.017	.30	19.75	9.97	.07	1.98
	4.3 MN-0.0 MO	E 806	INDUCTION	CW	.083	4.11	.046	.011	.37	20.28	9.88	—	2.05
				WM	.100	4.47	.053	.008	.34	19.79	10.02	.08	1.97
II	2.0 MN-1.5 MO	E 809	INDUCTION	CW	.092	1.92	.034	.015	.39	20.26	9.92	1.62	2.04
				WM	.098	1.98	.035	.025	.31	19.66	10.08	1.59	1.95
	2.0 MN-(1.5MO)	E 804	INDUCTION	CW	.096	1.90	.036	.012	.39	20.04	9.72	—	2.06
				WM	.140	1.81	.033	.035	.34	19.06	9.70	1.44	1.97
	2.0 MN-(1.5MO)-E	33005	ELECTRIC	CW	.071	1.82	.038	.015	.33	20.48	9.96	—	2.06
				WM	.080	1.80	.044	.020	.32	19.29	9.79	1.65	1.97
	2.0 MN-3.0 MO	E 811	INDUCTION	CW	.091	1.94	.032	.012	.43	20.31	10.01	3.07	2.03
				WM	.100	2.09	.038	.014	.25	19.72	10.10	2.96	1.95
III	4.3 MN-1.5 MO	E 813	INDUCTION	CW	.083	4.27	.044	.012	.44	20.50	9.94	1.61	2.06
				WM	.096	4.56	.051	.010	.28	19.79	10.00	1.57	1.98
	4.3 MN-(1.5MO)	E 807	INDUCTION	CW	.084	4.10	.047	.016	.39	20.20	9.86	—	2.05
				WM	.138	4.37	.045	.028	.35	19.26	9.72	1.44	1.98
	4.3 MN-3.0 MO	E 815	INDUCTION	CW	.099	4.35	.045	.015	.42	20.32	9.95	3.00	2.04
				WM	.100	4.56	.049	.008	.25	19.79	10.12	2.88	1.96

(1) ANALYSIS OF TEST COUPON POURED DURING TEEMING OF HEAT.

(2) ANALYSIS OF WELD PAD PREPARED FROM 1/4" DIAMETER COATED ELECTRODES IN ACCORDANCE WITH PROCEDURE GIVEN IN BUREAU OF SHIPS SPECIFICATION 46E4 (INT) APRIL 1,1943.

(3) ABBREVIATIONS: CW - CORE WIRE, WM - WELD METAL

TABLE II

SENSITIVITY TO ROOT CRACKING AS SHOWN BY CRITICAL ROOT THICKNESS

SERIES NO.	COMPOSITION IDENTITY	HEAT NO.	ROOT THICKNESS INCHES	APPEARANCE OF BEAD (1)	ESTIMATED CRITICAL ROOT THICKNESS INCHES
I	1.5 MN–0.0 MO	E 801	.280	N	.250 – .280
			.250	N	
			.250	P	
			.250	C	
			.220	C	
	2.0 MN–0.0 MO	E 803	.280	N	.250 – .280
			.250	N	
			.250	P	
			.230	P	
			.220	P	
	2.0 MN–0.0 MO–E	33005	.310	N	.250 – .260
			.280	N	
			.260	N	
			.250	N	
			.250	P	
			.230	P	
			.220	P	
			.190	C	
	4.0 MN–0.0 MO	E 806	.280	N	.250 – .280
			.250	N	
			.250	P	
			.250	C	
			.190	C	
II	2.0 MN–1.5 MO	E 809	.250	N	.190 – .230
			.230	N	
			.190	P	
			.170	C	
	2.0 MN–(1.5 MO)	E 804	.230	N	.220 – .230
			.220	P	
	2.0 MN–(1.5 MO)–E	33005	.250	N	UNDER .230
			.230	N	
	2.0 MN–3.0 MO	E 811	.250	N	.190 – .230
			.230	N	
			.190	P	
III	4.3 MN–1.5 MO	E 813	.250	N	.220 – .250
			.220	P	
			.200	P	
			.190	C	
	4.3 MN–(1.5 MO)	E 807	.250	N	.200 – .220
			.220	N	
			.200	P	
	4.3 MN–3.0 MO	E 815	.230	N	.220 – .230
			.220	N	
			.220	P	
			.190	P	

(1) ABBREVIATIONS;
N – NOT CRACKED
P – PARTIALLY CRACKED
C – COMPLETELY CRACKED

TABLE III

FREQUENCY OF INTERFACE CRACKING

SERIES NO.	COMPOSITION IDENTITY	HEAT NO.	TOTAL NO. PLATES WELDED	NUMBER DEFECTIVE	REMARKS
I	1.5 MN-0.0 MO	E801	3	3	VERY NUMBEROUS INTERFACE CRACKS
			3*	2	NUMEROUS INTERFACE CRACKS
	2.0 MN-0.0 MO	E803	3	1	FEW INTERFACE CRACKS
	2.0 MN-0.0 MO-E	33005	2	1**	ONE INTERFACE CRACK
	4.3 MN-0.0 MO	E806	5	3	NUMEROUS INTERFACE CRACKS
II	2.0 MN-1.5 MO	E809	2	0	NO INTERFACE CRACKS
	2.0 MN-(1.5 MO)	E804	2	0	NO INTERFACE CRACKS
	2.0 MN-(1.5 MO)-E	33005	2	0	NO INTERFACE CRACKS
	2.0 MN-3.0 MO	E811	2	0	NO INTERFACE CRACKS
III	4.3 MN-1.5 MO	E813	2	0	NO INTERFACE CRACKS
	4.3 MN(1.5 MO)	E807	2	0	NO INTERFACE CRACKS
	4.3 MN-3.0 MO	E815	3	1	ONE SMALL INTERFACE CRACK

* THREE PLATES PREHEATED TO 550, 600 AND 650° F., RESPECTIVELY. PLATE PREHEATED TO 550° F. DID NOT DEVELOP INTERFACE CRACKS.

** ONE SMALL INTERFACE CRACK DISCOVERED IN ONE PLATE IN TENSILE TEST SAMPLE MACHINED FROM ROOT. SEE TABLE IV.

TABLE IV

TENSILE TEST DATA

SERIES NO.	COMPOSITION IDENTITY	HEAT NO.	SPECIMEN (1)	ULT. TENS. STR. PSI	.2% YLD. STR. PSI (2)	ELONGATION – % IN 2" (3)	ELONGATION – % WIDEST (4)	ELONGATION – % NARROWEST (5)	ROCK. HARD. RANGE OF SHOULDER BEADS	REMARKS FRACTURE PASSED THROUGH:
I	1.5 MN–0.0 MO	E 801	F	60,500	–	4.3	–	12.0	35C–43C	SHOULDER
			R	88,100	68,400	7.0	21.4	29.8		WELD
			B	90,900	46,350	16.0	35.2	44.9		WELD (6)
	2.0 MN–0.0 MO	E 803	F	88,800	57,000	9.0	13.4	21.4	93B–41C	SHOULDER
			R	94,500	70,700	6.5	21.3	23.7		WELD
			B	84,200	56,500	7.8	11.7	18.4		SHOULDER
	2.0 MN–0.0 MO–E	33005	F	69,000	–	5.2	6.0	13.4	97B–33C	(INTERFACE CRACK IN UNTESTED SAMPLE)
			R	18,700	–	–	–	–		(INTERFACE CRACK IN UNTESTED SAMPLE)
			B	62,000	–	2.7	11.7	5.5		(INTERFACE CRACK IN UNTESTED SAMPLE)
	4.3 MN–0.0 MO	E 806	F	93,000	57,050	15.0	20.3	41.3	92B–94B	WELD
			R	102,800	72,500	10.3	27.8	28.3		WELD
			B	92,800	56,600	14.0	21.5	40.3		INTERFACE
II	2.0 MN–1.5 MO	E 809	F	96,600	61,950	12.0	23.2	31.6	89B–35C	WELD (6)
			R	105,500	74,600	9.3	25.6	29.4		INTERFACE AND WELD
			B	83,500	56,900	7.8	9.8	20.0		SHOULDER
	2.0 MN–(1.5 MO)	E 804	F	96,300	61,950	10.0	–	24.7	92B–27C	SHOULDER
			R	97,400	75,500	10.0	27.0	24.2		INTERFACE
			B	89,600	61,950	8.3	9.1	13.9		SHOULDER
	2.0 MN–(1.5MO)–E	33005	F	77,000	–	6.0	5.9	14.5	84B–38C	SHOULDER
			R	105,500	–	8.5	27.6	25.8		WELD
			B	96,000	–	13.0	30.7	19.6		WELD (6)
	2.0 MN–3.0 MO	E 811	F	95,500	63,900	14.0	22.4	34.0	94B–96B	WELD
			R	–	58,300	–	(19.2)	(20.2)		(BROKE IN ARMOR)
			B	90,300	62,500	9.0	9.9	18.3		SHOULDER
III	4.3 MN–1.5 MO	E 813	F	91,300	67,500	6.5	10.2	18.6	91B–96B	INTERFACE
			R	93,600	76,300	11.8	27.8	27.0		WELD
			B	95,600	58,900	13.2	25.5	33.3		WELD
	4.3 MN–(1.5MO)	E 807	F	98,600	63,100	13.0	17.9	35.6	91B–96B	WELD
			R	104,000	–	9.3	29.5	25.0		WELD
			B	101,200	63,500	11.8	15.9	30.4		INTERFACE
	4.3 MN–3.0 MO	E 815	F	98,100	64,500	13.3	16.2	34.7	92B–96B	WELD
			R	105,800	69,200	7.8	16.2	18.4		INTERFACE AND WELD
			B	102,300	55,800	12.0	16.3	30.8		WELD

(1) F – SPECIMEN FROM FACE
R – SPECIMEN FROM ROOT
B – SPECIMEN FROM BACK

(2) DETERMINED BY OFFSET METHOD FOR .2% GAUGE OF EQUAL TO AVERAGE WIDTH OF WELD METAL.

(3) INCLUDED WELD METAL AND SOME PLATE METAL ON EITHER SIDE OF JOINT.

(4) ACROSS WIDEST PORTION OF WELD METAL.

(5) ACROSS NARROWEST PORTION OF WELD METAL.

(6) SHOULDER METAL REMOVED IN GRINDING PLATES TO SIZE.

APPENDIX I - 5

TABLE V.

EXPLOSION TEST DATA

SERIES NO.	COMPOSITION IDENTITY	HEAT NO.	SAMPLE NO.	EXPLOSIVE CHARGE	BEND IN TESTED SPECIMEN	ESTIMATED BREAKING CHARGE	REMARKS
				GRAMS	°ANGLE		
I	1.5 MN-0.0 MO	E 801	B4	75	8.0	78	UNBROKEN-LARGE INTERNAL CRACK
			B5	80	13.5		BROKE
	2.0 MN-0.0 MO	E 803	D5	75	6.0	80	UNBROKEN-INTERNAL CRACKS
			DD2	80	8.0		BROKE
			DD3	80	10.0		UNBROKEN-EXTERNAL CRACK
			DD4	85	9.5		BROKE
			D4	250	-		BROKE
	2.0 MN-0.0 MO	E 33005	R5	70	10.0	73	UNBROKEN-EXTERNAL CRACK
			RR3	70	6.0		UNBROKEN-SMALL INTERNAL CRACK
			R4	75	9.0		BROKE
			RR2	75	-		BROKE
	4.3 MN-0.0 MO	E 806	G5	75	6.5	83	UNBROKEN-EXT. & INT. CRACKS
			GG2	80	8.0		UNBROKEN-SMALL INT. CRACK
			GG4	85	9.5		BROKE
			GG3	90	8.5		BROKE
			G4	200	6.5		BROKE
II	2.0 MN-1.5 MO	E 809	J5	75	6.0	80	UNBROKEN-INTERNAL CRACKS
			JJ2	80	10.5		BROKE
			JJ3	80	7.5		UNBROKEN -EXT. & INT. CRACKS
			JJ4	85	10.0		UNBROKEN- EXT. & INT. CRACKS
			J4	125	5.5		BROKE
	2.0 MN-(1.5MO)	E 804	E5	75	6.0	78	UNBROKEN-SMALL INT. CRACKS
			EE4	75	6.0		UNBROKEN-NO CRACKS
			EE2	80	7.5		BROKE
			EE3	80	-		BROKE
			E4	175	9.0		BROKE
	2.0 MN-(1.5 MO)	E 33005	S4	75	9.0	93	UNBROKEN- EXT. & INT. CRACKS
			S5	80	9.5		UNBROKEN- EXT. & INT. CRACKS
			SS2	85	7.5		UNBROKEN- LARGE EXT. CRACK
			SS4	90	11.0		UNBROKEN- EXT. & INT. CRACKS
			SS3	95	8.5		BROKE
	2.0 MN-3.0 MO	E 811	L5	65	5.5	75	UNBROKEN-LARGE INTERNAL CRACK
			LL2	70	5.0		UNBROKEN- NO CRACKS
			LL4	75	6.0		UNBROKEN-SMALL INTERNAL CRACKS
			L4	75	5.5		BROKE
			LL3	80	10.5		BROKE

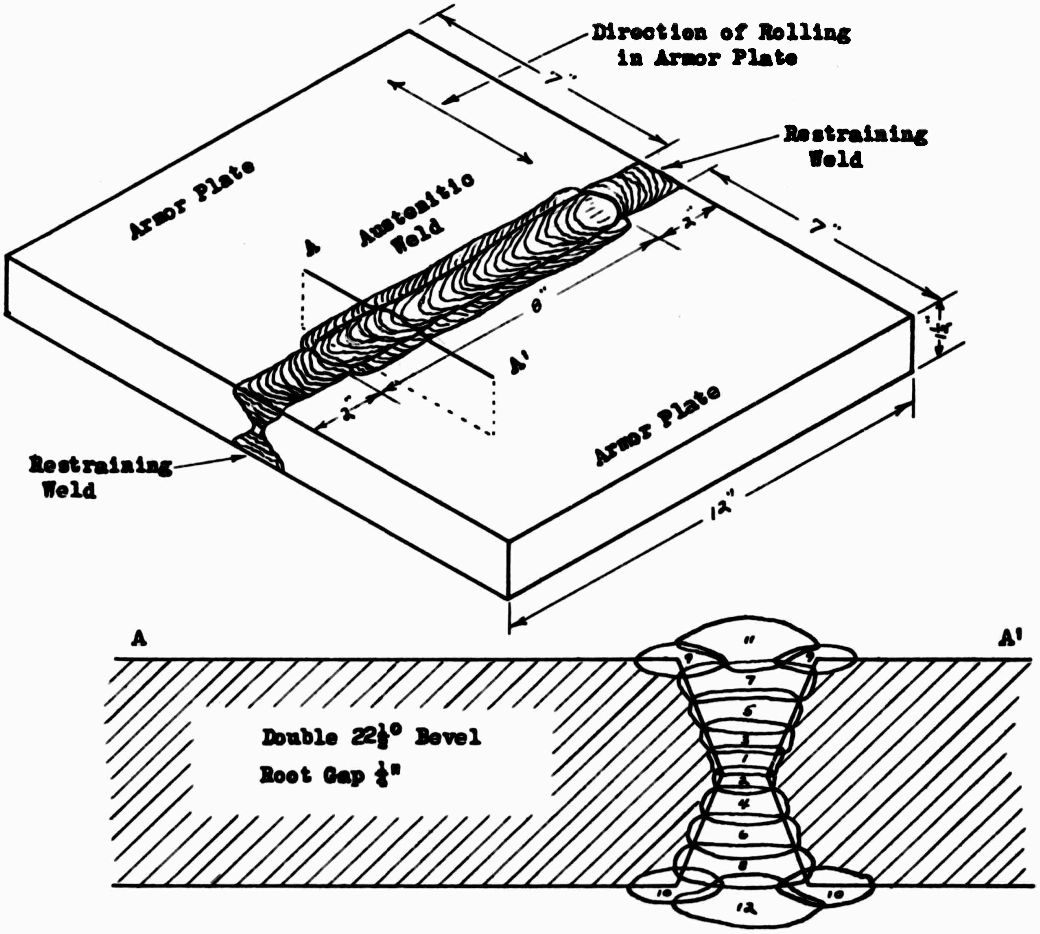
TABLE V -(CONT.)

EXPLOSION TEST DATA

SERIES NO.	COMPOSITION IDENTITY	HEAT NO.	SAMPLE NO.	EXPLOSIVE CHARGE	BEND IN TESTED SPECIMEN	ESTIMATED BREAKING CHARGE	REMARKS
				GRAMS	°ANGLE		
III	4.3 MN-1.5 MO	E 813	N4	75	5.5		UNBROKEN- NO CRACKS
			N5	80	7.5		UNBROKEN- INTERNAL CRACKS
			NN4	80	8.5	80	BROKE
			NN3	85	7.5		BROKE
			NN2	90	7.5		BROKE
	4.3 MN-(1.5MO)	E 807	H4	50	3.5		UNBROKEN - NO CRACKS
			H5	65	6.0		UNBROKEN - SMALL INT. CRACKS
			HH2	80	8.0	83	UNBROKEN-EXT.& INT CRACKS
			HH4	80	5.5		UNBROKEN-SMALL EXTERNAL CRACK
			HH3	85	-		BROKE
	4.3 MN-3.0 MO	E 815	P5	70	5.5		UNBROKEN - NO CRACKS
			PP3	70	5.5		UNBROKEN -SMALL INT. CRACK
			P4	75	6.0	73	BROKE
			PP4	75	-		BROKE
			PP2	80	6.0		BROKE
ARMOR	TRANSVERSE	9-04474	AT3	150	14.0		UNBROKEN-SMALL EXT. CRACK
	(LONG AXIS		AT4	200	20.0		UNBROKEN-LARGE EXT. CRACK
	RIGHT ANGLES		AT5	250	22.0	225	BROKE
	TO ROLLING		AT2	300	—		BROKE
	DIRECTION)		AT1	500	—		BROKE
ARMOR	LONGITUDINAL	9-04474	A1	175	16.0		UNBROKEN-SMALL EXT. CRACK
	(LONG AXIS		A2	225	19.0		UNBROKEN-LARGE EXT. CRACK
	PARALLEL TO		A3	300	22.5	OVER 700	UNBROKEN-LARGE EXT. CRACK
	ROLLING		A4	500	33.0		UNBROKEN-SEVERELY CRACKED
	DIRECTION)		A5	700	34.0		UNBROKEN-SEVERELY CRACKED

APPENDIX II

Drawings, Photographs and Photomicrographs. Figures 1 to 18, inclusive.	Pages 1 to 12



WELDING PRACTICE

Clamped in restraining jig during entire welding operation, plus 24 hours.
Maximum interpass temperature 200° Fahrenheit.

Layer No.	Electrode Size	Amperage	Remarks
1	3/16" Diameter	160 - 190	Root bead - copper back-up used
2	3/16" "	170 - 200	
3	1/4" "	250 - 290	
4	1/4" "	250 - 290	
5	1/4" "	250 - 290	
6	1/4" "	250 - 290	
7	1/4" "	250 - 290	
8	1/4" "	250 - 290	
9	3/16" "	190 - 210	Shoulder beads
10	3/16" "	190 - 210	Shoulder beads
11	1/4" "	270 - 300	Crown bead
12	1/4" "	270 - 300	Crown bead

Fig. 1 Test Plate Design and Welding Practice

Appendix II - 2

Preparation of Test Plate

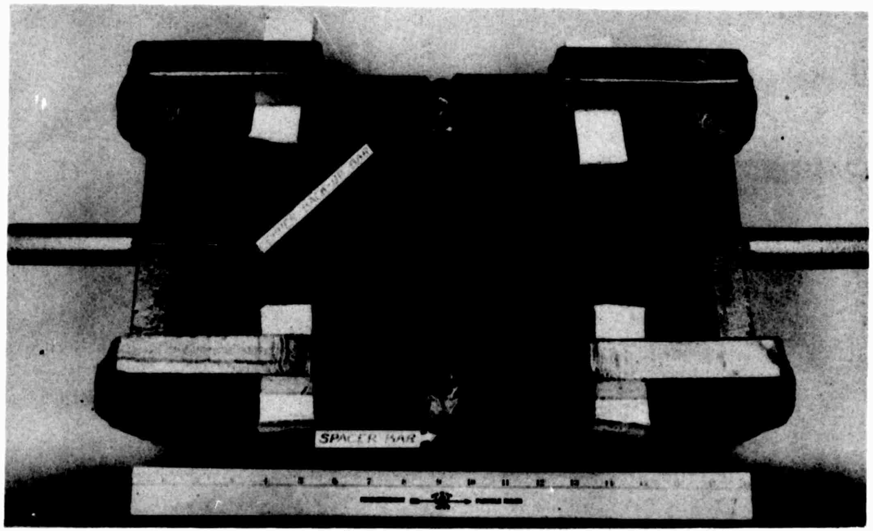


Fig. 2 Test Plate Clamped in Jig, Ready for Welding

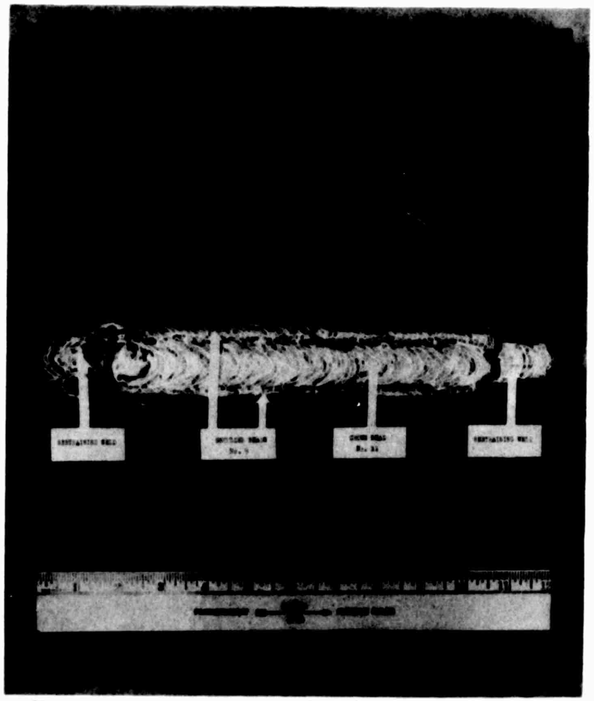


Fig. 3 Appearence of Welded Test Plate After Removing from Jig

Appendix II - 3

Determination of Sensitivity to Root Cracking

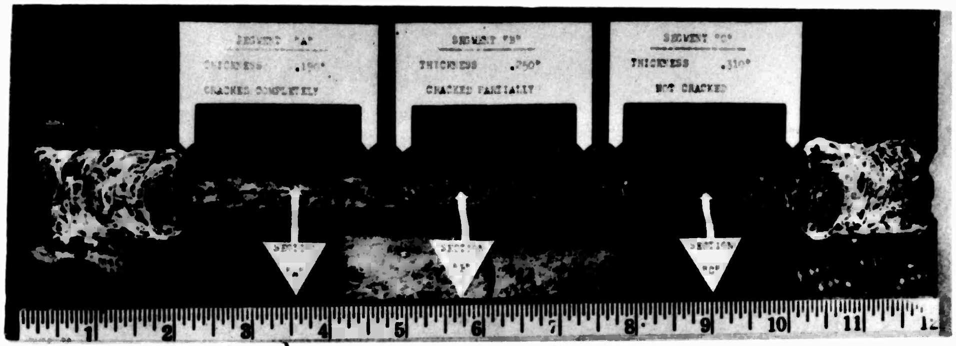


Fig. 4 Face Side

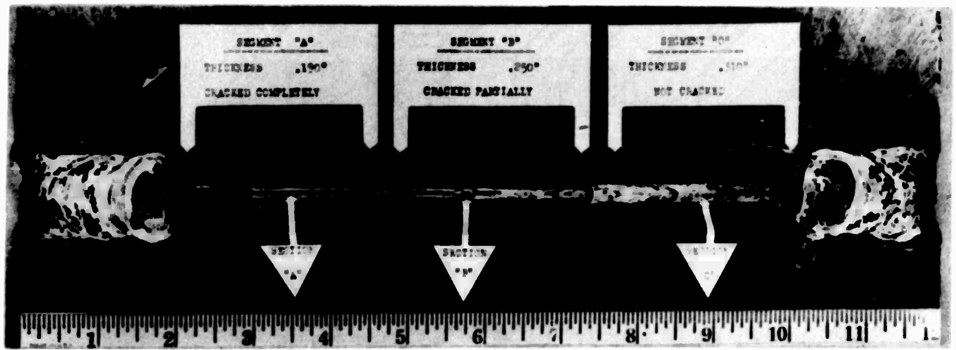


Fig. 5 Back Side

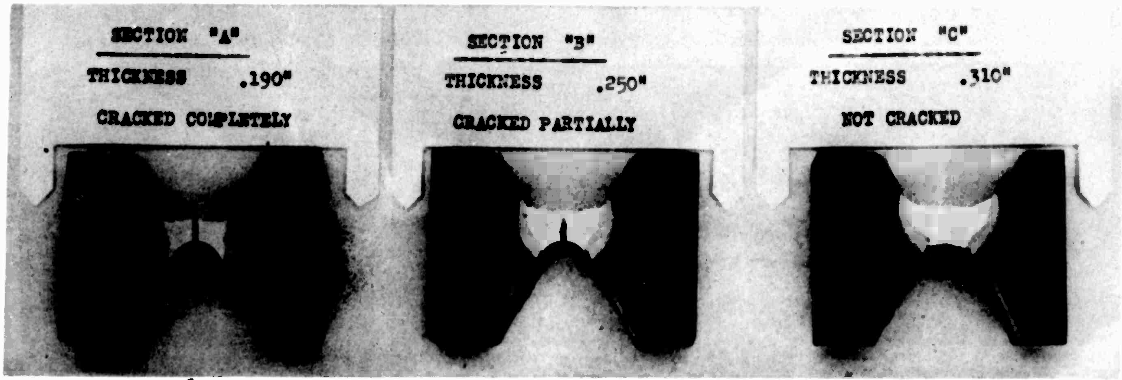


Fig. 6 Macro Etched Sections at Points Indicated in Figs. 4 and 5

Figs. 4, 5 and 6 Appearance of Root Pass with Beads of Three Thicknesses
Composition 2.0 Mn-0.0 Mo-E

Appendix II - 4

Sectioning Test Plato and Macro Etch Testing

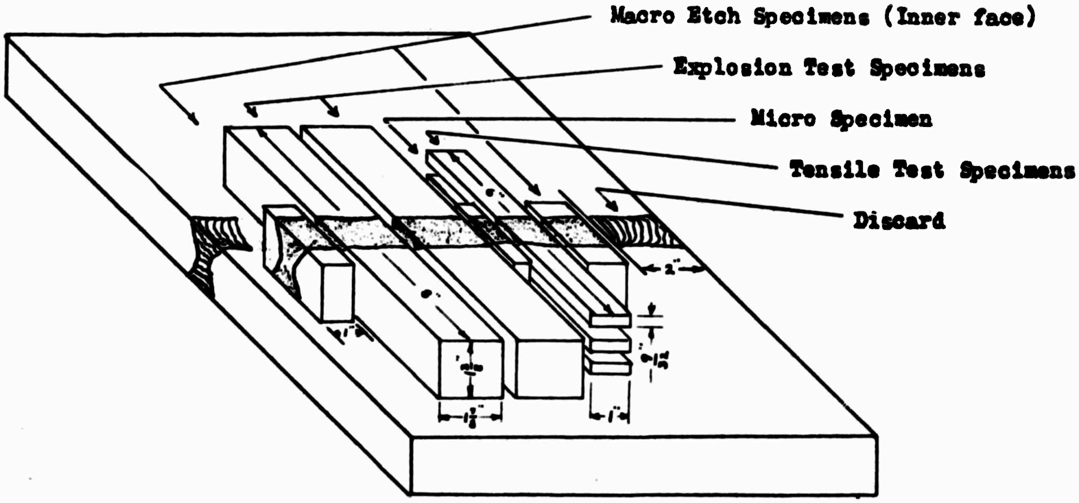


Fig. 7 Manner of Sectioning Test Plate for Test..Specimens

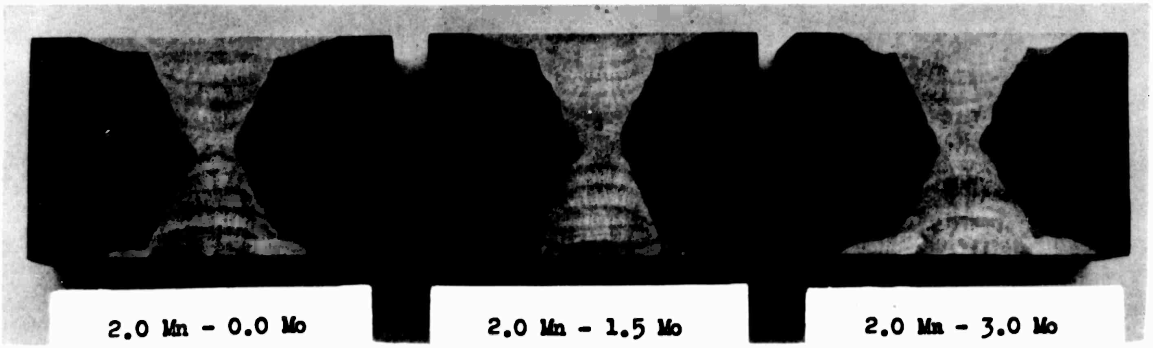
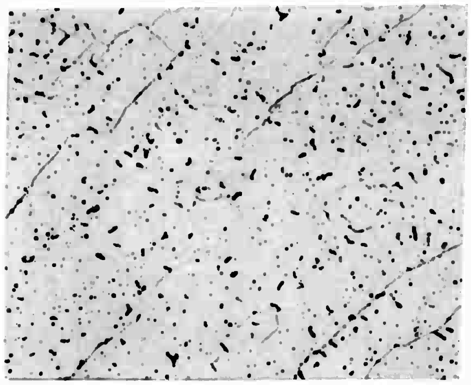


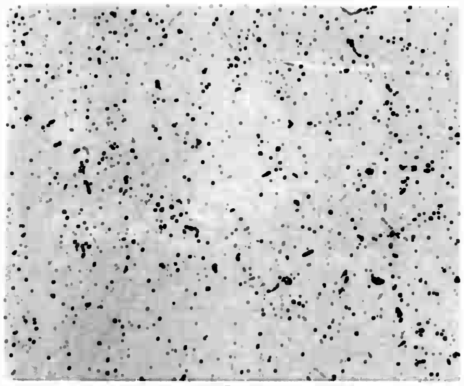
Fig. 8 Typical Macro Etched Samples from Series I, II and III

Appendix II - 5

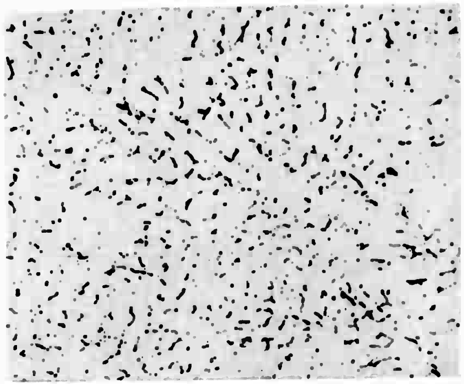
Microstructure in Root Pass, Series I



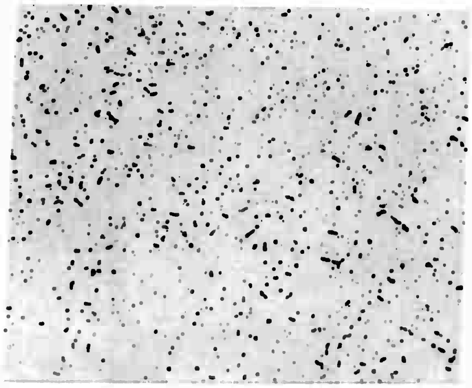
Composition 1.5 Mn-0.0 Mo



Composition 2.0 Mn-0.0 Mo



Composition 2.0 Mn-0.0 Mo-E

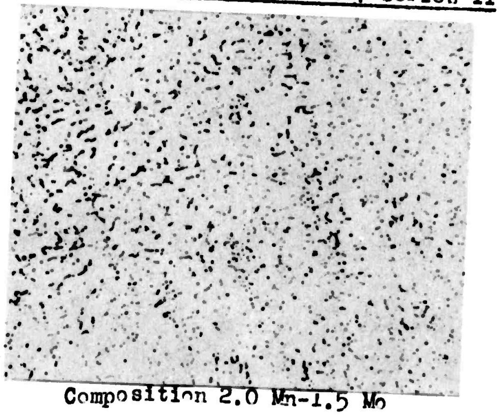


Composition 4.3 Mn-0.0 Mo

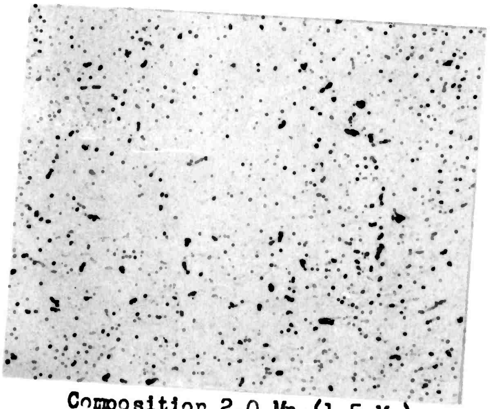
Fig. 9 Microstructure of Weld Metal in Root Pass X200

Appendix II - 6

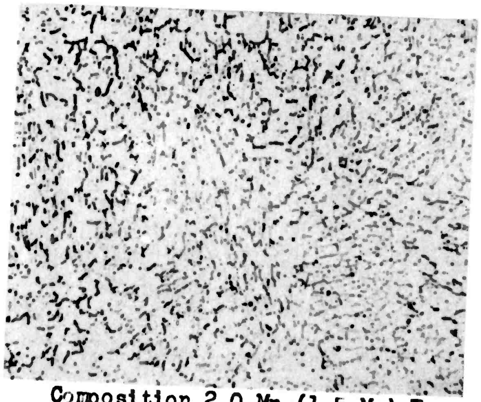
Microstructure in Root Pass, Series II



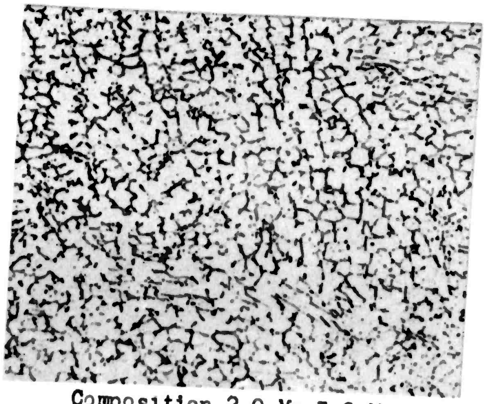
Composition 2.0 Mn-1.5 Mo



Composition 2.0 Mn-(1.5 Mo)



Composition 2.0 Mn-(1.5 Mo)-E

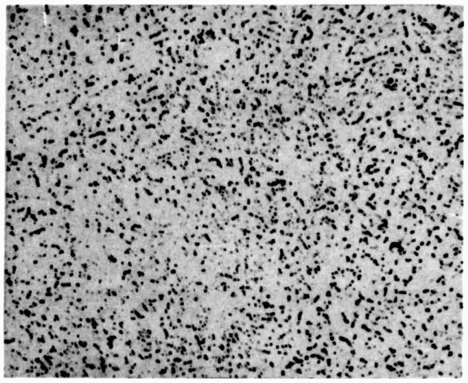


Composition 2.0 Mn-3.0 Mo

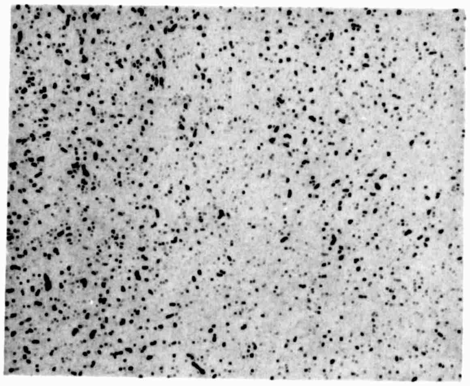
Fig. 10 Microstructure of Weld Metal in Root Pass X200

Appendix II -7

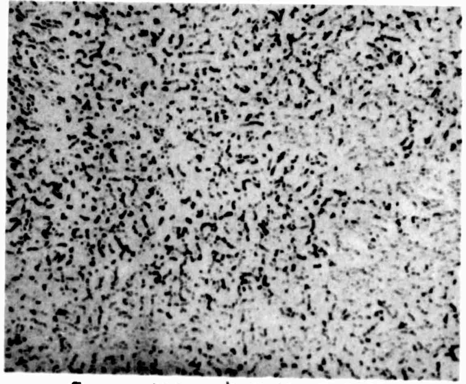
Microstructure in Root Pass, Series III



Composition 4.3 Mn-1.5 Mo



Composition 4.3 Mn-(1.5 Mo)



Composition 4.3 Mn-3.0 Mo

Fig. 11 Microstructure of Weld Metal in Root Pass X200

Appendix II - 8

Microstructure at Fusion Line

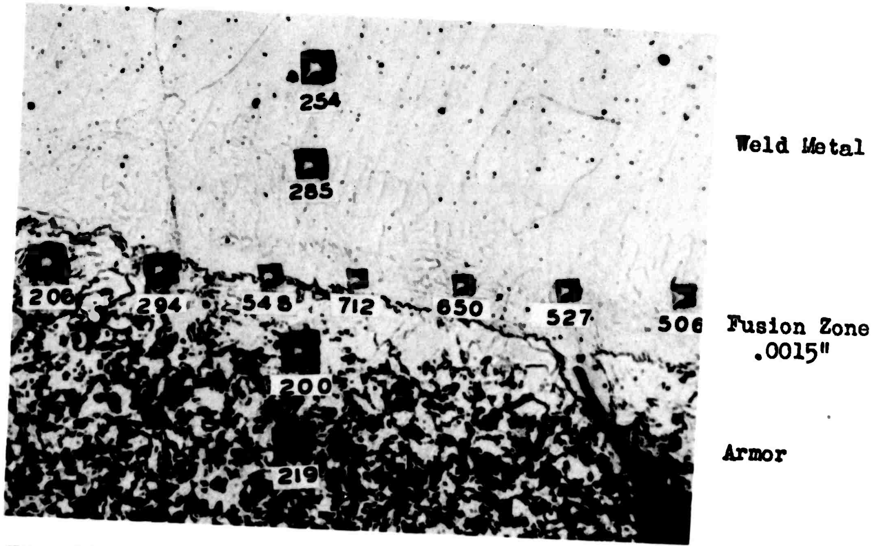


Fig. 12 Microstructure at fusion zone

Microhardness impressions with Eberbach Tester

Composition 1.5 Mn-0.0 Mo X500

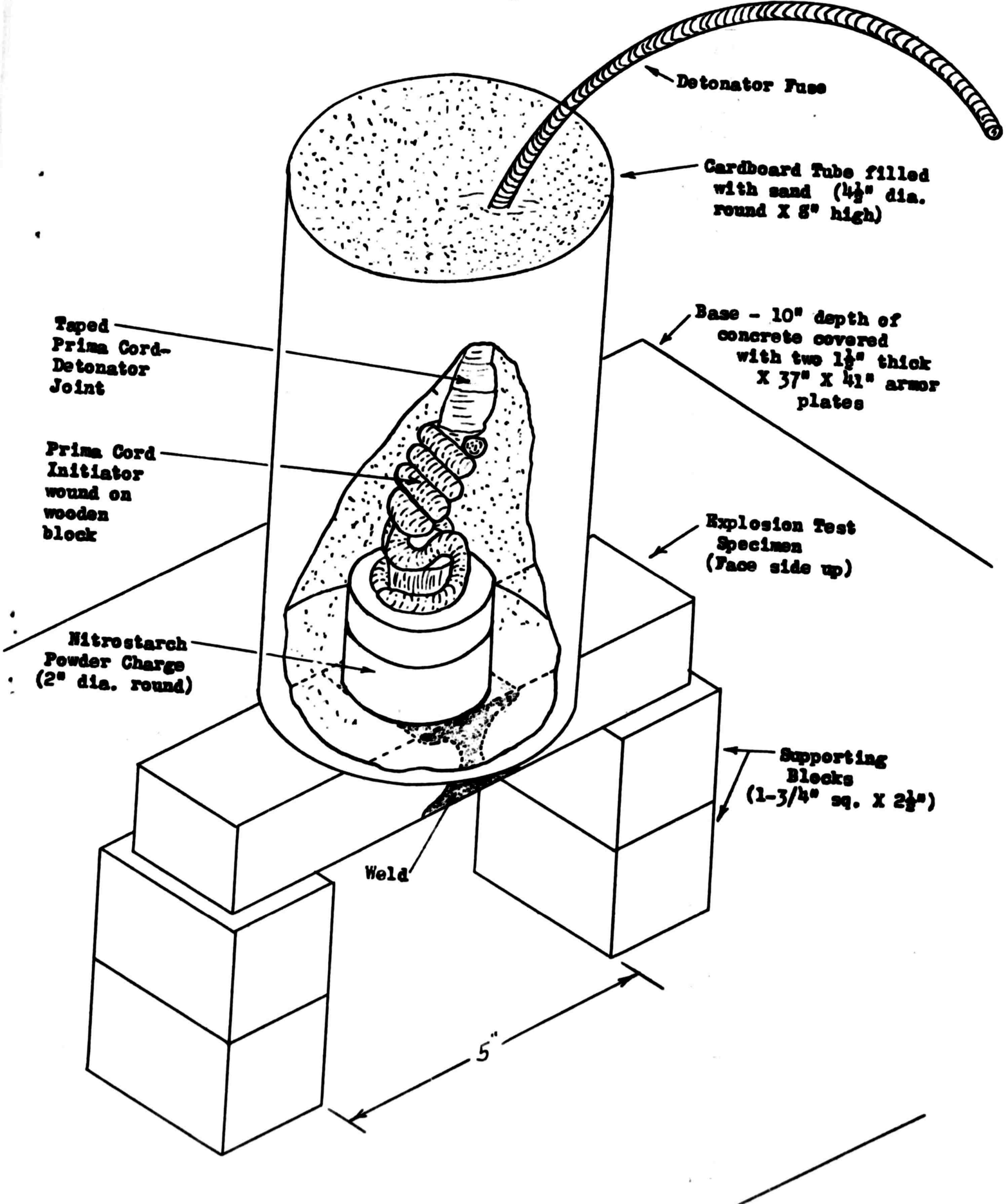
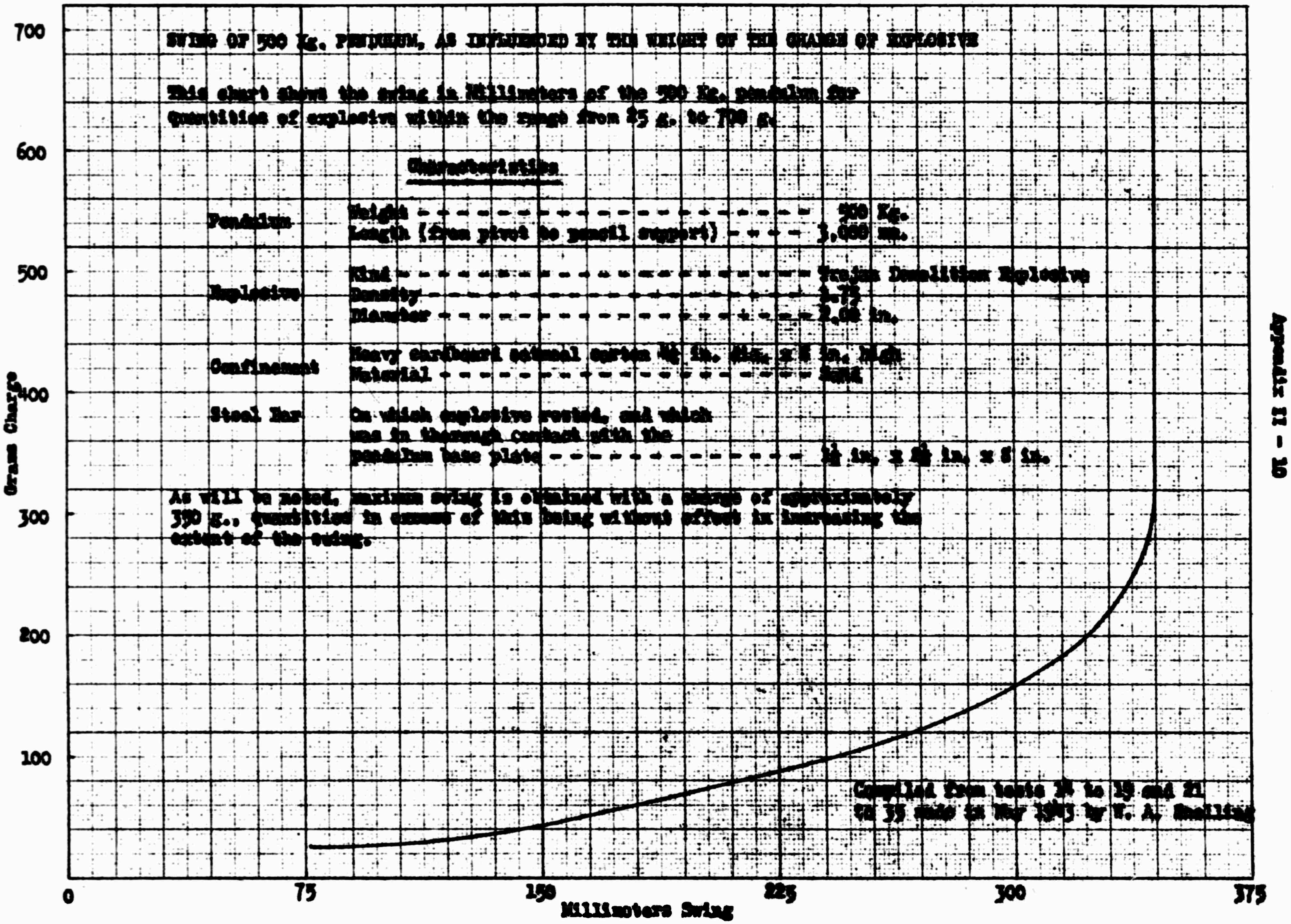


Fig. 13 Explosion Test Set-up

Fig. 14 EXPLOSION TESTING BALLISTIC PENDULUM



SWING OF 500 Kg. PENDULUM, AS INFLUENCED BY THE WEIGHT OF THE CHARGE OF EXPLOSIVE

This chart shows the swing in Millimeters of the 500 Kg. pendulum for quantities of explosive within the range from 25 g. to 700 g.

Characteristics

Pendulum	Weight	500 Kg.
	Length (from pivot to pencil support)	3,000 mm.
Explosive	Kind	Trojan Demolition Explosive
	Density	[illegible]
	Diameter	2.08 in.
Confinement	Heavy cardboard [illegible] carton 4½ in. dia. x 5 in. high	
	Material	None
Steel Bar	On which explosive rested, and which was in thorough contact with the pendulum base plate	1½ in. x 4½ in. x 8 in.

As will be noted, maximum swing is obtained with a charge of approximately 330 g., quantities in excess of this being without effect in increasing the extent of the swing.

Compiled from tests 14 to 19 and 21 to 35 made in May 1943 by W. A. Snelling

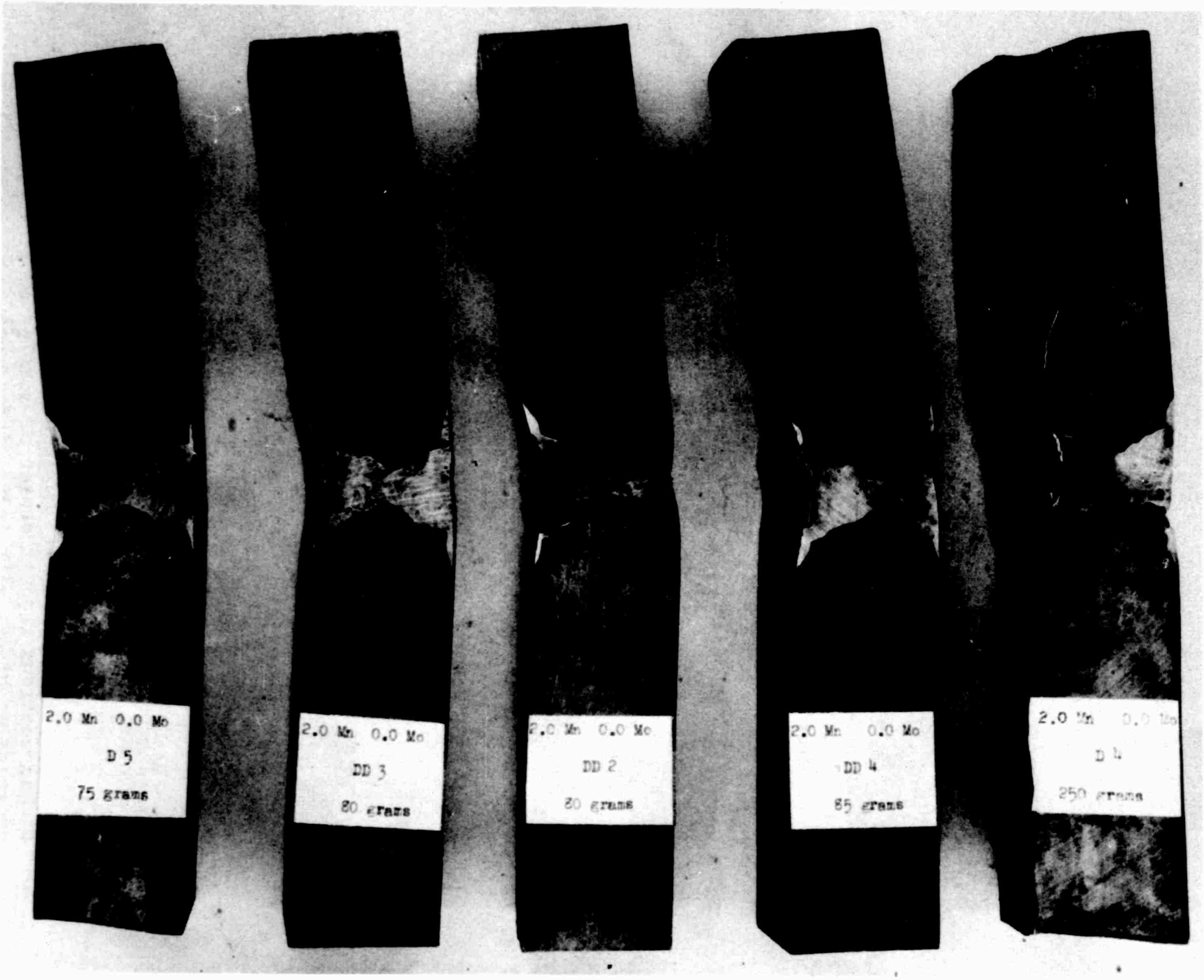


Fig. 15 Appearance of Explosion Tested Samples. Composition 2.0 Mn-0.0 Mo. X 3/4

Appendix II - 12

Development of Cracks in Explosion Tested Samples

Composition 2.0 Mn - 1.5 Mo

Fig. 16 Initiation of crack in armor X 500
Microhardness tests with Eberbach Tester

Fig. 17 Extension of crack along interface mostly in armor X 35

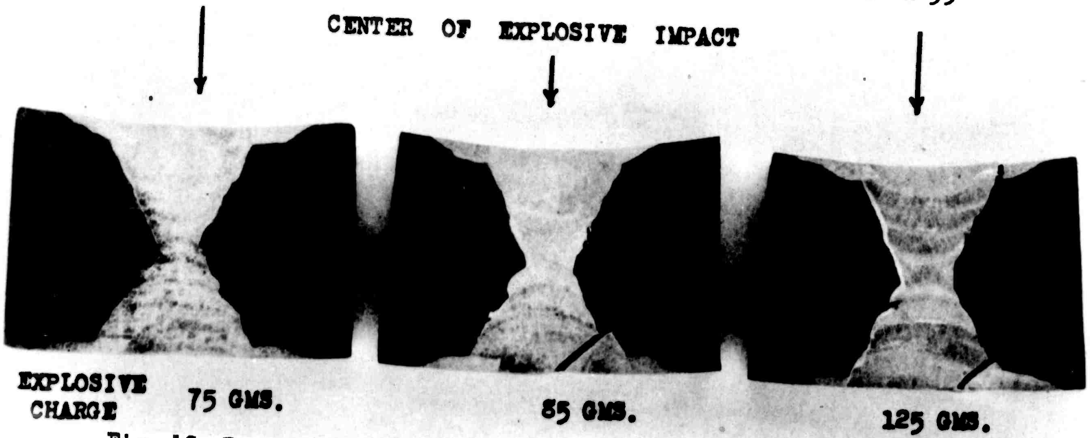


Fig. 18 Etched sections through center of samples showing final progress of cracks with increasing impact.

REEL – C

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TITLE: Development of Armor Welding Electrodes: Relation of The Composition of Austenitic (20 Cr-10 Ni) Electroded to the Physical and Ballistic Properties of *
AUTHOR(S): Feild, A. L.; Bloom, F. K.; Linnert, G. E.
ORIGINATING AGENCY: Rustless Iron and Steel Corp., Baltimore, Md.
PUBLISHED BY: Office of Scientific Research and Development, NDRC, Div 18

DATE	DOC. CLASS.	COUNTRY	LANGUAGE	PAGES	ILLUSTRATIONS
July'43	Unclass.	U. S.	Eng.	41	photos, tables, diagrs.

ABSTRACT: A study was made of the effect of variations in the composition of austenite 20 Cr-10 Ni type electrodes on the properties of restrained armor weldments. Restrained double bevel armor joints were welded with 20-10 electrodes having variation in manganese content of 1.5, 2.0, and 4.3% combined with molybdenum content variations of 0, 1.5, and 3%. Testing included determination of sensitivity to center root bead cracking, interface cracking, as well as X-ray, macro etch and metallographic examinations. Physical and ballistic properties were determined by tensile tests and a special explosion test. High manganese contents combined with the use of some molybdenum are believed to represent the best electrode combination. Ballistic properties could not be related to composition, and no difference was observed for molybdenum added through the electrode coating or through the core wire.

* Armor Weldments (OD-36-2)

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