WATERTOWN ARSENAL LABORATORY

EXPERIMENTAL REPORT

NO. WAL. 648/5

EVALUATION OF SHOCK PROPERTIES OF WELDED ARMOR JOINTS

Examination of Samples from 33 Commercially Welded, Ballistically Shock Tested "H" Plates

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Plate Group	Type Failure	Cause	Extent	Remarks
Austenitic Hand Welded	Fusion Zone	Incomplete fusion	Moderate	Correct by improved joint design and welding technique.
		Carbide precipitation at weld-plate interface	Moderate	Carbides are precipitated by reheating by subsequent welding passes. Condition more severe when large diameter electrodes are used.
		Possibly a linear precipitation of nonmetallics in weld metal adjacent to fusion line.	General	Tendency toward failure in this area most easily decreased by improvement in weld joint geometry through use of large annealing beads.
Austenitic Unionmelt Welded	Heat-Affected Zone	High transformation temperature carbides due to slow cooling rate.	General	Prevented only by use of very high alloy armor plate.
	Fusion Zone	Same as for Hand Welded Plates.		
Ferritic Unionmelt Welded	Weld Metal	High transformation temperature carbides. Dendritic segregation.	General	Prevent by use of increased alloy in weld metal.
	Heat-Affected Zone	Same as for Austenitic Unionmelt Welded Plates.		

In addition to the above, a tendency toward brittle failure under severe testing conditions was shown in manually deposited ferritic weld metal. The practice of grinding reinforcement flush with these plates considerably improves ballistic and bend tests but is not regarded as representative of fabrication armor weldments.

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Vickers-Brinell surveys were made at root, midwall, and near crown of weld cross sections after polishing through 000 emery paper. Specimens were then repolished and etched with 4% picral (unless otherwise noted) for microscopic examination, then further etched with hot acid (1 part H_2SO_4, 3 parts HCl, and 4 parts H_2O) for macroscopic examination.

Layout and dimensions of specimens are shown in Figure 2. In addition, standard V notch Charpy bars were taken to determine relative impact energy of the weld metal heat-affected zone, and unaffected plate metal of a few representative plates.

DATA AND DISCUSSION

1. Ballistic Shock Test Results

Results of ballistic tests are given in charts 1 through 13 (Appendix A) which are abstracts of Aberdeen Proving Ground Firing Records. A summary of the present specification requirements for H plates welded with austenitic electrodes is also included in Appendix A.

Ballistic shock test performances of plates in each thickness group are compared in Table I. It is readily apparent that while some indication of shock qualities are evident, inconsistencies in velocity, eccentricity and number of ballistic impacts prevent adequate comparisons of the shock properties of the various plates. The use of a high explosive type projectile, which will completely penetrate the plate unless it is detonated by the contact fuse, introduces further complications in the testing of lighter gage plates. Obviously, a rather critical relation between velocity of projectile, fuse sensitivity, eccentricity of impact, and geometry of weld are involved when the high explosive projectile is used. The possibilities of developing a direct explosive test to replace the high explosive projectile are being investigated at Aberdeen Proving Ground and elsewhere.

Location of ballistic cracking as reported in firing records is based on surface appearance only. It is evident that a crack in the vicinity of the weld may proceed principally through portions of weld metal, fusion zone, and heat-affected zone regardless of surface appearance. From a development viewpoint, the path of ballistic fracture of a group of plates in the weld heat-affected zone may call for a corrective entirely different from that required for other groups of plates which tend to fail through fusion zone, or weld metal.

At Aberdeen Proving Ground sections through ballistic fracture of some H plates are taken, macroetched and photographed. This was done on seven of the 1-1/2 inch thick Austenitic Unionmelt plates included in this report (Figure 10). It would be very desirable to have the path of ballistic fracture of a certain proportion of plates from each thickness and welding procedure group determined and reported.

2. Tensile Tests

Results of tensile tests are given in Table II. Figure 3 is a photograph of typical broken tensile specimens.

The transverse tensile test of a butt welded joint provides a means of determining the location of failure and the ultimate tensile strength of the joint under conditions of a single, slowly applied load. Weld reinforcements were left on the tensile test bars in order that the service strength of welded joint would be determined. In the absence of severe notches, caused by welding defects or by a sharp change in section at junction of weld and plate metals, failure must always occur in material having lowest ultimate strength under conditions of tensile test.

The armor used in these test plates has been heat treated, prior to welding, by quenching then tempering to a hardness level between a maximum of about 360 Brinell, (1/2 inch plate) and minimum of about 280 Brinell (1-1/2 inch plate). The minimum and maximum tensile and yield strengths equivalent to these hardnesses are approximately 125,000 to 165,000 psi. yield strength and 140,000 to 180,000 psi. tensile strength.

In general, the effect of welding heat has been to produce even greater hardnesses, and equivalent tensile strengths, in base metal immediately adjoining weld deposits. Consequently, and as indicated in Table II, the maximum tensile strength of the weld joint specimens represents strength of the weld metal. Low values are associated with presence of welding or plate metal defects.

Elongation values generally represent amount of local necking in the ductile weld metal, but are influenced by geometry and width of weld and gage length and afford only a general comparison of the ductility of the various joints under conditions of tensile testing.

Ballistic failures tend to proceed through zones of low impact energy rather than low static strength. Since austenitic or low carbon ferritic weld metals may have good impact resistance even at relatively low tensile strength values, the transverse tensile test neither reproduces the type of fracture nor correlates with performance obtained in ballistic shock testing.

3. Hardness Surveys

Table III summarizes results of Vickers-Brinell hardness surveys. Location of hardness impressions and plots of typical surveys are shown in Figures 4 and 5. Since considerable emphasis has been placed on maximum hardness of weld heat-affected zone of base metal by several investigators, it is necessary to consider the importance of this criterion.

Hardness of the heat-affected zone is dependent upon the response of the base metal to the effects of the welding cycle, i.e., to the amount of austenite formed and the completeness of carbide solution, to the rate of cooling as heat is conducted away by the unheated base metal mass, and to the tempering effects of subsequent welding passes.

Tensile and yield strength increase and notched-bar impact energy decreases with increase in final hardness. But while the relationship between static strength and hardness is independent of prior processing, impact energy is very greatly influenced by variables which do not affect hardness. Thus the notched-bar impact value of a steel heat treated to equivalent hardnesses by two different procedures may vary as follows:

Armor C Content	Armor Alloy Type	Heat Treatment*	Hardness Rockwell C	Hardness Brinell Equivalent	V Notch Charpy Value ft./lbs.
.27	Mn-Mo	1800°F. 1 hr. Air Cool	29	285	7.7
		1800°F. 1 hr. Water Quench 1100°F. 1 hr. Air Cool	31	302	49.0
.26	Mn-Ni-Cr-Mo	1800°F. 1 hr. Air Cool	27.5	273	20.8
		1800°F. 1 hr. Water Quench 1100°F. 1 hr. Air Cool	29.5	289	72.
.30	Mn-Cr-Mo	1600°F. 1 hr. Air Cool	34	331	7.7
		1600°F. 1 hr. Water Quench 1100°F. 1 hr. Air Cool	35.5	344	70.
.26	Ni-Cr-Mo-Si	1800°F. 1 hr. Air Cool	32	311	10.8
		1800°F. 1 hr. Water Quench 1100°F. 1 hr. Air Cool	31	302	67.

* Specimens heat treated in 1/2 inch round

Variations from one heat of steel to another, for bars of the same heat treatment, are largely due to differences in melting and rolling practice.

Steels of good quality (cleanliness and directional properties) may have surprisingly high impact energy values at high hardness, as shown by the following examples:

Armor C Content	Armor Alloy Type	Heat Treatment*	Hardness Rockwell C	Hardness Brinell Equivalent	V Notch Charpy Value ft./lbs.
.27	Mn-Ni-Cr-Mo	1600°F. 1 hr. Oil Quench	48.5	474	34.2
.30	Mn-Cr-Mo	1600°F. 1 hr. Oil Quench	50.0	490	28.
.27	Mn-Mo	1600°F. 1 hr. Oil Quench	47.5	460	27.3

* Heat treated in Charpy bar size

In the absence of notches the impact energy of high hardness areas may be excellent and at the high strength levels failure seldom originates in these areas. But the structure with moderate hardness, if produced by relatively slow cooling from the austenitizing temperature, has a very low impact energy at a much lower strength level and may lead to heat-affected zone failures. The practical importance of these considerations may be demonstrated by comparing ballistic and hardness test results of such plates as Midland RE-113 and New York 45 (see Tables I and III) and it becomes evident that no correlation is possible between hardness and shock performance.

4. Macroexamination

Figures 6 and 7 are photographs of macroetched sections from representative test plates. Value of the macroexamination is limited to disclosing welding defects and cracks present at the particular surface being examined. Correlation with ballistic performance is obtained only when defects such as extensive crack systems are revealed.

Examination of macroetched sections disclosed a few small cracks in weld metal, bond zone and heat-affected zone of some of the plates, but these cracks were found to be of a local nature and did not appear to influence ballistic or laboratory test results. Incomplete fusion was observed at the root of several of the plates, particularly the New York Air Brake series, and may have influenced ballistic shock performance. This condition was more evident in tensile and fracture tests.

5. Weld Joint Fracture Test

Examination of fibre of a fractured surface provides a rough means of evaluating impact resistance of a steel for the specific conditions under which the fracture was made. If fracture takes place with little or no deformation the fracture surface will have a bright crystalline, multifaceted appearance which is certain evidence of low energy of impact. High energy of impact is characterized by a dull gray fracture surface appearance. Increased severity of notching, increased velocity of impact, or decreased temperature of testing all may cause a steel fracture to change from fibrous to crystalline.

The weld joint nick-break specimen of Figure 1, when fractured by a sharp blow at ordinary temperatures, affords a very severe test of impact resistance of a section through unaffected armor plate, weld heat-affected zone, and weld metal. A crystalline appearance of any of these metals indicates an area which will be subjected to brittle failure under a ballistic impact. Such failure will be greatly accentuated by the presence of any kind of defect providing a notch which may initiate failure in the low impact energy metal.

Results of fracture test are given in Table IV. Figures 8 and 9 are photographs of typical weld joint fractures. It may be noted that:

a. Fractures of all austenitic weld metals and all manually deposited Mn-Mo type ferritic weld metals are fibrous while fractures of less hardenable ferritic Unionmelt weld metals are crystalline.

b. Fractures of weld heat-affected zones of manually welded plates are fibrous except where electrode size was relatively large in proportion to plate thickness (1/2 inch electrode on 1-1/2 inch plate and 1/2 inch electrode on 1/2 inch plate show crystalline patches in heat-affected zone). Fractures of heat-affected zones of Unionmelt plates are entirely crystalline except where effective hardenability of armor plate was very high (New York 46) or where a large portion of weld was completed by hand welding (Midland CR-25).

c. Fractures of plate metal of all but one sample are fibrous indicating adequate hardenability and satisfactory heat treatment for the rolled armor. The one exception (General Motors YT-18) showed crystalline patches near centerline of fracture in plate metal unaffected by welding heat.

Comparison of Tables I and IV establishes the following correlations:

1-1/2 inch thick plate - All plates with completely crystalline fracture of weld heat-affected zone showed excessive cracking during ballistic shock test. Figure 10, which is a reproduction of Aberdeen Proving Ground photomacrographs of sections through ballistic fracture, shows that the path of ballistic fracture of these plates was through the weld heat-affected zone. New York plate 46 in this Unionmelt welded group had a fibrous heat-affected zone in the fracture test (see Figure 8), and showed better ballistic performance with ballistic fracture principally through weld metal and fusion zone (see Figure 10).

1, 3/4, and 1/2 inch thick plates - Inconsistencies of ballistic test do not permit many comparisons, but all plates which showed crystallinity in either heat-affected zone or weld metal on fracture test also showed excessive cracking in ballistic test if eccentricity and velocity were within reasonable limits.

The fracture test thus seems to reveal areas which are subject to failure under ballistic test. Whe er or not failure does occur through these areas depends upon the presence of macrodefects, the goemetry of the joint, the occurrence of conditions which cause fusion zone failures, and the velocity and location of ballistic impacts.

6. <u>Weld Joint Bend Test</u>

It is apparent that in order to establish satisfactory correlation with ballistic shock test performance, the relative properties of heat-affected zone, fusion zone, and weld metal must be evaluated under conditions of loading simulating those obtained in ballistic testing.

A transverse section through the weld joint provides a suitable test specimen since all constituents of the welded joint are represented. If the section extends through thickness of the plate and includes weld reinforcement, the geometry of the joint is also represented.

If notches are absent (reinforcement removed) and such a section is broken by bending with a slowly applied load (ordinary free bend or guided bend tests) failure will occur by necking down and fracture of that part of the joint with lowest static strength as in the transverse tensile test. However, if bar is bent at a rapid rate fracture will tend to proceed through constituent with the lowest impact resistance.

Thickness of the plate (depth of the bend bar) has two important effects in this test. First, the deformation of the outer fibre is greater for a given bend angle the greater the thickness, hence the angle to failure will be less in a bar from 1-1/2 inch plate than in a 1/2 inch plate. Second, and more important, for a given deformation of the outer fibre much greater elastic stresses are set up in a bend bar from a heavy plate than in that from a light gage plate. Failure, once started through a brittle constituent in bars from 1-1/2 inch thick plate, proceeds with cannon shot vehemence. The rate of loading is much less critical in bars from 1-1/2 inch thick plates and fracture tends to go through brittle constituents even at very slow rate of application of external load. Bend bars from 3/4 inch thick plate, when broken with same rate of load application as bars from 1-1/2 inch thick plate, did not provide a severe enough test to reveal brittle constituents.

Geometry of the weld and particularly of the weld reinforcement has important effects in the bend test and also in the ballistic test.

Sharp changes in weld plate geometry both external and internal, as well as macrodefects, may influence origin of failure. It is believed that a bend bar should be representative of ballistic weld section in order that geometrical influences may be brought into effect in the bend test.

Transverse bend bars were taken from each of the subject plates. Bars from plates 3/4 inch or greater in thickness were broken in a steam press by rapid application of load and bars from 1/2 inch thick plates by a single drop of a 110-lb. weight from a height of 15 feet. As remarked above, this test was not entirely satisfactory for bend bars from 3/4 inch thick plate. Since the weld reinforcements had been removed from some of the 1/2 inch test plates before ballistic testing, bend bars from other 1/2 inch plates were tested both with and without reinforcement.

Table V gives location of fractures in the bend tests and typical tested bars are shown in the photographs of Figures 11, 12, and 13.

Exclusive of a small amount of plate metal cracking explained by weld geometry or plate defects such as severe laminations (Cadillac 140), three principal types of fracture were noted:

a. Heat-affected zone failure. Plates which were welded with a high ratio of heat input to plate section tend to fail in the armor plate adjacent to the weld. The fracture surface has a characteristic crystalline appearance and a comparison of Figures 10 and 11 shows that the path of fracture is through the same zone in both ballistic and bend tests. The exact path of fracture is apparently largely dependent upon weld geometry, macrodefects, and testing conditions. Heat-affected zone failures in the bend tests correlate with crystalline appearance of heat-affected zone in the nick-break fracture test and with excessive cracking in the ballistic shock test.

b. Fusion zone failures. Failure at the bond zone or in the weld metal immediately adjacent to the bond zone results in the type of fracture best illustrated by Midland RE-104 (Figure 11). Apparently a low impact energy zone exists near the fusion zone in many austenitic armor welds, but whether fracture proceeds through this area, depends to a large extent upon geometry at the crown of the weld, macrodefects (particularly incomplete fusion at the root of the weld) and external factors in the ballistic test. The cause of fusion zone fracture has been rather obscure, but will be discussed briefly under microexamination in this report and in more detail in a report now being prepared at this laboratory. Fusion zone failure in the bend test is undesirable and correlates with excessive cracking in the ballistic shock test.

c. Weld metal failure. Fracture through sound weld metal in the bend test indicates either: (1) absence of brittle constituent in fusion or heat-affected zones; (2) absence of notches which initiate failure in fusion or heat-affected zones; or (3) inferior weld metal properties. Hence, provided that impact energy of weld metal can be established as equivalent to armor plate, unaffected by welding heat, by some standard test such as the V notch Charpy, fracture through sound weld metal in a bend bar should correlate with satisfactory ballistic shock properties.

For 1-1/2 inch thick austenitic welded H plates, either manual or Unionmelt, ballistic shock results improve proportionately with the amount of fibrous fracture through sound weld metal. Charpy impact results (Table VI) indicate that weld metal from austenitic welds, both manual and Unionmelt, has very high impact energy.

Inconsistencies in ballistic test and greater influence of welding defects do not allow many comparisons for 1 inch and lighter gage plates. Special mention should be made of Cadillac plate 167 which failed in weld metal in bend test but showed considerable (but not excessive according to present specification) cracking on ballistic test. The wide taper of the weld crown at the top of this bar (see Figure 12) is very favorable and may have prevented fusion zone failure in the bend bar. This geometry was not representative of the entire plate and a duplicate bend bar failed largely through the fusion zone.

Weld reinforcement was ground flush with the plate surface prior to ballistic testing of a number of the plates. Figure 13 shows effect of removing the reinforcement on bend bars for two of the 1/2 inch plates which were ballistically tested with reinforcement. In both illustrations removing the reinforcement caused fracture to shift from fusion zone and heat-affected zone to weld metal. The practice of grinding reinforcements will obviously have a considerable influence on both ballistic and bend bar results, particularly in lighter gage plates. One-half inch thick plates hand welded with Mn-Mo ferritic electrodes and tested with reinforcement removed showed excellent performance in the drop weight bend test.

Notched bar impact values were obtained for the two types of ferritic weld metal used in 1/2 inch plates (see Table VI). These results indicate that the shock resistance of the Unionmelt ferritic weld metal was inadequate, as compared with unaffected armor plate, and weld metal failure in bend bars from these plates cannot be taken as an indication of satisfactory ballistic properties.

7. Microexamination

Microscopic examination provides a means of disclosing zones of ballistic weakness in a weld joint insofar as metallographic structures can be recognized which are known to have a low energy of impact under test conditions comparable to those produced by ballistic shock. Microscopic study of a constituent, known to be shock deficient, may help to determine the cause of such behavior. Within these limitations, microscopic examination of specimens from the subject plates, resulted in the following observations:

a. Weld heat-affected zones - In general a steel which has been quenched to martensite and tempered and has a microstructure consisting of very fine uniformly distributed carbide particles has relatively high impact energy. A steel with a heterogeneous microstructure consisting of high transformation temperature lamellar carbides has very low impact energy under severe conditions of testing. This is illustrated in Figure 14 showing photomicrographs of specimens of a .25 C Mn-Mo armor plate heat treated by two different procedures to equivalent tensile strength and hardness levels.

Figures 15, 16, and 17 illustrate typical microstructures observed in Unionmelt and hand welded plates. Table VI gives results of V notch Charpy tests for bars taken transverse to weld with base of notch located at various distances from fusion line.

The two Unionmelt welded plates show low impact energy for the coarse grained, high transformation temperature carbide microstructure adjacent to the fusion line. At a distance of approximately 1/8 to 1/4 inch from the fusion line, the grain size decreases, the carbides are finer but are recognized as high transformation temperature products when examined at high magnification, the hardness is a maximum, and the impact energy a minimum. At a distance of approximately 5/16 inch from the fusion line there is a zone of incomplete austenitization (islands of martensite in a matrix of low carbon non-austenitized structure and coarse tempered carbides*). At greater distances the size and number of austenitized islands decrease and finally at the outer edge of the heat-affected zone is a narrow band of base metal which has been tempered where the heat of welding exceeded the original draw temperature. At approximately 3/8 inch from the fusion line no effect of the heat of welding is evident. Impact energy increases through the tempered zone and reaches a maximum in the tempered zone. The photographs and discussion apply to heat-affected zones of second Unionmelt pass, but the same principles apply to the first pass heat-affected zone except that the structures of the first pass are somewhat tempered by the heat of the second pass.

Hand welded 1-1/2 inch thick plates generally have relatively high impact values through the heat-affected zone associated with a microstructure of very fine uniformly distributed carbides resulting from formation of martensite in one welding pass and tempering by subsequent welding passes. Heat-affected zone impact values of the two hand welded plates (Figure 16 and Table VI) are considerably higher than for the two Unionmelt plates. A few areas of high transformation temperature carbides were present in these two plates as a result of the use of 1/2 inch diameter electrodes (see discussion of fracture test). The difference in impact energy level for these two plates appears to be largely due to directional properties. Both plates are very dirty and rolling direction is parallel to leg weld in Midland plate RE-113 and transverse to leg weld (not in accordance with specification) for Midland plate CR-45 as is apparent from distribution of inclusions in photomicrographs.

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* In certain alloy steels, e.g., high Si, equiaxed ferrite may be present in this zone.

The microstructure of the heat-affected zones of two ferritic hand welded 1/2 inch thick plates (Figure 17) showed some areas of high transformation temperature carbides, but most of the zone was of tempered martensite. Charpy impact values (Table VI) are higher for weld heat-affected zone than for unaffected plate, the former having been tempered by the heat of welding to a considerably lower hardness than the base metals (see Table III and Figure 5).

b. Fusion Zones - There is a pronounced tendency for austenitic hand welded plates to fail through the bond zone and this tendency is an indication of inferior ballistic performance as discussed in connection with the bend test. Careful examination of ballistic and bend test fractures disclosed three separate conditions which may lead to fusion zone failures: (1) Lack of fusion and fusion zone cracks. Lack of fusion at the root of New York Air Brake Unionmelt plates was disclosed in several tests and failure usually proceeded through this defect in bend tests. No extensive crack systems were observed.* A few small cracks observed on macroexamination appear to be local defects which did not influence bend or tension test results to an appreciable extent. Photomicrographs in Figure 17 illustrate types of cracking observed. (2) Precipitation of carbides at weld-plate interface. Failure right at the bond line has been observed to a limited extent in a few plates. A characteristic very fine grained crystalline fracture is observed. Microexamination indicates that this condition is caused by a heavy precipitation of carbides at the weld-plate interface on reheating by subsequent welding passes as illustrated in the upper two photomicrographs of Figure 18. Heating a hand welded austenitic bend bar at 1350° F. for one hour produced a heavy carbide precipitation and caused the bar to break without deformation and almost entirely along the tempered interface. Very limited carbide precipitation occurs in hand welded plates, but the condition tends to be more serious when large electrodes are used and in Unionmelt welded plates. The presence of a very low impact energy heat-affected zone in most of the Unionmelt plates afforded an easier path of failure. Preheating or stress relieving of austenitic welds would probably favor precipitation of carbides and interface failures. (3) Linear precipitation of nonmetallics in weld metal adjacent to fusion line. The majority of fusion zone failures proceed through the weld metal a few thousandths of an inch from the true fusion line. The fracture has the characteristic scaled appearance of plate Midland RE-104 in Figure 11. Microscopic examination of a number of austenitic welds reveals a fine precipitation of nonmetallic inclusions lined up parallel to the fusion line. This condition is illustrated in the two center photomicrographs of Figure 18. The lining up is in contrast to the random distribution of nonmetallics throughout the remainder of the weld metal. An attempt is being made to connect this phenomenon to the observed tendency for greater fusion zone cracking in austenitic welds made with certain armor compositions, and photomicrographs are now available which clearly indicate that a majority of fusion zone failures proceed through the area of lined-up inclusions.

* Extensive heat-affected zone crack systems which undoubtedly influence ballistic results have been observed in American armor weldments made with ferritic electrodes with organic type coating and in German welds made with high carbon high alloy armor and various unclassified electrodes. (WAL Reports Nos. 642/115 and 710/608)

When lined-up inclusions are present, the geometry of the weld is usually the determining factor as to the extent of fusion zone failure. Midland Plates RE-104 and 113 (Figure 11) both show large numbers of lined-up inclusions but the geometry of the latter weld is much superior and so are the ballistic and bend test results. The main benefit obtained from the so-called "annealing bead" technique appears to be in devel ping a geometry with less tendency toward initiation of fusion zone failures.

In austenitic Unionmelt welded plates the inclusions are larger and lined up at a greater distance from the fusion zone. Inferior heat-affected zone properties preclude failure through the weld-fusion area, but plate New York 46 (high alloy with comparatively good heat-affected zone) failed partially through the region of lined-up nonmetallics (see Figure 10). No lining up of weld inclusions has been observed in ferritic welds regardless of type of electrode covering.

c. Weld Metals - Fractures of all austenitic welds were fibrous and had high impact energies (see Table VI); therefore were not studied microscopically. The manually deposited Mn-Mo ferritic weld metal was comparatively good and the Unionmelt ferritic very poor in impact energy (Table VI). Photomicrographs of both weld metals are shown in Figure 18. The finer more uniform distribution of carbides in the hand weld indicates better properties than could be expected of the Unionmelt weld metal, but the presence of high temperature transformation carbides in both welds indicate poor impact properties under very severe testing conditions as confirmed by the Charpy values at subnormal testing temperatures.

TABLE I

Ballistic Shock Test Results

Plate No.	Projectile	Rd. No.	Eccentricity (center impact to center weld) in.	Vel. f/s	Weld Cracking (within 1/8 in. of weld) in.	Plate Cracking (outside 1/8 in. of weld) in.
1-1/2 Inch Thick - Austenitic Hand Welded						
Midland RE-104	75 mm. T-21	1	3/4	1116	15-1/4	0
		2	3/4	1119	20	0
Midland RE-113	"	1	1/2	1109	4-3/4	0
		2	1-3/4	1152	0	0
		3	3/4	1153	8	0
Midland CR-45	"	1	1	1105	4	0
		2	1-1/4	1175	0	0
		3	1-1/2	1241	0	0
		4	0	1315	18	5-1/4
Ford W-235	"	1	3/4	1098	5	0
		2	1-1/4	1191	10-1/4	0
1-1/2 Inch Thick - Austenitic Unionmelt Welded						
New York 41	75 mm. T-21	1	1/4	1095	9-3/4	0
		2	1-1/4	1198	36	0
New York 42	"	1	1/4	1095	12-3/4	0
		2	1/4	1196	17-1/2	0
New York 44	"	1	1/4	1107	12-1/2	0
		2	1	1197	18-3/4	0
New York 45	"	1	1-3/4	1107	0	0
		2	1	1118	17-3/4	0
		3	1/2	1198	5	2-1/4
		4	1/2	1196	22	0
New York 46	"	1	1/4	1106	14	0
		2	1	1198	12	0
		3	0	1196	22	0
New York 47	"	1	0	1106	17-3/4	0
		2	3/4	1196	4-3/4	0
		3	3/4	1199	19-1/4	0
New York 48	"	1	3/4	1084	17-3/4	0
		2	0	1196	17-3/4	0
Midland CR-25	"	1	0	1099	6-3/4	0
		2	3/4	1099	5-1/4	0

TABLE I (Cont. - p.2)

Plate No.	Projectile	Rd. No.	Eccentricity (center impact to center weld) in.	Vel. f/s	Weld Cracking (within 1/8 in. of weld) in.	Plate Crackin (outside 1/8 in. of weld) in.
1 Inch Thick - Austenitic Hand Welded						
Gen. Motors		1	0	1101	2-1/2	0
Truck &	57 mm.	2	2-1/4	1135	0	0
Coach 35	T-1	3	1	1140	11-1/4	0
Cadillac	75 mm.	1	1-3/4	756	1/2	0
143	T-21	2	1-1/4	783	18	0
Cadillac	"	1	2	756	5	0
140		2	1-3/4	767	1/2	0
		3	3/4	782	12	0
Cadillac	"	1	1	757	13-1/2	0
167		2	1-1/2	752	10	2-1/2
1 Inch Thick - Austenitic Unionmelt Welded						
Gen. Motors		1	3-1/4	1102	0	0
Truck &	57 mm.	2	1/2	1147	12-1/2	2-1/2
Coach 34	T-1	3	1/2	1097	1/4	0
		4	3-1/2	1083	0	0
		5	1/4	1144	16-3/4	2
3/4 Inch Thick - Austenitic Unionmelt Welded						
Fisher	75 mm.	1	1/2	789	13-1/2	0
U-37	T-21	2	1-1/4	783	8	3-1/2
		3	1-1/2	799	11	1-1/8
		4	1-1/4	795	9-1/8	2
Fisher	57 mm.	1	2-1/8	808	0	0
U-39	T-1	2	7/8	800	4	5-1/2
		3	1-1/2	813	5-1/8	3
		4	1-1/4	800	5-1/2	4-1/2
1/2 Inch Thick - Austenitic Hand Welded						
Cadillac	37 mm. HE	1	2	2527	0	0
178	M-54	2	1/2	2513	0	0
		3	2	2519	0	0
		4	4-1/2	2525	0	0
Fisher	"	1	3	2514	0	0
H-110		2	1-1/8	2519	15	0
		3	3/8	2519	16-3/4	0
General	"	1	2-3/4	2600	0	0
Motors		2	4-1/4	2600	0	0
Truck &		3	1-1/4	2600	0	0
Coach 18		4	4	2600	0	0
		5	6	2600	0	0
		6	2-1/4	2600	0	0
		7	3	2600	0	0

TABLE I (Cont. - p.3)

Plate No.	Projectile	Rd. No.	Eccentricity (center impact to center weld) in.	Vel. f/s	Weld Cracking (within 1/8 in. of weld) in.	Plate Cracking (outside 1/8 in. of weld) in.
1/2 Inch Thick - Austenitic Unionmelt Welded						
General Motors Truck & Coach 3	37 mm. M-52	1	2-1/2	670	0	0
		2	2	696	0	0
		3	3-1/2	710	0	0
		4	0	672	0	0
		5	3	689	0	2
		6	0	653	2-1/4	0
1/2 Inch Thick - Ferritic Hand Welded						
Fisher H-98	37 mm. HE M-54	1	3/4	2577	1	0
		2	1/2	2587	14-1/2	2-1/2
Fisher H-100	"	1	1/4	2517	0	0
		2	0	2556	15-1/2	0
Fisher H-101	"	1	1	2515	8	0
		2	1/4	2521	11-1/2	0
Fisher H-103	"	1	1	2509	2	0
		2	1/2	2533	3-1/4	10
		3	1/2	2528	9	12
Fisher H-111	"	1	1-3/4	2525	0	0
		2	1-1/2	2516	0	0
		3	3/4	2516	7	0
		4	3/4	2520	0	0
Fisher H-114	"	1	1-1/4	2513	1-1/2	0
		2	1/2	2516	0	0
		3	2-1/4	2565	0	0
		4	3/4	2564	8	0
Fisher H-115	"	1	1-1/2	2513	0	0
		2	1-3/4	2518	0	0
		3	1-3/4	2518	0	0
		4	1-1/2	2592	0	0
Fisher H-116	"	1	3/4	2511	3	0
		2	2-1/2	2534	3	4-1/2
		3	2	2534	4-3/4	1/2
		4	0	2537	0	1/2
1/2 Inch Thick - Ferritic Unionmelt Welded						
Fisher U-44	37 mm. HE M-54	1	1	2515	0	0
		2	3/4	2513	11-1/2	0
General Motors Truck & Coach Y-1	"	1	3/4	2600	6-1/2	6-3/4
		2	4	2600	0	0
		3	2-1/2	2600	0	0
		4	3	2600	1-1/2	0
		5	1-3/4	2600	2	0

TABLE II

Weld Joint Transverse Tensile Test Results

Plate No.	Thickness (in.)	Welding Process	Tensile Strength psi.	% Elongation		Path of Fracture					Remarks
				1" gage	2" gage	crn.	body	root	body	crn.	
Midland RE-104	1-1/2	Manual Austenitic	112,400	13.0	10.5	W,FZ	W,FZ	W,FZ	FZ	FZ	Undercut at crowns. Incomplete fusion in body.
			112,200	12.0	9.0	W,FZ	W,FZ	W,FZ	W,FZ	FZ	Ditto. Porosity.
Midland RE-113	"	"	103,300	20.0	10.5	W	W,FZ	W,FZ	FZ	FZ	Incomplete fusion in root, slag inclusion in body, porosity. Undercut at crown.
			99,300	23.0	12.5	W	W	W,FZ	W,FZ	W	Incomplete fusion at root.
Midland CR-45	"	"	114,600	25.0	14.0	W	W	FZ	W	W	" " " "
			116,000	22.0	16.5	W	W	W	W	W	
Ford W235*	"	"	103,500	body	13.6	-	W	-	-	-	
			102,500	"	10.0	-	-	-	W	-	Slight porosity.
			98,000	root	3.6	-	-	W	-	-	Incomplete fusion between beads.
New York 41	"	Unionmelt Austenitic	84,000	25.0	13.5	W	W	W,FZ	W	W	Incomplete fusion at root.
			86,600	27.0	13.5	W	W	FZ	W	W	" " " "
New York 42	"	"	92,600	27.0	14.0	W	W	FZ	W	W	" " " "
			83,000	27.0	14.0	W	W	FZ	W	W	" " " "
New York 44	"	"	98,200	21.0	11.0	W	W,HAZ	FZ	HAZ	FZ	" " " "
			91,000	26.0	13.5	W	W,FZ	FZ	W	W	" " " "
New York 45	"	"	104,500	34.0	19.0	W	W	P,FZ	P	FZ	Undercut at crown.
			101,800	21.0	13.0	W	W	FZ	FZ	FZ	Incomplete fusion at root.
New York 46	"	"	88,000	31.0	16.0	W	W	FZ	W	W	
			100,000	23.0	13.5	W	W	FZ	W,FZ	FZ	Incomplete fusion at root.

* = .357 dia. tensile bars.

W = Weld
FZ = Fusion zone
P = Plate
HAZ = Heat-Affected Zone

TABLE II (Cont. - p.2)

Plate No.	Thick-ness (in.)	Welding Process	Tensile Strength psi.	% Elongation 1"gage	2"gage	Path of Fracture crn.	body	root	body	crn.	Remarks
New York 47	1-1/2	Unionmelt Austenitic	96,000	31.0	16.0	W	W	W	W	W	
			86,500	26.0	14.0	W	W	FZ	W	W	Incomplete fusion at root.
New York 47*	"	"	108,000*	body	22.9	–	W	–	–	–	
			105,500*	"	16.4	–	–	–	W	–	
			74,500*	root	2.9	–	–	W,FZ	–	–	Incomplete fusion.
New York 48	"	"	89,700	27.0	14.0	W	W	FZ	W	W	Incomplete fusion at root.
			85,500	26.0	14.0	W	W	FZ	W	W	" " " "
Midland CR-25	"	"	106,000	20.0	10.5	W	W,FZ	FZ	W	W,FZ	" " " "
			100,000	25.0	1[illegible]	W	W	FZ	W	W	" " " "
Gen.Motors Truck 35	1	Manual Austenitic	123,200	10.0	6.0	W	W	FZ	FZ	W	
			125,000	13.0	7.0	FZ	W,FZ	FZ	W,FZ	W	
Cadillac 140	"	"	111,000	17.0	9.0	W	W	W	W	W	
			92,000	17.0	9.0	W	W	W,FZ	W	W	Incomplete fusion in root.
Cadillac 143	"	"	113,000	22.0	11.5	W	FZ	FZ	W	W	Incomplete fusion in root & body.
			107,400	18.0	9.5	W	W	FZ	W	W	" " " " " "
Cadillac 167	"	"	121,600	19.0	10.5	W	W	W	W	W	
			112,600	20.0	10.5	W	W	W	W	W	
Gen.Motors Truck 34	"	Unionmelt Austenitic	110,800	25.0	13.0	W	W	W,FZ	W,FZ	W	Incomplete fusion at root.
			109,400	25.0	13.0	W	W	W	W	W	
Fisher U-37	3/4	"	108,100	28.0	14.5	W	W	W	–	–	
			97,000	30.0	15.5	W	W	W	W	W	
Fisher U-39	"	"	99,200	24.0	12.5	FZ	HAZ	W	–	–	Porosity.
			96,300	25.0	13.0	W	W	W	–	–	
Cadillac 178	1/2	Manual Austenitic	131,200	24.0	12.5	W,FZ	P,FZ	P,FZ	W	W	Undercut at crown.
			114,000	16.0	9.0	FZ	FZ	FZ	W,FZ	W	" " "
Fisher H-110	"	"	91,300	8.0	5.5	W	W	W	–	–	Porosity.
			92,100	11.0	6.0	W	FZ	W	–	–	Incomplete fusion in body.

* = .357 dia. tensile bars.

TABLE II (Cont. - p.3)

Plate No.	Thickness (in.)	Welding Process	Tensile Strength psi.	% Elongation 1"gage	% Elongation 2"gage	Path of Fracture crn.	body	root	body	crn.	Remarks
Gen.Motors Truck 18	1/2	Manual Austenitic	125,000	9.0	6.0	FZ	FZ	FZ	-	-	Undercut at root.
			117,000	6.0	4.0	W	FZ	FZ	-	-	
Gen.Motors Truck 3	"	Unionmelt Austenitic	30,500	4.0	4.0	W	W	W	-	-	Reinforcement removed on half of weld - broke at notch.
			98,800	4.0	3.5	W	W	W	-	-	Ditto.
Fisher H-98	1/2	Manual Ferritic	114,100	29.0	15.5	W	W	W	-	-	
			113,300	28.0	15.0	W	W	W	-	-	
Fisher H-100	"	"	131,400	17.0	10.5	W	P	P	-	-	
			123,600	25.0	15.0	W	W	FZ	-	-	Incomplete fusion at root.
Fisher H-101	"	"	115,700	25.0	13.5	W	W	W	-	-	
			115,000	26.0	13.5	W	W	W	-	-	
Fisher H-103	"	"	108,800	18.0	10.5	HAZ	W	W	-	-	Incomplete fusion at root.
			120,800	23.0	14.5	W	W	W	-	-	
Fisher H-111	"	"	110,800	22.0	13.0	W	W	W	-	-	Porosity.
			115,400	17.0	9.0	W	W	W	-	-	"
Fisher H-114	"	"	113,000	28.0	15.0	W	W	W	-	-	
			109,000	30.0	15.5	W	W	W	-	-	
Fisher H-115	"	"	110,000	23.0	12.5	W	W	W	-	-	
			113,600	22.0	11.5	W	W	W	-	-	
Fisher H-116	"	"	119,200	23.0	12.0	W	W	W	-	-	
			114,000	27.0	13.0	W	W	W	-	-	
Fisher U-44	"	Unionmelt Ferritic	92,000	26.0	14.0	W	W	W	-	-	
			91,000	26.0	13.5	W	W	W	-	-	
Gen.Motors Truck 41	"	"	110,200	7.0	5.0	W	W	FZ	-	-	Failure at junction of plate & weld metal at root.
			107,000	8.0	4.5	W	W,P	FZ	-	-	Ditto.

TABLE III

Summary of Results from Vickers-Brinell Hardness Surveys

Plate Number	Thickness (in.)	Welding Process	Weld Metal Hardness	Hardness of Heat-Affected Zone Max.	Hardness of Heat-Affected Zone Min.	Hardness of Unaffected Plate
Midland RE-104	1-1/2	Manual Austenitic	224 - 292	560	245	256 - 279
Midland RE-113	"	" "	221 - 274	536	249	266 - 276
Midland CR-45	"	" "	253 - 348	446	247	317 - 330
Ford W235	"	" "	213 - 283	464	285	292 - 306
New York 41	"	Unionmelt Austenitic	249 - 299	442	247	272 - 302
New York 42	"	" "	236 - 345	488	285	292 - 306
New York 44	"	" "	236 - 330	536	268	289 - 312
New York 45	"	" "	240 - 348	373	228	294 - 302
New York 46	"	" "	225 - 286	606	292	302 - 319
New York 47	"	" "	193 - 215	413	254	279 - 309
New York 48	"	" "	232 - 270	380	270	287 - 304
Midland CR-25	"	" "	194 - 224	397	268	294 - 314
General Motors Truck 35	1	Manual Austenitic	268 - 345	519	302	327 - 342
Cadillac 140	"	" "	253 - 351	446	268	327 - 354
Cadillac 143	"	" "	225 - 281	525	302	322 - 333
Cadillac 167	"	" "	242 - 302	373	251	325 - 354
General Motors Truck 34	"	Unionmelt Austenitic	198 - 254	413	253	322 - 342
Fisher U-37	3/4	" "	198 - 348	314	221	264 - 297
Fisher U-39	"	" "	176 - 240	380	251	358 - 370
Cadillac 178	1/2	Manual Austenitic	191 - 247	397	253	370 - 375
Fisher H-110	"	" "	193 - 268	429	228	317 - 336
General Motors Truck 18	"	" "	247 - 314	417	297	330 - 373
General Motors Truck 3	"	Unionmelt Austenitic	225 - 333	421	279	363 - 376

TABLE III (Cont. - p.2)

Plate Number	Thickness (in.)	Welding Process	Weld Metal Hardness	Hardness of Heat-Affected Zone Max.	Hardness of Heat-Affected Zone Min.	Hardness of Unaffected Plate
Fisher H-98	1/2	Manual Ferritic	235 - 266	292	206	319 - 339
Fisher H-100	"	" "	266 - 285	387	235	381
Fisher H-101	"	" "	233 - 276	342	251	380 - 391
Fisher H-103	"	" "	228 - 281	468	219	351 - 354
Fisher H-111	"	" "	238 - 285	339	221	370 - 381
Fisher H-114	"	" "	233 - 264	314	213	311 - 330
Fisher H-115	"	" "	228 - 268	345	245	370
Fisher H-116	"	" "	238 - 254	330	236	325 - 327
Fisher U-44	"	Unionmelt Ferritic	188 - 219	264	207	294 - 312
General Motors Truck Y-1	"	" "	235 - 260	405	243	325 - 347

TABLE IV

Weld Joint Fracture Test Results

Plate Number	Thickness (in.)	Welding Process	Plate Fracture	Weld Metal Fracture	Heat-Affected Zone Fracture	Remarks
Midland RE-104	$1\frac{1}{2}$	Manual Austenitic	Fibrous	Fibrous	Fibrous	
Midland RE-113	"	" "	"	"	Fibrous with small crystalline patches	Severely laminated plate
Midland CR-45	"	" "	"	"	Ditto	
Ford W-235	"	" "	"	"	Fibrous	
New York 41	"	Unionmelt Austenitic	"	"	Crystalline	
New York 42	"	" "	"	"	"	
New York 44	"	" "	"	"	"	
New York 45	"	" "	"	"	"	Laminated plate
New York 46	"	" "	"	"	Fibrous & silky	
New York 47	"	" "	"	"	Crystalline	
New York 48	"	" "	"	"	"	
Midland CR-25	"	" "	"	"	Fibrous, small crystalline patches on first pass, crystalline zone bodering weld on 2nd pass.	Laminated plate
Gen.Motors 35	1	Manual Austenitic	"	"	Fibrous	Incomplete penetration at root
Cadillac 140	"	" "	"	"	"	Severely laminated plate. Porosity in weld metal.
Cadillac 143	"	" "	"	"	"	Laminated plate
Cadillac 167	"	" "	"	"	"	
Gen.Motors 34	"	Unionmelt Austenitic	"	"	Crystalline	Laminated plate
Fisher U37	3/4	" "	"	"	Crystalline, fibrous at seal bead	
Fisher U39	"	" "	"	"	Ditto	

TABLE IV (Cont. - p.2)

Plate Number	Thickness (in.)	Welding Process	Plate Fracture	Weld Metal Fracture	Heat-Affected Zone Fracture	Remarks
Cadillac 178	1/2	Manual Austenitic	Fibrous	Fibrous	Fibrous	
Fisher H-110	"	" "	"	"	"	
Gen.Motors 18	"	" "	Some crystal-linity	"	"	Laminated plate
Gen.Motors 3	"	Unionmelt Austenitic	Fibrous	"	Fibrous & crystalline	
Fisher H-98	1/2	Manual Ferritic	"	"	Fibrous with cyrstalline patch	
Fisher H-100	"	" "	"	"	Fibrous	
Fisher H-101					Fibrous with crystalline patch	
Fisher H-103	"	" "	"	"	Ditto	
Fisher H-111	"	" "	"	"	"	
Fisher H-114	"	" "	"	"	"	
Fisher H-115	"	" "	"	"	Fibrous	
Fisher H-116	"	" "	"	"	"	
Fisher J-44	"	Unionmelt Ferritic	"	Crystalline	Crystalline	
Gen.Motors Y-1	"	" "	"	"	"	

TABLE V

Bend Test Results*

Plate Number	Thickness (in.)	Welding Process	Path of Fracture crn.	body	root	body	crn.	Remarks
Midland RE-104	1-1/2	Manual Austenitic	FZ	FZ	FZ	FZ	W	Incomplete fusion in body and root
Midland RE-113	"	"	W	W	FZ		W	Incomplete fusion at root; porosity
Midland CR-45	"	"	W	W	W, FZ	W	W	
Ford W-235	"	"	-	-	-	-	-	
New York 41	"	Unionmelt Austenitic	-	-	-	-	-	
New York 42	"	"	W	FZ	FZ, HAZ	HAZ	W, HAZ	Incomplete fusion at root
New York 44	"	"	HAZ	HAZ	P	HAZ	FZ	
New York 45	"	"	FZ	HAZ	P	HAZ	W	
New York 46	"	"	W	FZ	FZ	W	W	
New York 47	"	"	FZ	HAZ	P	P	HAZ	
New York 48	"	"	W	W	FZ	HAZ	HAZ	Incomplete fusion at root
Midland CR-25	"	"	W	W	FZ	W, HAZ	W	
Gen. Motors Truck 35	1	Manual Austenitic	W	W, FZ	FZ	FZ	FZ	Incomplete fusion at root
Cadillac 140	"	"	FZ	FZ, P	FZ, P	FZ, P	FZ, P	Incomplete fusion at root
Cadillac 143	"	"	FZ, HAZ	P	P	P	W	
Cadillac 167	"	"	W	W	W	W	W	Geometry not representative
			W	W	FZ	FZ	FZ	
Gen. Motors Truck 34	"	Unionmelt Austenitic	W	W	HAZ	HAZ	W	
Fisher U-37	3/4	"	W	W	W	-	-	Tested as received - reinforcement removed. Test not severe enough. Duplicate bar did not break.
Fisher U-39	"	"	HAZ	HAZ	HAZ	-	-	Tested as received - reinforcement removed.

*Unless otherwise noted duplicate bars showed similar paths of fracture.

W = Weld P = Plate
FZ = Fusion zone HAZ = Heat-Affected Zone

TABLE V (Cont. - p.2)

Plate Number	Thickness (in.)	Welding Process	Path of Fracture crn.	body	root	body	crn.	Remarks
Cadillac 178	1/2	Manual	W,FZ	HAZ	FZ			As received - with reinforcement
		Austenitic	W	W	W			Reinforcement removed
Fisher H-110	"	"	W	W	W			Porosity & incomplete fusion
Gen. Motors Truck 18	"	"	FZ	FZ,HAZ	FZ,HAZ			Plate metal laminations opened up
Gen. Motors Truck 3	"	Unionmelt Austenitic	W	W	W			Reinforcement removed from half of weld; broke at notch.
Fisher H-98	"	Manual Ferritic	Not Tested					
Fisher H-100	"	"	Did not break					90° bend; as received - reinforcement removed.
Fisher H-101	"	"	Not Tested					
Fisher H-103	"	"	Not Tested					
Fisher H-111	"	"	W	W	W	W	W	As received - reinforcement removed
			Did not break					60° bend.
Fisher H-114	"	"	Did not break					90° bend; as received - reinforcement removed.
Fisher H-115	"	"	Not Tested					
Fisher H-116	"	"	Not Tested					
Fisher U-44	"	Unionmelt Ferritic	Not Tested					
Gen. Motors Truck Y-1	"	"	HAZ	HAZ	HAZ			As received - with reinforcement.
			W	W	W			Reinforcement removed.

TABLE VI

Results of V Notch Charpy Tests

(All bars taken transverse to weld)

Plate No.	Thickness (in.)	Armor Plate	Welding Process	Heat-Affected Zone Values - Ft. Lbs. Location of Notch*: Fusion Zone	1/8" from Fusion Line	1/4" from Fusion Line	5/16" from Fusion Line	3/8" from Fusion Line	Unaffected Plate
New York 44	1-1/2	Jones & Laughlin	Unionmelt Austenitic	23.9	10.5	18.1	---	52.4	42.0
New York 47	"	Carnegie-Illinois	"	15.5	14.2	11.8	35.8	---	38.2 - 40.5
Midland HE-113	"	Republic	Manual Austenitic	46.6	28.2	37.2	---	38.1	32.6 - 33.7
Midland CR-45	"	Carnegie-Illinois	"	45.8	64.7	98.9	---	84.5	69.4 - 70.3
Fisher H-115	1/2	Jones & Laughlin	Manual Ferritic	54.6	38.1	---	29.7	---	26.8
Fisher H-116	"	Great Lakes	"	48.0	49.4	---	65.6	---	35.

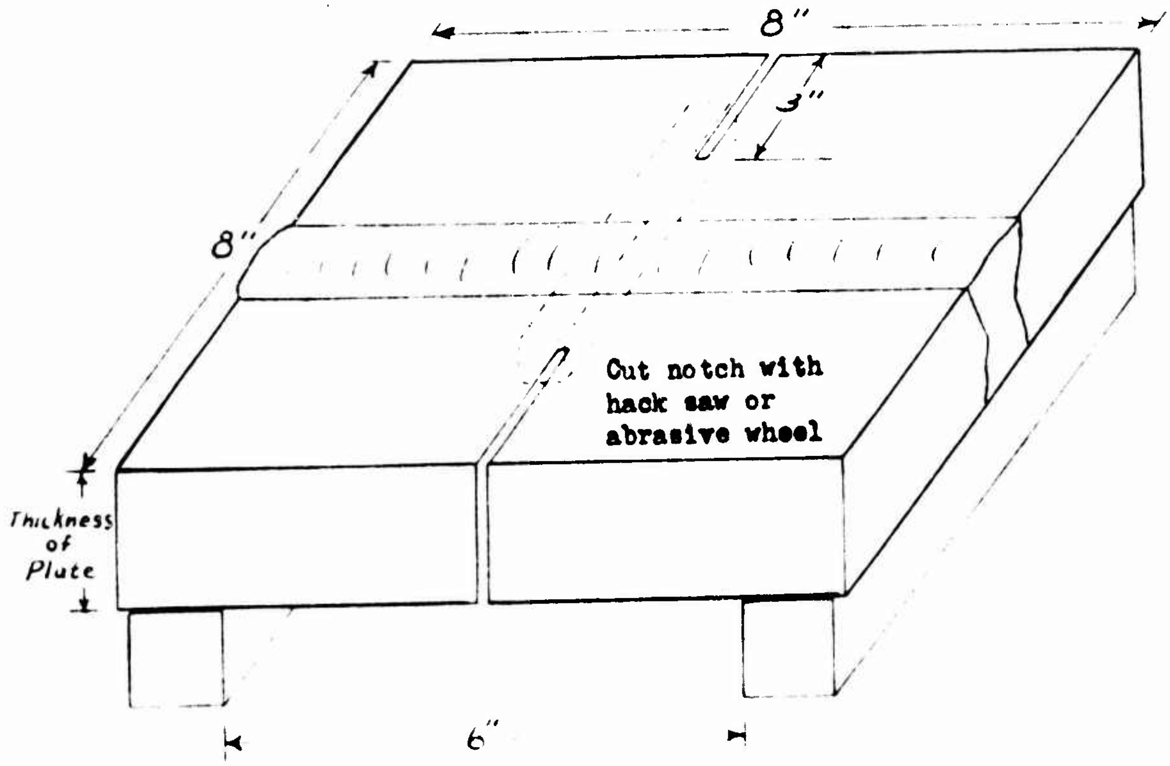
* Midwall in 1-1/2 inch thick plates

Plate No.	Thickness (in.)	Welding Process	Weld Charpy Values Location of Notch (center of weld)	Temperature of Testing 70°F.	0°	-40°F
New York 47	1-1/2	Unionmelt Austenitic	Root	46.3 ft.lbs.*		
			Body - Midwall	84.0		
Midland CR-45	"	Manual Austenitic	Root	51.7		
			Body - Midwall	52.1 - 54.		
Fisher U-44	1/2	Unionmelt Ferritic	Body	13.2 - 14.2	7.3	5.7
Fisher H-101	"	Manual Ferritic	Body	30.9 - 44.1	12.0	9.2

* .ncomplete fusion

Nick-Break Fracture Test of Weld Joint

1/2 x 1/2 x 4 inch bar used as striking block. 1 x 6 x 6 inch plate placed on top of bar to prevent damage to steam hammer or drop weight.



Support on six-inch span; break with one blow of drop weight or steam hammer

Figure 1

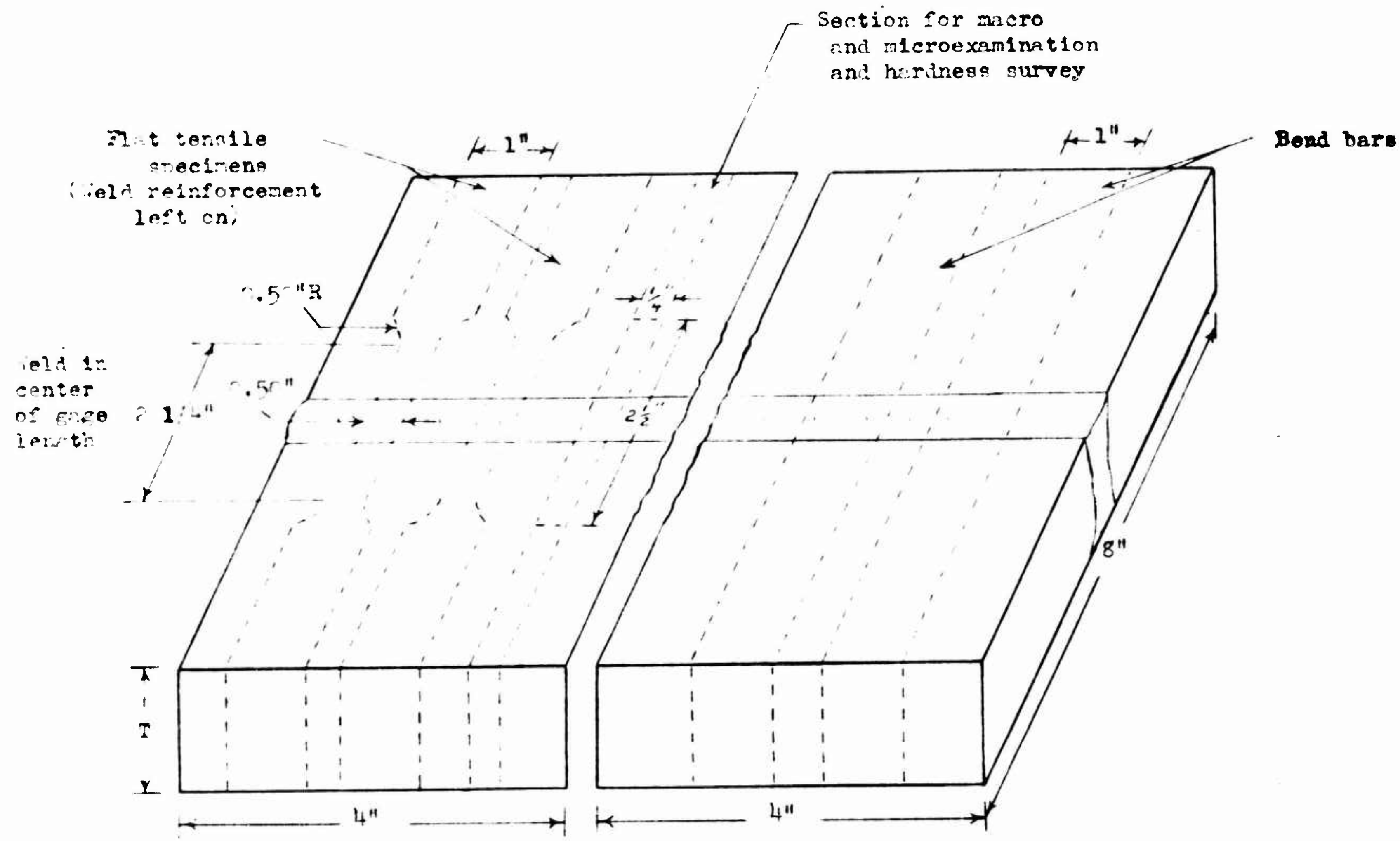


Figure 2. Layout and Dimensions of Bend Bars, Flat Tensile Specimens, and Section for Macro and Microexamination and Hardness Survey.

1½ INCH THICK, AUSTENITIC, UNIONMELT WELDED PLATE NEW YORK 48

1½ INCH THICK, AUSTENITIC, HAND WELDED PLATE MIDLAND CR45

1½ INCH THICK, AUSTENITIC, UNIONMELT WELDED PLATE NEW YORK 44

1 INCH THICK, AUSTENITIC UNIONMELT WELDED PLATE GENERAL MOTORS TRUCK 34

1 INCH THICK, AUSTENITIC, HAND WELDED PLATE CADILLAC 167

½ INCH THICK, FERRITIC, UNIONMELT WELDED PLATE FISHER U-44

½ INCH THICK, FERRITIC, HAND WELDED PLATE FISHER H-114

FIGURE 3 TYPICAL BROKEN TENSILE SPECIMENS [illegible]

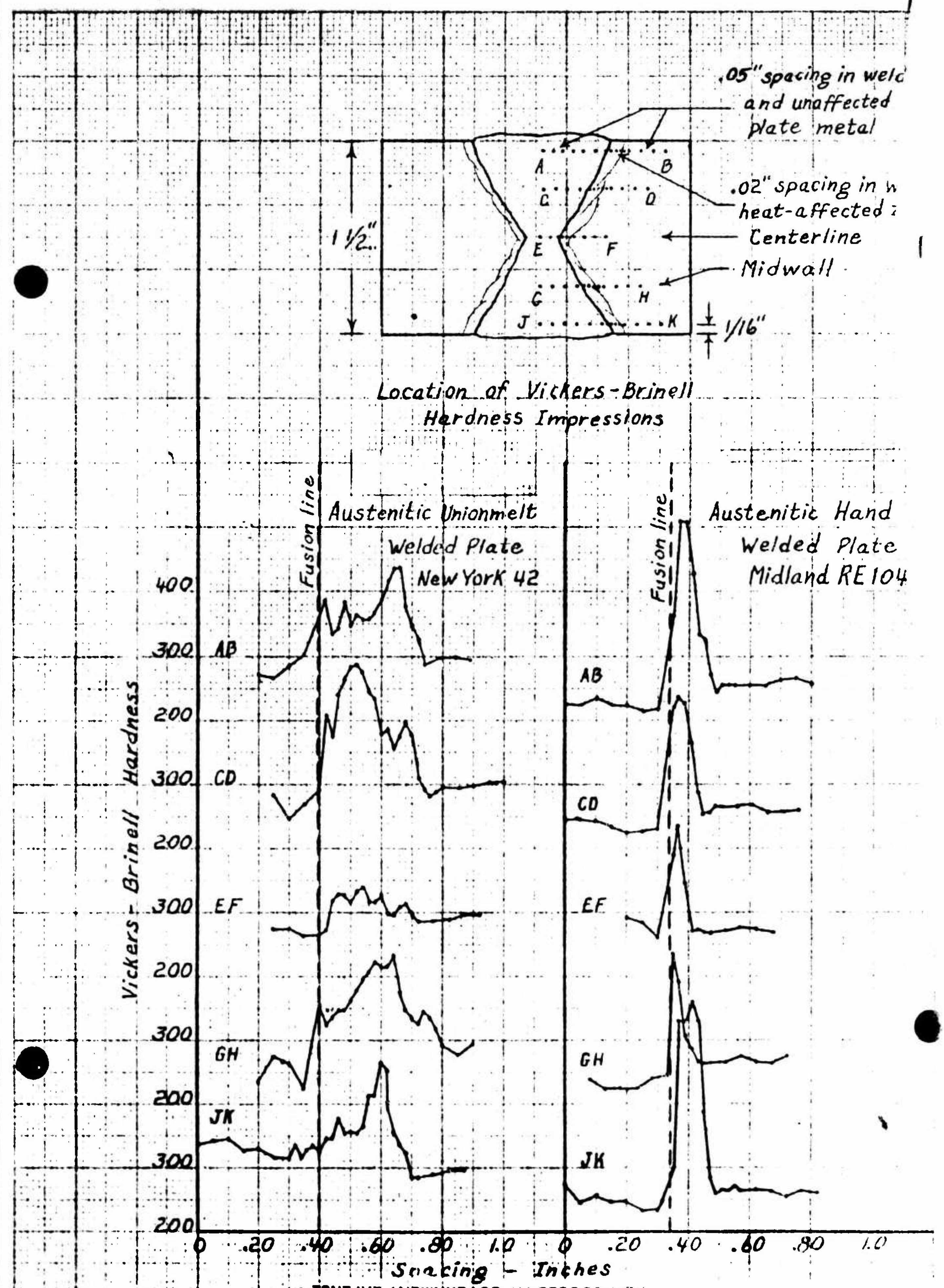


FIGURE 4 - ... INCH THICK PLATES

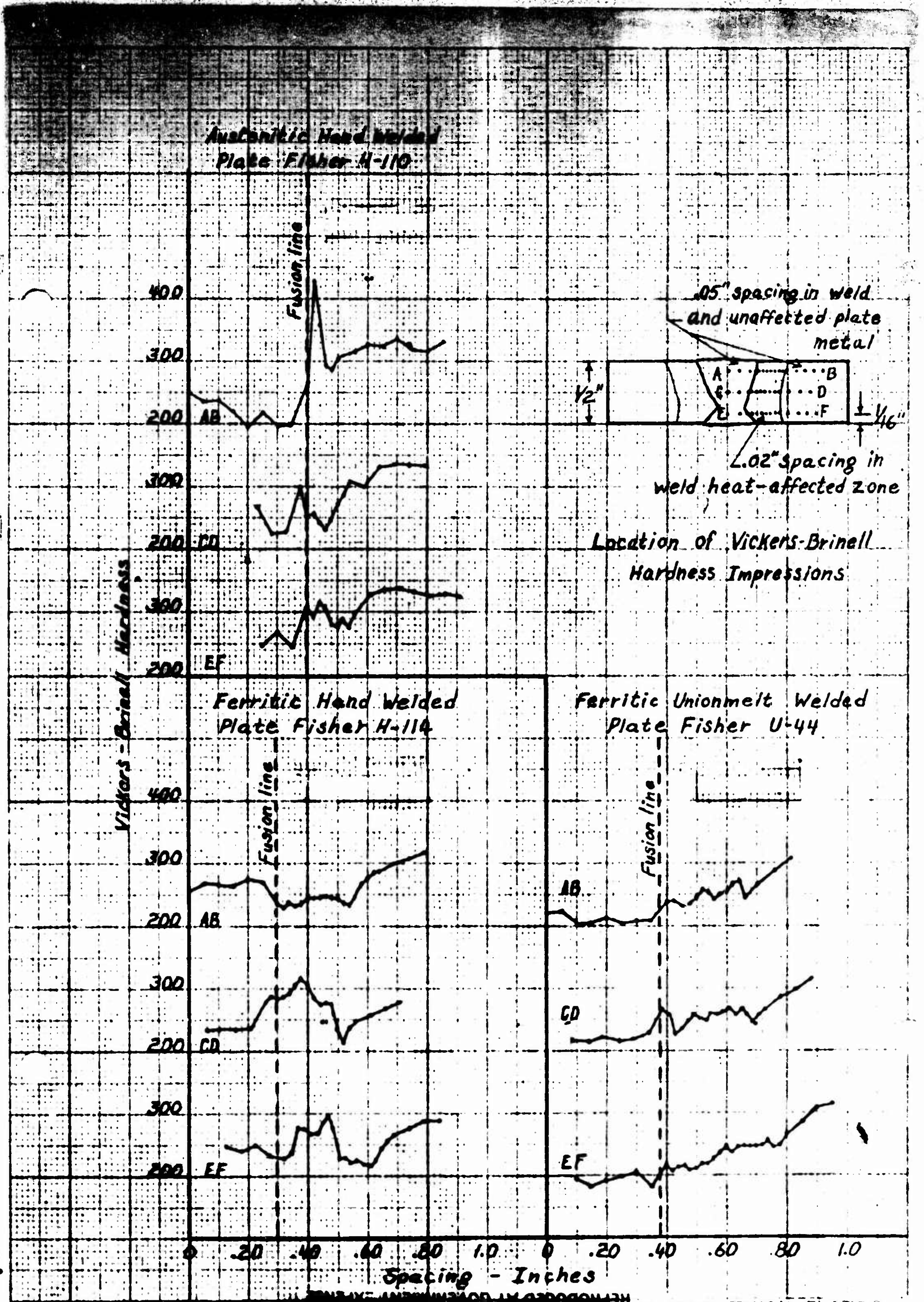


FIGURE 5. TY[illegible] ½ INCH THICK PLATES

Austenitic Hand Welded Plate
Midland RB 104

Austenitic Hand Welded Plate
Ford W-235

Austenitic Hand Welded Plate
Midland RB 113

Austenitic Unionmelt Welded
Plate New York 47

1 1/2 Inch Thick Test Plates

Austenitic Hand Welded Plate
Cadillac 140

Austenitic Hand Welded Plate
Cadillac 167

Austenitic Hand Welded Plate
Cadillac 143

Austenitic Unionmelt Welded Plat
Gen. Motors Truck 34

1 Inch Thick Test Plates

Figure 6. Macroetched Sections from Typical Test Plates

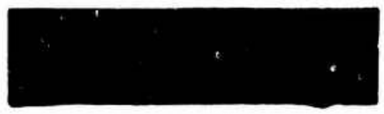
VTN.121-581

Austenitic Unionmelt Welded Plate
Fisher U 37

Austenitic Unionmelt Welded Plate
Fisher U 39

3/4 Inch Thick Test Plates

Austenitic Hand Welded Plate
Cadillac 178

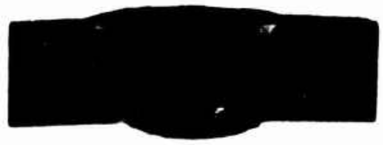


Ferritic Hand Welded Plate
Fisher H-114

Austenitic Hand Welded Plate
Gen. Motors Truck 18

Ferritic Unionmelt Welded Plate
Fisher U 44

Austenitic Unionmelt Welded Plate
Gen. Motors Truck 3



Ferritic Unionmelt Welded Plat
Gen. Motors Truck Y 1

1/2 Inch Thick Test Plates

WTN.121-582

FIGURE 7 MACROETCHED SECTIONS FROM TYPICAL TEST PLATES

1 1/2 Inch thick austenitic hand welded plates

1 1/2 Inch thick austenitic Unionmelt welded plates

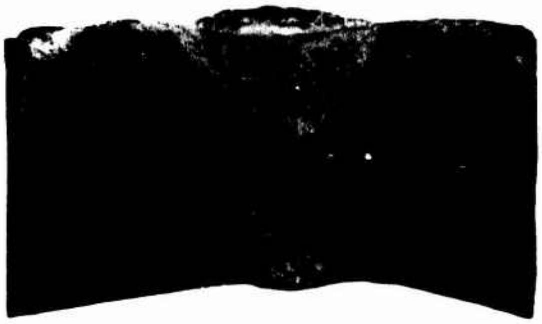


Plate: Midland KB 104
Max. size electrode: 5/16 in. dia.

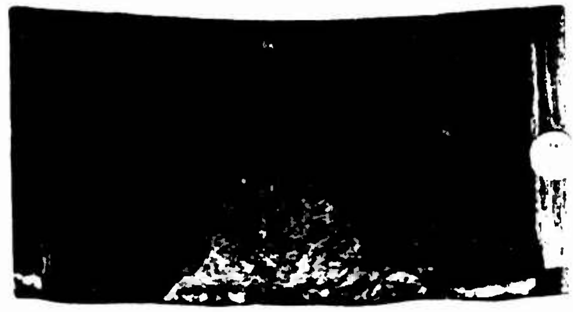


Plate: New York 45

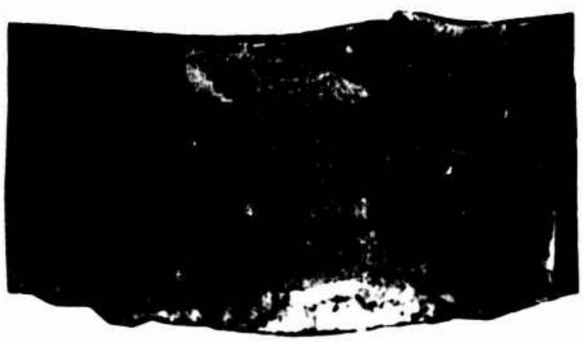


Plate: Midland KB 113
Max. size electrode: 1/2 in. dia.

Plate: New York 46

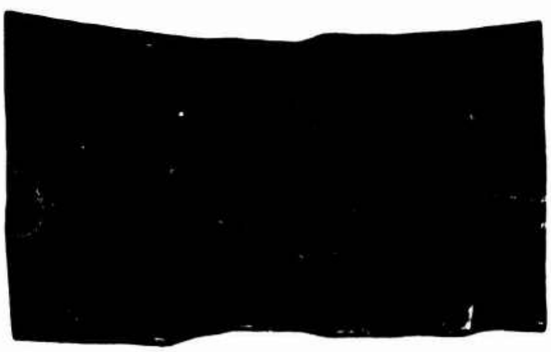


Plate: Midland CR 45
Max. size electrode: 1/2 in. dia.

Plate: Midland CR 25

WTN.639-6676

Figure 5. Typical Weld Joint Fractures.

CONTENTS

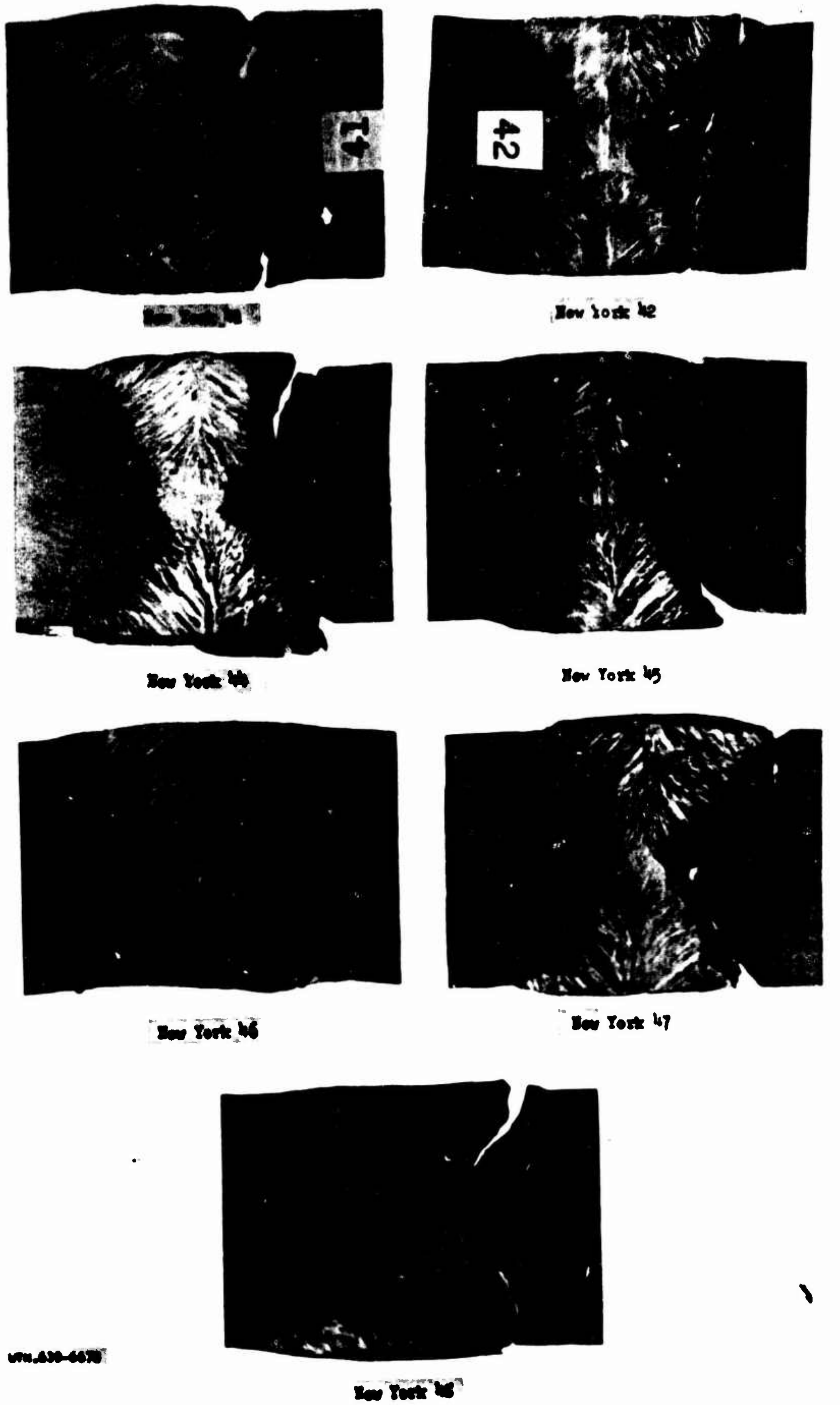
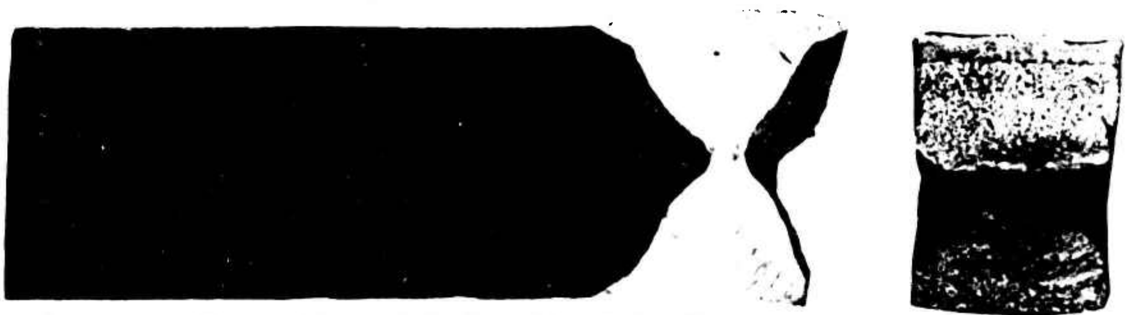


Figure 10. Aberdeen Proving Ground Photomacrographs of Sections through Ballistic Fractures.

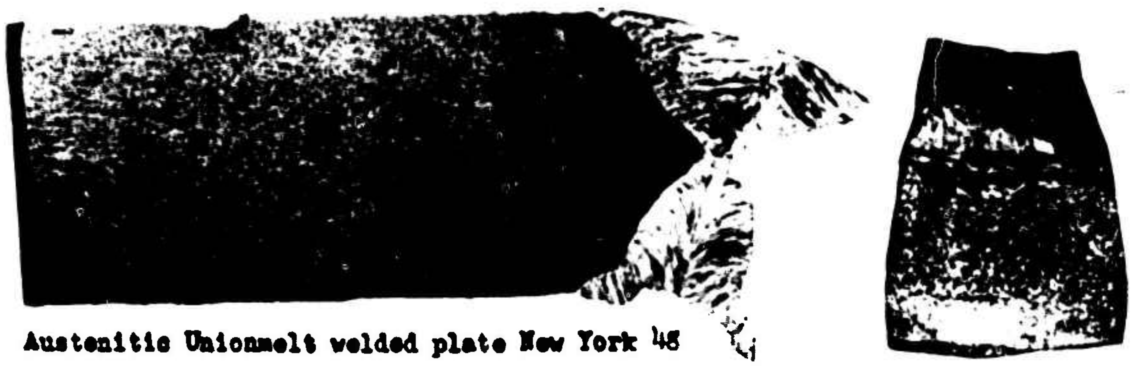
Austenitic hand welded plate Midland RB 104

Austenitic hand welded plate Midland RB 113



Austenitic Unionmelt welded plate New York 45

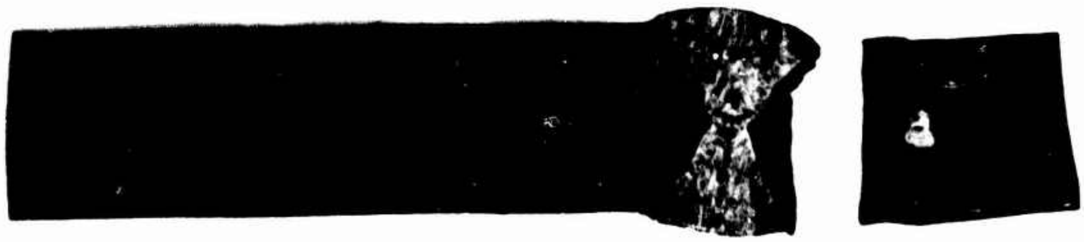
Austenitic Unionmelt welded plate New York 46



Austenitic Unionmelt welded plate New York 48

WTN.639-6679

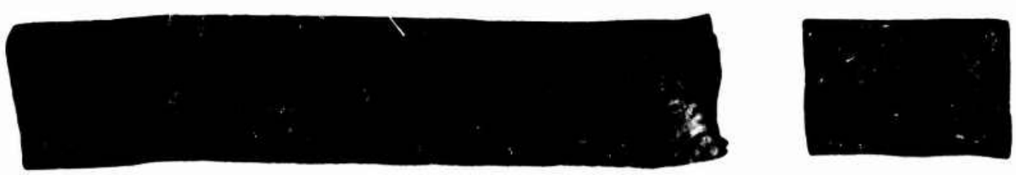
Figure 11. Fractures of Typical Bend Bars from 1 1/2 Inch Thick Test Plates.



1 Inch thick austenitic hand welded plate Cadillac 140

1 Inch thick austenitic hand welded plate Cadillac 167

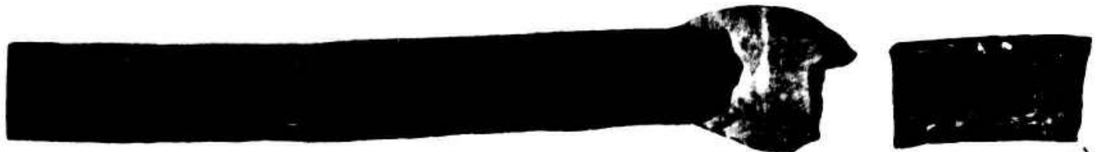
1 Inch thick austenitic Unionmelt welded plate General Motors Truck 34



3/4 Inch thick austenitic Unionmelt welded plate Fisher U 39 (as received-reinforcement removed)

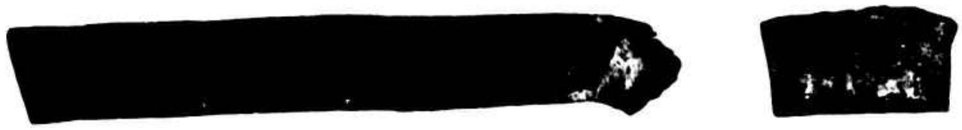
WTN.639-6680

Figure 12. Fractures of Typical Bend Bars from 1 and 3/4 Inch Thick Test Plates.

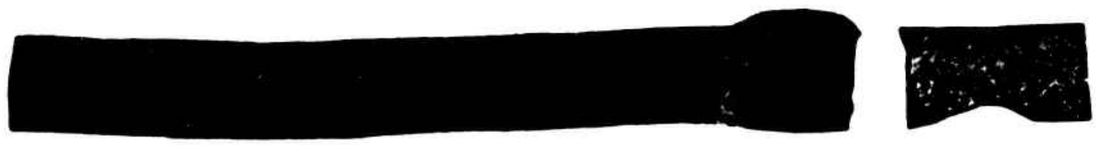


Hand welded austenitic plate Cadillac 178 (as received--with reinforcement)

Hand welded austenitic plate Cadillac 178 (reinforcement removed)



Hand welded austenitic plate Fisher H-110(as received--reinforcement removed)



Unionmelt welded ferritic plate General Motors Truck Y 1 (as received--with reinforcement)

Unionmelt welded ferritic plate General Motors Truck Y 1 (reinforcement removed)

Hand welded ferritic plate Fisher H-114 (as received--reinforcement removed)

WTN.639-6681

Figure 13. Fractures of Typical Bend Bars from 1/2 Inch Thick Test Plates.

X750 Picral
Water quenched and drawn.
Hardness: 30 Rc
Charpy Value: 49 ft. lbs.
Fracture: Fibrous

WTN.639-668Z

X750 Picral
Air cooled.
Hardness: 29 Rc
Charpy Value: 7.7 ft. lbs.
Fracture: Crystalline

Figure 14. Fracture Edges of 0.25 Carbon Mn-Mo Armor Plate Heat-Treated by Two Different Methods to Equivalent Tensile Strength and Hardness Levels.

Fusion line - Midwall | 1/8 inch from fusion line | 1/4 inch from fusion line | 5/16 inch from fusion line | 3/8 inch from fusion line

Plate New York 44 (Jones and Laughlin Armor)

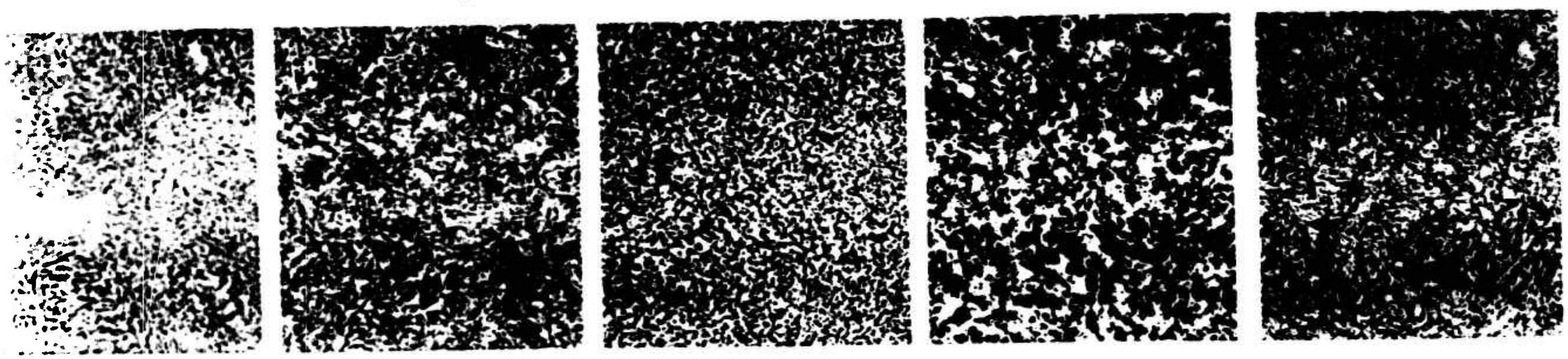


Plate New York 47 (Carnegie-Illinois Armor)

Figure 15. Microstructure of Heat-Affected Zones of Typical 1 1/2 Inch Thick [illegible]

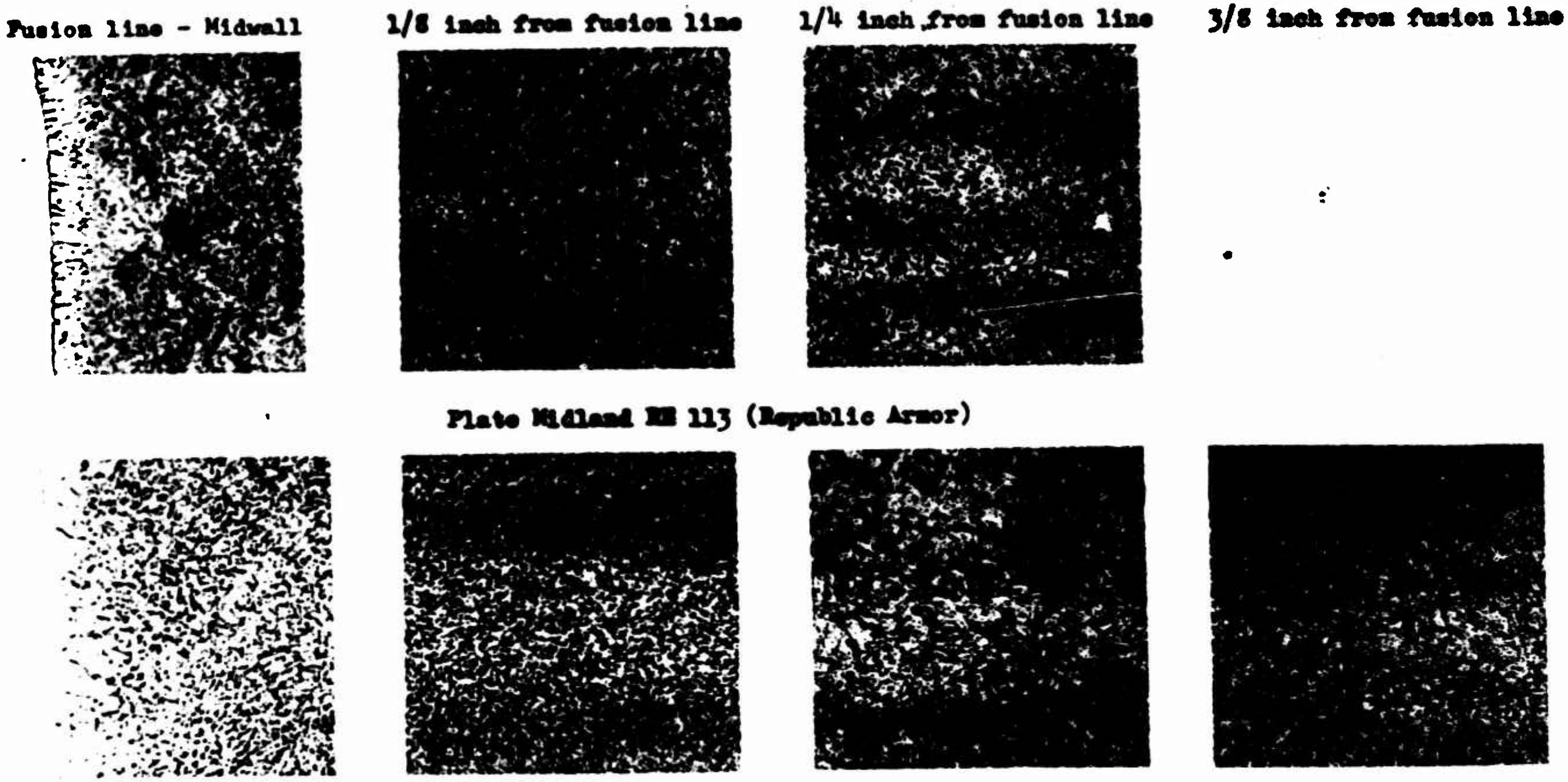


Plate Midland [illegible] 113 (Republic Armor)

Plate Midland CR 45 (Carnegie - Illinois Armor)

Figure 16. Microstructure of Heat-Affected Zones of Typical 1 1/2 Inch Thick Austenitic Hand Welded Test Plates (4% Picral etch - X250).

Fusion line - midwall | 1/8 in. from fusion line | 5/16 in. from fusion line

Plate Fisher H 115 (Jones and Laughlin Armor)

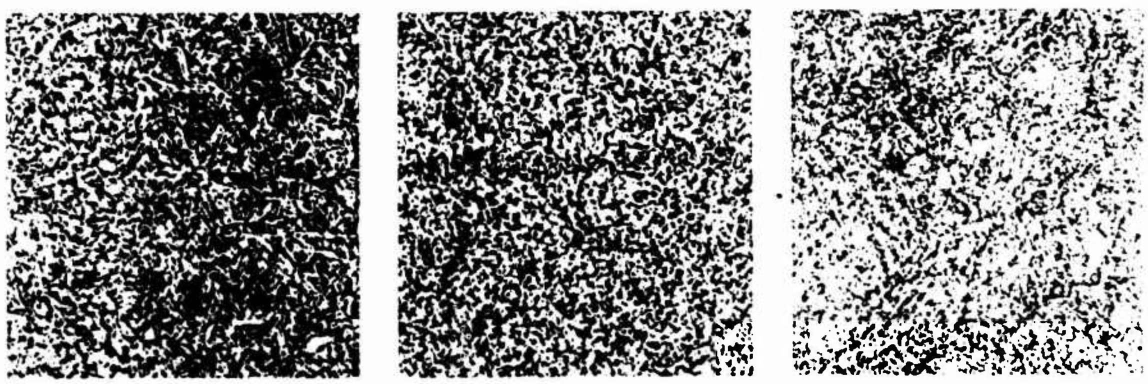
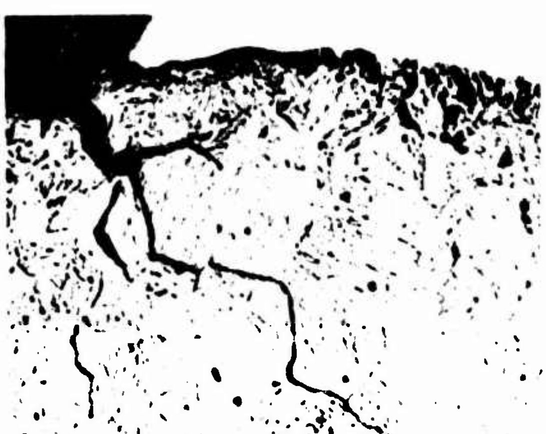


Plate Fisher H 116 (Great Lakes Armor)

Microstructure of Heat-Affected Zones of Typical 1/2 Inch Thick Ferritic Hand Welded Test Plates (4% Picral etch - X250).



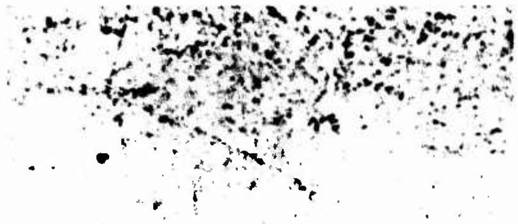
X250 Hydrochloric and Picric Acids
Fusion zone and heat-affected zone cracks from area of incomplete fusion in Plate Ford W-235.

X100 Hydrochloric and Picric Acids
Fusion zone crack in Plate Midland RE113

X100 Hydrochloric and Picric Acids
Weld and heat affected zone crack in Plate Midland RE113.

WTN.639-6685

Figure 17

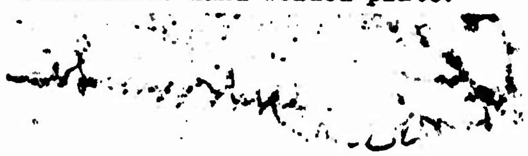


X500 Picral

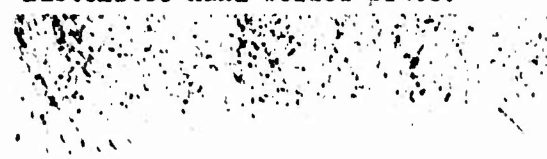
Slightly tempered fusion zone in austenitic hand welded plate.

X500 Picral

Highly tempered fusion zone in austenitic hand welded plate.

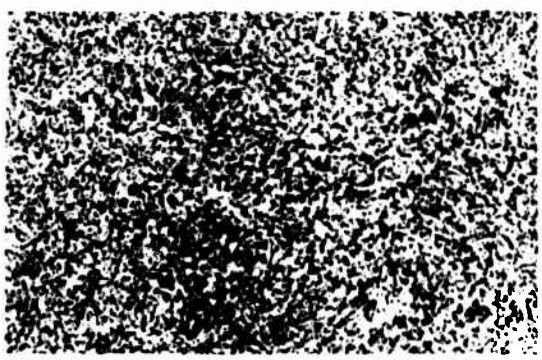


X500 Picral

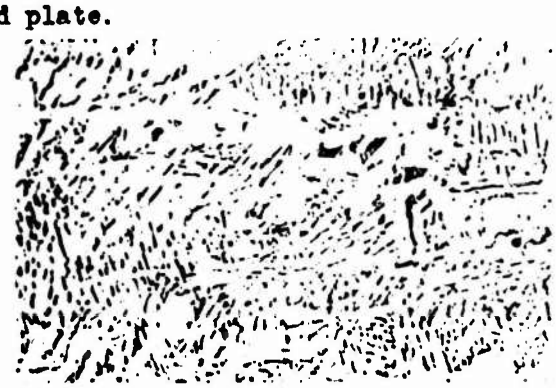


X500 Picral

Linear precipitation of non-metallic inclusions near fusion line in austenitic hand welded plate.



X250 Picral



X250 Picral

X1000 Picral

Typical weld metal microstructure of 1/2 inch thick ferritic hand welded plates.

X1000 Picral

Typical weld metal microstructure of 1/2 inch thick ferritic Unionmelt welded plates.

WTN.630-6686

Figure 18

APPENDIX A

1. Key to tabulation method and symbols.

2. Specification requirements for H plates welded with austenitic electrodes.

3. Tabulation of firing record data for H plates.

KEY TO TABULATION METHOD AND SYMBOLS

1. Identification of Test

Information in the first column identifies the test.

2. Armor Data

A. Plate Thickness

Subject plates vary in thickness from 1/2 inch to 1-1/2 inches.

B. Type Armor

Armor compositions are typed as follows:

R (Rolled)

		Typical Analyses							
	Type	C	Mn	Si	Cr	Mo	Ni	Zr	
I	Mn-Ni-Cr-Mo	.26	1.15	.20	.60	.20	1.00		B added .002
II	Mn-Cr-Mo	.27	1.30	.25	.55	.42			
III	Mn-Mo	.25	1.60	.22	--	.37			B added .002
IV	Mn-Cr-Mo-Si	.27	.86	.79	.62	.17		.09	
V	Special	(Special compositions to be noted in tabulation.)							

C. Carbon Content

Carbon content is listed as given.

D. Brinell Hardness Number (BHN)

The Brinell hardness numbers on both the front and back of plate are tabulated.

E. Process

This refers to the melting practice and is given as basic open hearth (B.O.H.), acid open hearth (A.O.H.), basic electric (B. Elec.), and acid electric (A. Elec.).

F. Heat Treatment

The temperature, time of hold, and type of quench and draw are recorded as given in the firing record.

3. Electrode Data

These data are listed as given in each firing record.

A. Type

Since alloys are sometimes added in the coating, electrodes are typed according to the chemical analysis of the weld metal when given. The types are as follows:

A (Austenitic)

I Mn-Mo Modified 18/8 (Cr-Ni-Fe alloy)
Weld Analysis - at least 1% Mn and .3% Mo.

II Mn Modified 18/8 (Cr-Ni-Fe alloy)
Weld Analysis - at least 1% Mn and less than .3% Mo.

III Mo Modified 18/8 (Cr-Ni-Fe alloy)
Weld Analysis - at least .3% Mo and less than 1% Mn.

IV Special

F (Ferritic)

B. and C. Trade Name and Coating

Trade names and type coating (lime or titania) are listed.

D. Current and Polarity

These are to be tabulated as DC straight (str.), DC reversed (rev.), or AC.

4. Joint Design

A. Groove, etc.

This item notes the type of groove - single vee (SV) bevel or double vee (DV) bevel - the included angle, and the width of the root face (RF).

B. Root Gap

This is the distance in inches between the plates as set up for welding.

C. Plate Preparation

This indicates whether the plate edges to be welded together were flame cut, ground, machined, buttered, etc.

5. Welding Procedure

A. Backing

Backing if used, i.e. back-up bar, chill, filler, and spacer strips, is noted.

B. Deposition

Figure 1 shows how the weld is broken up into root, body, and crown types. The size electrode is noted with the number of passes, type of passes, and the current and voltage. Passes are divided into two kinds:

(a) layer, if the pass bridges the gap; and (b) bead, if the pass does not bridge the gap. SB designates seal bead.

C. Total Welding Time and Interpass Temperature

These are listed as given.

D. Remarks

Any comments on chipping, grinding, and other special techniques used, not noted above but which might affect ballistic properties of welded armor plate, are noted under "remarks."

6. Heat

Preheat and postheat of weldment are tabulated.

7. Ballistic Results

The type projectile used in testing is noted for each plate. Hits, velocity, and location of each, cracking and remarks on cracking, are recorded. Symbols used are as follows:

H. - hit
F/S - feet per second
L.L. - left leg
R.L. - right leg
CB. - crossbar
LOC. - location
R - right of
L - left of
X - on weld
U - above
D - below
IMP - running from or through impact
O - not running from or through impact

Types of cracking:

I - Weld (includes weld, fusion zone, and heat-affected zone cracking within 1/8 inch from weld)
Iv - Star plate cracking
V - Linear plate cracks

Cracking is measured on the back of the plate.

8. The remarks on cracking and results of radiographic examination are recorded in the last column. P signifies the welded plate passed radiographic inspection, and F that it failed.

SPECIFICATION REQUIREMENTS FOR "H" WELDED PLATES

Figure ii shows the construction and intended aiming points for the ballistic shock test plate.

As of 25 June 1943, the following requirements were in effect (as abstracted from Specification AXS-497, Rev. 5, 15 December 1943):

"F-3. Ballistic tests. Test plates required by paragraph F-2a(1)a shall be supported solidly on each of the two sides parallel to the longest welds and with these welds upright. The plate shall be tested for compliance with the requirements of Table II.

TABLE II

Thickness of shock test plate, inches	Type of homogeneous armor	Projectile	Striking velocity f/s, plus or minus 25 f/s	Allowable weld cracking, inches, maximum
1-1/2	rolled	75 mm. T21	1200	15
1-1/2	cast	"	1050	10
1	rolled	"	725	17
1	cast	57 mm. T1	975	6
3/4	rolled	"	800	12
1/2	rolled	37 mm. H.E. M54	2525	12

"F-3a. Cracks in the armor parallel to the weld and within 1/8 inch of the edge of the weld shall be considered in the total weld cracking.

"F-3b. All impact velocities specified for cast homogeneous armor are subject to variation depending on the actual armor thickness. This variation shall be based on the velocities specified for testing primary armor and results in velocity of 6 f/s for each increase of 0.01 inch in armor thickness.

"F-3c. Cracking of the plate outside a circle of 6 inches radius, the center of which is the center of impact, or plate cracks greater than 6 inches in length not passing through the point of impact shall be considered cause for reporting 'no test.' Other types of armor cracking which indicate that the test of the welding procedure is insufficient may also be cause for reporting 'no test.' The phrase 'no test' is defined as that condition existing when the results of the ballistic test are such that it is impossible to arrive at a decision as to the acceptability of the welding procedure.

"F-3d. The impact of the 75 mm. proof projectile T21 or the 57 mm. proof projectile T1 shall touch the edge of the weld to be considered as conforming to the requirements of the test.

"F-3e. The impact of the 37 mm. H.E. projectile M54 shall be within 1-3/4 inches of the weld as measured from the center of the impact to the center of the weld to be considered as conforming to the requirements of the test.

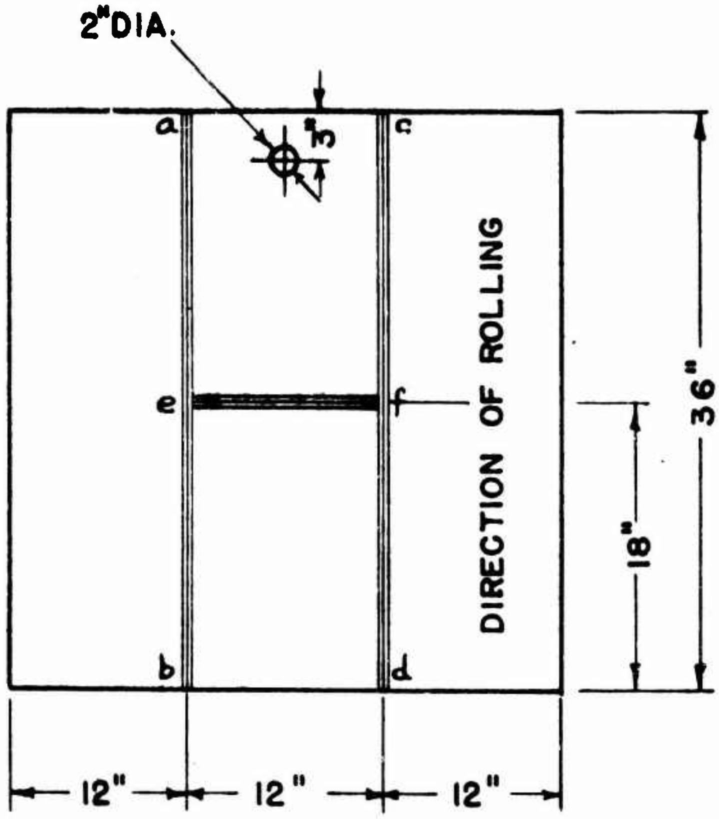
"F-3f. Impacts, the edges of which are more than 2 inches from the edge of the crossbar weld, which cause cracking in the crossbar either on the front or back of the plate, which is not an extension of cracking a leg weld, shall be cause for rejection of the welding procedure.

"F-3g. Any inconsistency in the quality of the welding procedure revealed by impact on a ballistic test plate may be considered cause for reporting 'no test' at the discretion of the proof officer.

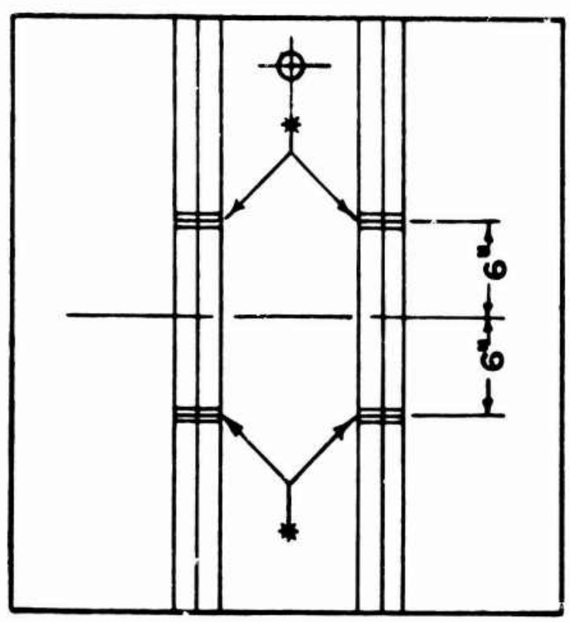
"F-3h. Any length of weld cracking revealed as a result of an impact outside the acceptable limits for impacts shall be cause for rejection of the welding procedure.

"F-3i. Impacts less than 6 inches from the top or bottom edge of the plate, which cause excessive weld cracking, shall be considered as not conforming to the requirements of the test. If, however, the cracking is not excessive and the requirements referred to in paragraph F-3d are met, the impact will be considered acceptable."

WELD SEQUENCE:
ab, cd, fe.



QUALIFICATION SHOCK TEST PLATE



* INTENDED AIMING POINTS

FIG. 1

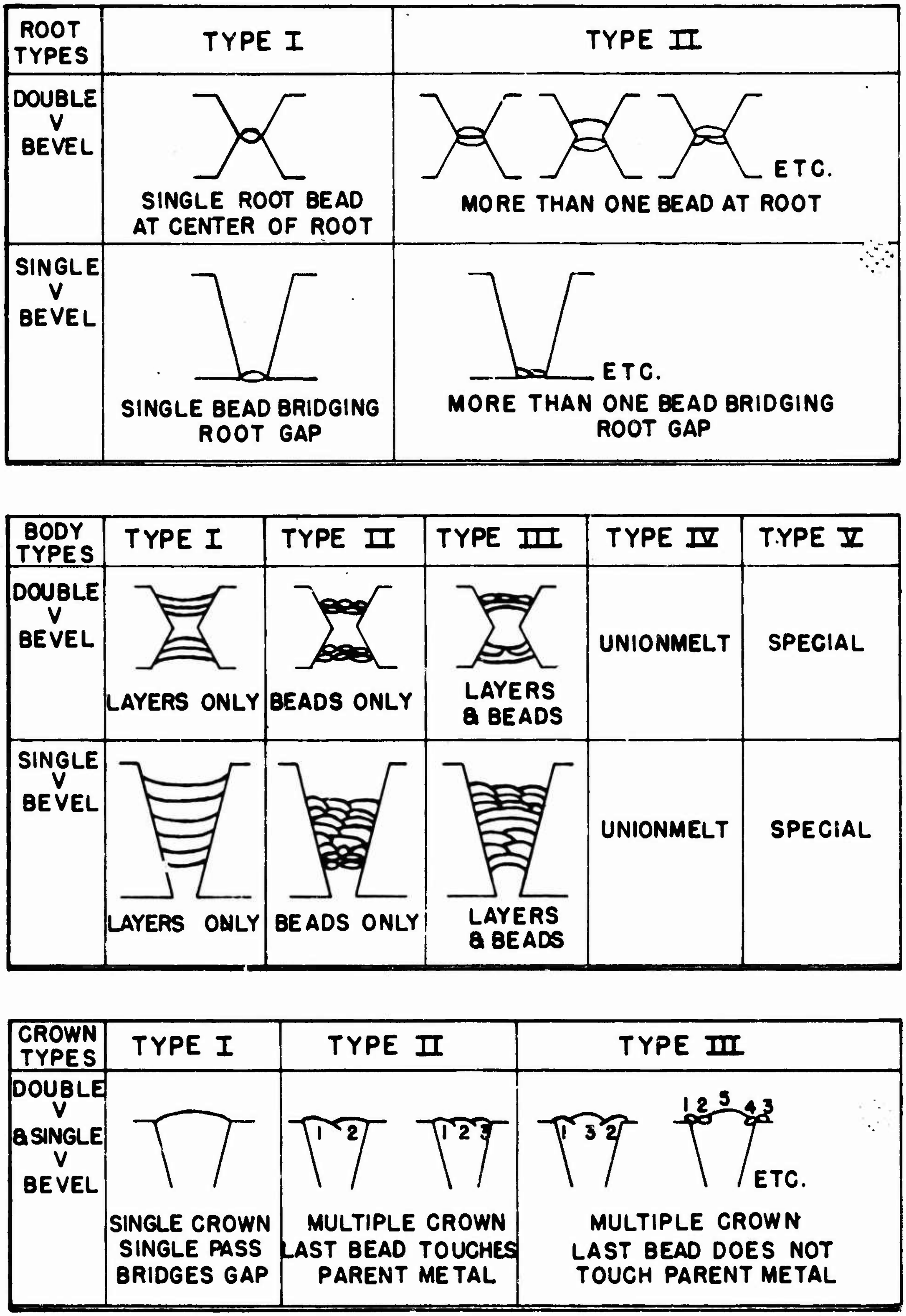


FIG. 11 WELD METAL DEPOSITION TYPES

IDENTIFICATION A. FIRING RECORD NO. B. DATE OF TEST C. PLATE NO. D. ARMOR MANUFACTURER E. ELECTRODE MFGR. F. ARMOR FABRICATOR	ARMOR DATA A. PLATE THICKNESS B. TYPE C. CARBON CONTENT D. BHN E. PROCESS F. HEAT TREATMENT TEMP. TIME QUENCH	ELECTRODE DATA A. TYPE B. TRADE NAME C. COATING D. CURRENT & POLARITY	JOINT DESIGN A. GROOVE. INCLUDED ANGLE. ROOT FACE B. ROOT GAP C. PLATE PREPARATION	WELDING PROCEDURE A. BACKING B. DEPOSITION SIZE EL. NO. TYPE AMP. V. (PASSES) 1. ROOT TYPE 2. BODY TYPE 3. CROWN TYPE C. TOTAL WELDING TIME & INTER PASS TEMPERATURE D. REMARKS	HEAT A. PRE B. POST	#	BALLISTIC RESULTS VEL. F/S	LOCATION OF # L.L.	R.L.	C.B.	CRACKING LOC.	TYPE	AMT	REMARKS ON CRACKING RADIOGRAPHIC RESULTS, ETC.
A. AD 1 B. 9/8/42 C. RE-104 D. Republic Steel Corp. E. Crucible Steel Corp. F. Midland Steel Products Co.	A. 1-1/2" B. R I .87Mn .27Si .98Cr 1.28Ni .76Mo C. .28C D. — E. B.O.H. F. —	A. A I .07C 1.64 Mn .40Si 1.96Mo 20.12Cr 10.67Ni* B. Rezistal C. TiO_2 D. AC STR	A. 45° DV B. 1/4" C. Flame cutting.	A. Copper B. 1. II 5/32" 2a 125 23 2. I 3/16" 2a 200 24 5/16" 4a 330 28 3. I 5/16" 2a 330 28 C. 12 hours — D.	A. None B. None	1 2	1116 1119 75mm T1 projectile	1/2" L	 1/2" L	11" U 5 1/2" D	IMP O IMP	I I I	15 1/2" 2 18 35 1/2"	P Few scattered slag inclusions
A. AD 1 B. 9/8/42 C. RE-113 D. Republic Steel Corp. E. Crucible Steel Corp. F. Midland Products Co.	A. 1-1/2" B. R I .90Mn .28Si .98Cr 1.22Ni .61Mo C. .28C D. — E. B.O.H. F. —	A. A I .09C 1.78Mn .50Si 19.17Cr 10.81Ni 2.90Mo* B. Armorize C. TiO_2 D. AC STR	A. 45° DV B. 5/16" C. Flame cutting.	A. Copper B. 1. II 3/16" 2a 200 24 2. I 5/16" 2a 340 27 1/2" 2a 575 33 3. I 1/2" 2a 600 35 C. 10 hours. 110°-284°F D.	A. None B. None	1 2 3	1109 1152 1153 75mm T1 projectile	1/2" R	 1 1/2" L 1/2" R	6" D 7 1/2" U 5" D	IMP - IMP	I - I	4 1/2" - 6 12 1/2"	P Large amount of scattered porosity.
A. AD 415 B. 5/4/43 C. CR-45 D. Carnegie Steel Corp. E. Crucible Steel Corp. F. Midland Products Co.	A. 1-1/2" B. R I 1.01Mn .19Si .42Cr 1.00Ni .37Mo C. .24C D. Face 293 Back 286 E. B.O.H. F. 650°F 1 1/4 hr 545°F 2 hrs. water	A. A I .09C 1.82Mn .23Si 19.52Cr 9.24Ni 1.94Mo* B. Armorize C. TiO_2 D. AC STR	A. 75° DV B. 1/4" C. Flame cutting	A. Copper B. 1. II 3/16" 2a 150 23 2. I 5/16" 2a 330 28 1/2" 2a 550 33 3. I 1/2" 2a 550 33 C. 2-1/4 hours. 120°-400°F D.	A. None B. None	1 2 3 4	1105 1175 1241 1315 75mm T1 projectile	 1 1/2" R X	1" R 1 1/2" L	6 1/2" D 6" U 6 1/2" U 8 1/2" D	IMP - - IMP IMP	I - - I V	4" - - 18" 5 1/2 27 1/2"	P
		*Weld metal												

IDENTIFICATION A. Firing Record No. B. Date of Test C. Plate No. D. Armor Manufacturer E. Electrode Mfgr. F. Armor Fabricator	ARMOR DATA A. Plate Thickness B. Type C. Carbon Content D. BHN E. Process F. Heat Treatment Temp. Time Quench	ELECTRODE DATA A. Type B. Trade Name C. Coating D. Current & Polarity	JOINT DESIGN A. Groove. Included Angle. Root Face B. Root Gap C. Plate Preparation	WELDING PROCEDURE A. Backing B. Deposition Size El. No. Type Amp. V. (Passed) 1. Root Type 2. Body Type 3. Crown Type C. Total Welding Time & Inter Pass Temperature D. Remarks	HEAT A. Pre B. Post	#	BALLISTIC RESULTS: VEL. F/S	LOCATION OF # L.L.	LOCATION OF # R.L.	LOCATION OF # C B.	CRACKING LOC.	CRACKING TYPE	CRACKING AMT	REMARKS ON CRACKING RADIOGRAPHIC RESULTS, ETC.
A. AD 750 B. 7/20/43 C. W 235 D. Ford Motor Co. E. Crucible Steel Corp. F. Ford Motor Company	A. 1-1/2" B. R II 1.36Mn .28Si .54Cr .08Ni .40Mo C. .28C D. Face 286 Back 293 E. E.O.E. F. 1650°F 3½ hr spray 1100°F 5½ hr air	A. A I .09C 3.91Mn .18Si 20.06Cr 10.0Ni .96Mo* B. Armorize C. Lime TiO_2 D. DC-REV	A. 45° DV B. 1/4" C. Flame cutting.	A. Copper B. 1. II 5/32" 1a 135 25; 3/16" 1a 180 27 2. I 1/4" 2a 260 30; 5/16" 4a 340 32 3. III 1/4" 4b 260 30; 5/16" 2b 340 32 C. 8 hours. 160°-200°F D. Grinding after second pass.	A. None B. None	1 2	1098 1191 75 mm T1 projectile	½" L	1½" R	3¼" U 5¼" D	IMP O IMP	I I I	5" 3 7½ 15½"	P Small amount of porosity and 5/8 of incomplete fusion at junct of crossbar and left leg welds.
A. AD 754 B. 7/22/43 C. 41 D. Carnegie Ill. Steel Corp. E. Lincoln Electric Co. Linde Air Products Co. F. New York Air Brake Co.	A. 1-1/2" B. R I 1.15Mn .18Si .60Cr .75Ni .21Mo C. .25C D. Face 285 Back 285 E. — F. 1562°F ½ hr water 1040°F 1½ hr air	A. A II .10C 4.0Mn .60Si 19.5Cr 9.0Ni* B. Armorweld Oxweld C. — D. AC DC-REV	A. 45° DV B. 3/16" C. Flame cutting. Grinding.	A. Copper B. 1. II 5/32" 1a 150 30; 3/16" 1a 200 28 2. & 3. 1/4" 2a 250 25; 1/4" 20M 825 32 C. 6 hours. 100°-175°F D. Grinding after first, second and last passes; time 6:10 hours. 1" crack on right leg ground out & repaired; 1-1/2" crack in center section ground out & repaired by hand welding.	A. None B. None	1 2	1095 1198 75 mm T1 projectile	½" L	1½" R	5" U 6" D	IMP IMP	I I	9½" 36 45½"	F Excessive amount of slag and gas inclusi[illegible] and cracking in crossbar.
A. AD 754 B. 7/22/43 C. 42 D. Carnegie Ill. Steel Corp. E. Lincoln Electric Co. Linde Air Products Co. F. New York Air Brake Co.	A. 1-1/2" B. R I 1.26Mn .83Cr .75Ni .21Mo C. .25C D. Face 285 Back 285 E. — F. 1562°F ½ hr water 1040°F 1½ hr air	A. A II .10C 4.0Mn .60Si 19.5Cr 9.0Ni* B. Armorweld Oxweld C. — D. AC DC-REV	A. 45° DV B. 5/16" C. Flame cutting. Grinding	A. Copper B. 1. II 5/32" 1a 150 30; 3/16" 1a 200 28 2. & 3. 1/4" 2a 250 25; 1/4" 20M 825 32 C. 12 hours. 110°-170°F D. Chipping and grinding after second and last passes; time 7-1/2 hours. Entire center section ground out and repaired.	A. None B. None	1 2	1095 1196 75 mm T1 projectile	 ½" L	½" L	8" U 7½" D	IMP IMP	I I	12½" 17½ 30½"	F 4" of cracking at ends of crossbar.

* Weld metal

IDENTIFICATION A. Firing Record No. B. Date of Test C. Plate No. D. Armor Manufacturer E. Electrode Mfgr. F. Armor Fabricator	ARMOR DATA A. Plate Thickness B. Type C. Carbon Content D. BHN E. Process F. Heat Treatment Temp. Time Quench	ELECTRODE DATA A. Type B. Trade Name C. Coating D. Current & Polarity	JOINT DESIGN A. Groove. Included Angle. Root Face B. Root Gap C. Plate Preparation	WELDING PROCEDURE A. Backing B. Deposition Size El. No. Type Amp. V. (Passes) 1. Root Type 2. Body Type 3. Crown Type C. Total Welding Time & Inter Pass Temperature D. Remarks	HEAT A. Pre B. Post	#	BALLISTIC RESULTS Vel. F/S	Location of # L.L.	R.L.	C B.	Cracking Loc.	Type	Amt	REMARKS ON CRACKING Radiographic Results, etc.
A. AD 754 B. 7/22/43 C. 44 D. Jones & Laughlin Steel Corp. E. Lincoln Electric Co. Linde Air Products Co. F. New York Air Brake Co.	A. 1-1/2" B. R III 1.82Mn .20Si .03Cr .03Ni .26Mo C. .29C D. — E. — F. 1625°F 3¼ hr 1060°F	A. A II .10C 4.0Mn .60Si 19.5Cr 9.0Ni* B. Armorweld Oxweld #42 C. — D. AC DC-REV	A. 45° DV B. 5/16" C. Flame cutting. Grinding.	A. Copper B. 1. II 5/32" 1a 150 30 3/16" 1a 200 28 2. & 3. 1/4" 2a 250 25 1/4" 20M 825 32 C. 8 hours. 100°-170°F D. Chipping and grinding after first, third and fourth passes; time 3:20 hours. 1-1/2" crack on root bead repaired. 1-1/2" crack on center section of unionmelt weld ground out and repaired by hand weld.	A. None B. None	1	1107		¼" L	5½" U	IMP	I	18½	F 2" of cracking in crossbar; excessive incomplete fusion.
						2	1197	1" L		8¼" D	IMP	I	18½	
							75mm T1 projectile						37½"	
A. AD 754 B. 7/22/43 C. 45 D. Jones & Laughlin Steel Corp. E. Lincoln Electric Co. Linde Air Products Co. F. New York Air Brake Co.	A. 1-1/2" B. R III 1.82Mn .20Si .03Cr .03Ni .26Mo C. .29C D. — E. — F. 1625°F 3¼ hr 1060°F	A. A II .10C 4.0Mn .60Si 19.5Cr 9.0Ni* B. Armorweld Oxweld #42 C. — D. AC DC-REV	A. 45° DV B. 5/16" C. Flame cutting. Grinding.	A. Copper B. 1. II 5/32" 1a 150 30 3/16" 1a 200 28 2. & 3. 1/4" 2a 250 25 1/4" 20M 825 32 C. 5 hours. 90°-190°F D. Chipping and grinding after first and last passes; time 5.10 hours.	A. None B. None	1	1107	1½" R		6½" U	-	-	-	F 2" crack at left junction of crossbar and 3/8" crack at right junction.
						2	1108		1" L	10½" D	IMP	I	17½"	
						3	1198	½" R		4½" D	IMP IMP	I V	5 2½	
						4	1196	½" R		10½" U	IMP	I	22	
							75mm T1 projectile						47"	
A. AD 754 B. 7/22/43 C. 46 D. Republic Steel Corp. E. Lincoln Electric Co. Linde Air Products Co. F. New York Air Brake Co.	A. 1-1/2" B. R V .46Mn .20Si .04Cr 4.74Ni .36Mo C. .29C D. — E. — F. 1550°F 3¼ hr 1150°F	A. A II .10C 4.0Mn .60Si 19.5Cr 9.0Ni* B. Armorweld Oxweld #42 C. — D. AC	A. 45° DV B. 5/16" C. Flame cutting. Grinding.	A. Copper B. 1. II 5/32" 1a 150 30 3/16" 1a 200 28 2. & 3. 1/4" 2a 250 25 1/4" 20M 825 32 C. 7 hours. 100°-180°F D. Chipping and grinding after first and fourth passes; time 4-1/2 hours. 1-1/2" crack on root bead, repaired. 1" crack on center section of unionmelt, repaired by hand welding.	A. None B. None	1	1106	½" R		7" U	IMP	I	14"	F 3/8" crack at right junction of crossbar; some slag and incomplete fusion; two cracker cracks in crossbar.
						2	1198		1" R	6½" D	IMP	I	12	
						3	1196		X	7½" U	IMP	I	22	
							75mm T1 projec[tile]						48"	

*Weld metal

IDENTIFICATION A. FIRING RECORD NO. B. DATE OF TEST C. PLATE NO. D. ARMOR MANUFACTURER E. ELECTRODE MFGR. F. ARMOR FABRICATOR	ARMOR DATA A. PLATE THICKNESS B. TYPE C. CARBON CONTENT D. BHN E. PROCESS F. HEAT TREATMENT TEMP. TIME QUENCH	ELECTRODE DATA A. TYPE B. TRADE NAME C. COATING D. CURRENT & POLARITY	JOINT DESIGN A. GROOVE. INCLUDED ANGLE. ROOT FACE B. ROOT GAP C. PLATE PREPARATION	WELDING PROCEDURE A. BACKING B. DEPOSITION SIZE EL. PASSES NO. TYPE AMP. V. 1. ROOT TYPE 2. BODY TYPE 3. CROWN TYPE C. TOTAL WELDING TIME & INTER PASS TEMPERATURE D. REMARKS	HEAT A. PRE B. POST	BALLISTIC RESULTS #	VEL. F/S	LOCATION OF # L.L.	LOCATION OF # R.L.	LOCATION OF # C B.	CRACKING LOC.	CRACKING TYPE	CRACKING AMT	REMARKS ON CRACKING RADIOGRAPHIC RESULTS, ETC.
A. AD 754 B. 7/22/43 C. 47 D. Carnegie Ill. Steel Corp. E. Lincoln Electric Co. Linde Air Products Co. F. New York Air Brake Co.	A. 1-1/2" B. R I 1.09Mn .19Si .57Cr .87Ni .20Mo C. .25C D. Face 285 Back 285 E. — F. 850°F 1½ hrs water 555°F 2½ hrs air	A. A II .10C 4.00Mn .45Si 20.0Cr 9.5Ni* B. Armorweld Oxweld #42 C. — D. AC DC-REV	A. 45° DV B. 5/16" C. Flame cutting. Grinding.	A. Copper B. 1. II 5/32" 1a 150 30; 3/16" 1a 200 28 2. & 3. 1/4" 2a 250 25; 1/4" 2UM 825 32 C. 6 hours. 90°-185°F D. Chipping and grinding time 6:40 hours.	A. None B. None	1 2 3	1106 1196 1199 75mm Ti projectile	 ¼" R ¼" L	X	7½" U 6½" D 8¼" U	IMP IMP IMP	I I I	17½" 4½ 19½ 41½"	F 1/8 crack at left end of crossbar; 3/8" crack at junction of leg and cross-bar.
A. AD 754 B. 7/22/43 C. 48 D. Carnegie Ill. Steel Corp. E. Lincoln Electric Co. Linde Air Products Co. F. New York Air Brake Co.	A. 1-1/2" B. R I 1.19Mn .20Si .75Cr .77Ni .18Mo C. .28C D. — E. — F. 1562°F ½ hr water 1040°F 1½ hr air	A. A II .10C 4.0Mn .60Si 19.5Cr 9.0Ni* B. Armorweld Oxweld #42 C. — D. AC DC-REV	A. 45° DV B. 5/16" C. Flame cutting. Grinding.	A. Copper B. 1. II 5/32" 1a 150 30; 3/16" 1a 200 28 2. & 3. 1/4" 2a 250 25; 1/4" 2UM 825 32 C. 8 hours. 85°-170°F D. Chipping and grinding after second pass, time 2 hours. 1" crack on unionmelt, repaired by grinding out and hand welding.	A. None B. None	1 2	1084 1196 75mm Ti projectile	¼" L	 X	7" U 10" D	IMP IMP	I I	17½" 17½ 35½"	F 1-3/4" of cracking in crossbar.
A. A 3222 B. 5/26/42 C. CR 25 D. Carnegie Steel Corp. E. Linde Air Products Co. F. Midland Steel Products Co.	A. 1-1/2" B. R V .19Mn .07Si 1.27Cr 3.21Ni C. .32C D. — E. — F. —	A. A — B. Oxweld #41 C. — D. AC	A. 45° DV B. 3/16" C. Flame cutting.	A. Copper B. 1. 1a 2. 3a & 2UM C. — D. First four passes were handwelded with Rezistal, next two passes with Unionmelt.	A. None B. None	1 2	1099 1099 75mm Ti projectile	 ¼" R	X	4½" D 7½" U	IMP IMP O	I I I	6½" 4 1½ 12"	P Few small cracks present along crosswelds.

*Weld metal

IDENTIFICATION A. FIRING RECORD NO. B. DATE OF TEST C. PLATE NO. D. ARMOR MANUFACTURER E. ELECTRODE MFGR. F. ARMOR FABRICATOR	ARMOR DATA A. PLATE THICKNESS B. TYPE C. CARBON CONTENT D. BHN E. PROCESS F. HEAT TREATMENT TEMP. TIME QUENCH	ELECTRODE DATA A. TYPE B. TRADE NAME C. COATING D. CURRENT & POLARITY	JOINT DESIGN A. GROOVE. INCLUDED ANGLE. ROOT FACE B. ROOT GAP C. PLATE PREPARATION	WELDING PROCEDURE A. BACKING B. DEPOSITION SIZE EL. PASSES NO. TYPE AMP. V. 1. ROOT TYPE 2. BODY TYPE 3. CROWN TYPE C. TOTAL WELDING TIME & INTER PASS TEMPERATURE D. REMARKS	HEAT A. PRE B. POST	#	BALLISTIC RESULTS VEL. F/S	LOCATION OF # L.L.	B.L.	C.B.	CRACKING LOC.	TYPE	AMT	REMARKS ON CRACKING RADIOGRAPHIC RESULTS, ETC.
A. AD 43 B. 10/3/42 C. 36 D. Jones & Laughlin Steel Corp. Great Lakes Steel Corp. E. Harnischfeger Company. F. General Motors Truck & Coach.	A. 1" B. R III J&L 1.75Mn .24Si .56Mo C. .25C D. Face 321-341 Back 321-341 E. B.O.H. F. 1625°F 2¼ hr water 1075°F 4 hrs draw A. 1" B. R IV GL .94Mn .81Si .70Cr .22Mo .09Zr C. .32C D. Face 321-341 Back 321-341 E. B.O.H. F. 1625°F 2¼ hr water 1060°F draw	A. A I .10C 1.78Mn .58Si 19.36Cr 11.40Ni 2.2Mo* B. AW 3 C. Lime D. DC-REV	A. 45° DV B. 3/16" C. Flame cutting.	A. Not given B. 1. II 5/32" 1a 100 - 5/32" 1a 135 - 2. II 5/32" 12b 135 - 3. III 5/32" 6b 135 - C. 8 hours. 200°F D. Total chipping or grinding time 3 hours., details not given.	A. None B. None	1 2 3	1101 1135 1140 57mm T1 projectile	 2¼ L 1" R	X	2¼" U 6" D 6¼" U	IMP - IMP	I - I	2½" - 11¼ 13¼"	P
A. AD 339 B. 3/23/43 C. 143 D. Great Lakes Steel Corp. E. McKay Company F. Cadillac Motor Car Company	A. 1" B. R IV .95Mn .87Si .62Cr .17Mo C. .27C D. Face 321 Back 302 E. —— F. 1650°F 1½ hr water 970°F 1½ hr air	A. A II .09C 4.85Mn .55Si 22.05Cr 10.55Ni .10Mo* .08C 4.50Mn .42Si 20.40Cr 10.10Ni* B. Armorloy C. —— D. AC REV	A. 60° DV B. 3/16" C. Flame cutting. Grinding.	A. Not given B. 1. II 3/16" 1a 105 25 1/4" 1a 280 25 2. I 5/16" 1a 360 25 1/4" 1a 280 25 3. III 3/16" 4b 160 25 5/16" 1b 360 25 remaining pass not given. C. 2.03 hours. 70°-200°F D. Some cracking after 15th and 16th passes in the crown.	A. None B. None	1 2	756 783 75mm T1 projectile	 1½" R	1¼" L	5½" U 6½" D	IMP IMP	I I	½ 17½ 18"	P
		*Weld metal												

IDENTIFICATION A. FIRING RECORD NO. B. DATE OF TEST C. PLATE NO. D. ARMOR MANUFACTURER E. ELECTRODE MFGR. F. ARMOR FABRICATOR	ARMOR DATA A. PLATE THICKNESS B. TYPE C. CARBON CONTENT D. BHN E. PROCESS F. HEAT TREATMENT TEMP. TIME QUENCH	ELECTRODE DATA A. TYPE B. TRADE NAME C. COATING D. CURRENT & POLARITY	JOINT DESIGN A. GROOVE. INCLUDED ANGLE. ROOT FACE B. ROOT GAP C. PLATE PREPARATION	WELDING PROCEDURE A. BACKING B. DEPOSITION SIZE EL. PASSES NO. TYPE AMP. V. 1. ROOT TYPE 2. BODY TYPE 3. CROWN TYPE C. TOTAL WELDING TIME & INTER PASS TEMPERATURE D. REMARKS	HEAT A. PRE B. POST	#	BALLISTIC RESULTS VEL. F/S	LOCATION OF R L.L.	R.L.	C.B.	CRACKING LOC.	TYPE	AMT	REMARKS ON CRACKING RADIOGRAPHIC RESULTS, ETC.
A. AD 370 B. 4/13/43 C. 140 D. Great Lakes Steel Corp. E. McKay Company F. Cadillac Motor Car Company	A. 1" B. R IV .93Mn .87Si .62Cr .17Mo C. 27C D. Face 321 Back 311 E. —— F. 1650°F 1½ hr water 970°F 1½ hr air	A. A II .10C 4.80Mn .66Si 17.9CCr 9.75Ni .08Mo* .09C 4.85Mn .55Si 20.10Cr 10.20Ni .15Mo* B. Armorloy C. —— D. AC REV	A. 60° DV B. 3/16" C. Flame cutting.	A. Not given. B. 1. II 5/32" 2a 135 25 2. I 3/16" 2a 165 25 3. III 5/32" 1b 140 25 1/4" 2b 240 25 5/32" 2b 135 25 Remaining pass not given. C. 3.10 hours. 70°-140°F D.	A. None B. None	1	756		2" L	2¼" U	IMP	I	5"	F Scattered slag, inclusions and 5" of incomplete fusion.
						2	767	1¾" R		5" D	O	I	½	
						3	782	¾" R		6¼" U	IMP	I	12	
							75mm T1 projectile						17½"	
A. AD 792 B. 8/19/43 C. 167 D. Youngstown Sheet & Tube Company E. Crucible Steel Corp. F. Cadillac Motor Car Company	A. 1" B. R III 1.44Mn .21Si .26Mo C. .26C D. Face 321 Back 332 E. —— F. 1600°F ½ hr water 875°F 2½ hr air	A. A II .06C 1.74Mn .22Si 18.96Cr 10.32Ni* .15C 1.76Mn .41Si 19.66Cr 10.34Ni* B. Armorize C. Titanium oxide D. AC	A. 45° DV B. 1/4" C. Flame cutting.	A. Not given. B. 1. II 3/16" 2a 190 23 2. I 1/4" 4a 265 25 3. I 5/16" 2a 370 27 C. —— 105°-210°F D.	A. None B. None	1	757		1" R	1" U	IMP	I	13½"	F 1/8" crack at right junction 1/2" crack in left leg weld.
						2	752	1½" L		9" D	IMP IMP	I V	10 2½	
							75mm T1 projectile						26"	
		*Weld metal												

IDENTIFICATION A. FIRING RECORD NO. B. DATE OF TEST C. PLATE NO. D. ARMOR MANUFACTURER E. ELECTRODE MFGR. F. ARMOR FABRICATOR	ARMOR DATA A. PLATE THICKNESS B. TYPE C. CARBON CONTENT D. BHN E. PROCESS F. HEAT TREATMENT TEMP. TIME QUENCH	ELECTRODE DATA A. TYPE B. TRADE NAME C. COATING D. CURRENT & POLARITY	JOINT DESIGN A. GROOVE, INCLUDED ANGLE, ROOT FACE B. ROOT GAP C. PLATE PREPARATION	WELDING PROCEDURE A. BACKING B. DEPOSITION SIZE EL. PASSES: NO. TYPE AMP. V. 1. ROOT TYPE 2. BODY TYPE 3. CROWN TYPE C. TOTAL WELDING TIME & INTER PASS TEMPERATURE D. REMARKS	HEAT A. PRE B. POST	R	BALLISTIC RESULTS: VEL. F/S	LOCATION OF R: L.L.	LOCATION OF R: R.L.	LOCATION OF R: C B.	CRACKING: LOC.	CRACKING: TYPE	CRACKING: AMT	REMARKS ON CRACKING, RADIOGRAPHIC RESULTS, ETC.
A. AD 43 B. 10/6/42 C. 34 D. Jones & Laughlin Steel Corp. Great Lakes Steel Corp. E. Linde Air Products Company F. General Motor Truck & Coach.	A. 1" B. R III J&L 1.75Mn .2481 .55Mo C. .25C D. Face 321-341 Back 321-341 E. B.O.H. F. 1625°F 2¼ hr water 1075°F 4 hrs draw A. 1" B. R IV GL .94Mn .6181 .70Cr .22Mo .09Zr C. .32C D. Face 321-341 Back 321-341 E. B.O.H. F. 1625°F 2¼ hr water 1030°F 4 hrs draw	A. A — B. AW 3 Oxweld # 42 C. #60 20XD & 8X200 D. AC DC-REV	A. 60° DV B. 3/16" C. Flame cutting.	A. Not given B. 1. II 5/32" 1a 100 - 5/32" 1a 135 - 2. IV 3/16" 1UM 640 - 3/16" 1UM 680 - C. 8 hours. 150°- 200°F D. Root passes-hand welded. Right and lower center sections by Great Lakes, left and upper center sections by Jones & Laughlin. Total chipping and grinding time 3 hours, details not given.	A. None B. None	1	1102	3¼" R		5½" U	-	-	-	P
						2	1147		½" L	8½" D	IMP IMP	I V	12½ 2¼	
						3	1097	1" L		½" D	O	I	¼	
						4	1083	3½ R		11" U	-	-	-	
						5	1144	1¼ R		¼" U	IMP IMP	I V	16¾ 2	
							57mm T1 projectile						34"	
A. AD 905 B. 9/28/43 C. U 37 D. Jones & Laughlin Steel Corp. E. Allegheny Ludlum McKay Company F. Fisher Tank Division. This plate originally 1-1/2" thick was planed down to 3/4" thickness.	A. 3/4" B. R III 1.59Mn .0381 .45Mo C. 28C D. Face 332 Back 352 E. — F. Not known	A. A ? .23C 5.56Mn .8081 11.36Cr 9.87Ni .45Mo* B. Allegheny # 42 McKay A-5 C. Bare (both) D. AC DC-REV	A. 90°/60° DV B. 3/16" C. Flame cutting. Grinding.	A. Copper B. 1. I 3/16" 1a 160 21 90° side - 2. II 3/16" 2b 175 21 4b 180 21 3. III 3/16" 3t 160 21 60° side - 2. & 3. 1/4" 1UM 760 31 C. 1 hour. 13 minutes. 100°-200°F for hand welds. 340°-380° for unionmelt. D. 3 min. chipping after each pass; 20 min. grinding to produce flush welds.	A. None B. None	1	789	½" L		14" D	IMP	I	13¼	P
						2	785	1½" R		1½" U	IMP IMP	I V	8 3¼	Small amount of slag.
						3	799	1-9/16" R		8" U	IMP	V	12-1/8"	
						4	795		1¼" L	8" U	IMP IMP	I V	9-1/8" 2	
							75mm T1 projectile						48¼ "	

*Weld metal

IDENTIFICATION A. Firing record no. B. Date of test C. Plate no. D. Armor manufacturer E. Electrode mfgr. F. Armor fabricator	ARMOR DATA A. Plate thickness B. Type C. Carbon content D. BHN E. Process F. Heat treatment temp. time quench	ELECTRODE DATA A. Type B. Trade name C. Coating D. Current & polarity	JOINT DESIGN A. Groove. Included angle. Root face B. Root gap C. Plate preparation	WELDING PROCEDURE A. Backing B. Deposition size el. no. Passes type amp. v. 1. Root type 2. Body type 3. Crown type C. Total welding time & inter pass temperature D. Remarks	HEAT A. Pre B. Post	#	VEL. F/S	LOCATION OF # L.L.	B.L.	C B.	CRACKING LOC.	TYPE	AMT	REMARKS ON CRACKING RADIOGRAPHIC RESULTS, ETC.
A. AD 905 B. 9/28/43 C. U 39 D. Jones & Laughlin Steel Corp. E. Allegheny Ludlum. McKay Company F. Fisher Tank Division	A. 3/4" B. R III 1.76Mn .22Si .46Mo C. .25C D. Face 341 Back 341 E. — F. 1650°F ½ hr water 960°F 1½ hr air	A. A II .08C 4.03Mn .62Si 19.53Cr 9.71Ni .10Mo* B. Allegheny # 42 McKay A5 C. Allegheny Bare McKay-Lime D. AC DC-REV	A. 90°/60° DV B. 3/16" C. Flame cutting. Grinding.	A. Copper B. 1. I 3/16" 1a 175 28 90° side – 2. III 3/16" 1a 175 28; 2b 175 28 3. III 3/16" 3b 175 28 60° side – 2. & 3. 1/4" 1UM 800 31 C. 47 minutes. 100°-200° hand 300° for UM D. 3 minutes. chipping after each pass. 20 minutes grinding to form flush welds.	A. None B. None	1 2 3 4	808 800 813 800 Est.	 7/8" R 1½" L 	2-1/8" R 1½" L	4" U 4" D 3½" U 4½" D	- IMP IMP IMP IMP IMP	- I V I V V	- 4" 5½ 5-1/8" 3 10 27-5/8"	P Small amount of slag.
				57mm proof projectile T1										
A. AD 793 B. 8/19/43 C. 178 D. Great Lakes Steel Corp. E. Harnischfeger F. Cadillac Motor Car Company.	A. 1/2" B. R IV .84Mn .85Si .62Cr .24Mo .07Zr C. .27C D. Face 363 Back 363 E. — F. 1625°F 40 min. water 900°F 30 min air	A. A II .12C 2.13Mn .63Si 21.32Cr 10.80Ni .10Mo* B. AW 3 C. Lime D. DC-REV	A. 60° DV B. 1/4" C. Flame cutting.	A. Not given. B. 1. II 5/32" 2a 135 25 2. & 3. 5/32" 6b 135 25 C. 2.38 hours 70°-165°F. D.	A. None B. None	1 2 3 4	2527 2513 2519 2525 est.	2" L 2" R 	 ½" L 4½" R	5½" U 9" D 7½" D 6" U	- - - -	- - - -	- - - -	P
							37mm HE M-54 projectile							
A. AD 791 B. 8/17/43 C. F 110 D. Great Lakes Steel Corp. E. McKay Company F. Fisher Tank Division.	A. 1/2" B. R V 1.46Mn .25Si .33Cr .18Mo C. .23C D. Face 321 Back 311 E. F. 1650°F ½ hr water 930°F ½ hr air	A. A II .08C 4.03Mn .62Si 19.5Cr 9.71Ni .10Mo* B. A 5 C. Lime D. DC	A. 45° SV B. 3/8" C. Flame cutting. Grinding.	A. Copper B. 1. I 3/16" 1a 175 21 2. I 1/4" 2a 250 21 3. I 1/4" 1a 250 21 Seal bead – 1/4" 1a 250 21 C. 1 hour 120°-170°F D. 3 minutes chipping after each pass; 25 minutes grinding after back-up strip was removed. Reinforcements removed.	A. None B. None	1 2 3	2514 2519 2519	 1-1/8" L 	3" L 3/8" L	5" U 5" D 6¼" D	- IMP IMP O	- I I I	- 15 15½ 1 31½"	F Excessive imperfect fusion and slag.
							37mm HE M-54 projectile							
		*Weld metal												

IDENTIFICATION A. FIRING RECORD NO. B. DATE OF TEST C. PLATE NO. D. ARMOR MANUFACTURER E. ELECTRODE MFGR. F. ARMOR FABRICATOR	ARMOR DATA A. PLATE THICKNESS B. TYPE C. CARBON CONTENT D. BHN E. PROCESS F. HEAT TREATMENT TEMP. TIME QUENCH	ELECTRODE DATA A. TYPE B. TRADE NAME C. COATING D. CURRENT & POLARITY	JOINT DESIGN A. GROOVE. INCLUDED ANGLE. ROOT FACE B. ROOT GAP C. PLATE PREPARATION	WELDING PROCEDURE A. BACKING B. DEPOSITION SIZE EL. NO. PASSES TYPE AMP. V. 1. ROOT TYPE 2. BODY TYPE 3. CROWN TYPE C. TOTAL WELDING TIME & INTER PASS TEMPERATURE D. REMARKS	HEAT A. PRE B. POST	BALLISTIC RESULTS # / VEL. F/S / LOCATION OF # (L.L. / H.L. / C B.) / CRACKING (LOC. / TYPE / AMT)	REMARKS ON CRACKING RADIOGRAPHIC RESULTS, ETC.
A. A 4603 B. 9/14/42 C. 18 D. Great Lakes Steel Corp. Jones & Laughlin E. Lincoln Electric Co. F. General Motors Truck & Coach Co.	A. 1/2" B. R IV GL .86Mn .74Si .65Cr .20Mo .06Zr C. .28C D. Face 331-352 Back 352-363 E. B.O.H. F. 1600°F ½ hr oil 975°F draw A. 1/2" B. R III J&L 1.73Mn .19Si .52Mo C. .28C D. Face 331-352 Back 352-363 E. B.O.H. F. 1625°F ½ hr water 1000°F draw	A. A II .10C 4.00Mn .50Si 20.0Cr 9.0Ni* B. Armorweld C. Lime D. DC-REV	A. 45° SV B. 3/16" C. Flame cutting.	A. Not given B. 1. I 5/32" 1a 90 - 2. III 3/16" 1a 1b 165 - 5/32" 1b 115 - 3. III 5/32" 2b 115 - 3/16" 1b 165 - C. 8 hours. 150°-200°F D. Some chipping after first pass. One seal bead. Left and upper center sections by Jones & Laughlin, right and lower center sections by Great Lakes.	A. None B. None	1 / 2600 / L.L. 3" L / C.B. 2½" D / - - - 2 / 2600 / H.L. 4½" L / C.B. 8" D / - - - 3 / 2600 / H.L. 3¼" R / C.B. 1½" U / - - - 4 / 2600 / L.L. 7½" L / C.B. 4" U / - - - 5 / 2600 / L.L. 6" R / C.B. 6½" U / - - - 6 / 2600 / H.L. 2½" R / C.B. 7" U / - - - 7 / 2600 / L.L. 3" L / C.B. 9" D / - - - 37mm HE M-54 projectile	P
A. A 3681 B. 7/8/42 C. 3 D. Jones & Laughlin Great Lakes Steel Corp. E. Linde Air Products Co. F. Gen'l Motors Truck & Coach Co.	A. 1/2" B. R III J&L 1.40Mn .18Si .50Mo C. .24C D. Face 341 Back 341 E. — F. — A. 1/2" B. R IV GL .96Mn .74Si .56Cr .20Mo C. .28C D. Face 341 Back 341 E. — F. —	A. A — B. Oxweld #42 C. 80 x 20D Flux D. —	A. 45° SV B. 1/16" C. —	A. Copper B. Unionmelt 3/16" 640 30 3/16" 640 32-1/2 C. 4 hours. — D. Corners ground out. Tacked at 8" spacing.	A. None B. None	2 / 670 / L.L. 2¼" R / Intact / - - - 3 / 696 / L.L. 2" L / H.L. " 4 / 710 / L.L. 3¼" L / H.L. " 6 / 689 / H.L. 3" L / C.B. 4" U / - - - 5 / 672 / L.L. X / C.B. 11" D / - - - 7 / 653 / H.L. X / C.B. 4" U / IMP / I / 2½" 37mm M-52 projectile - - - -	P 3/4" crack near left weld junction Small crack in lower left leg. Several large gas pores.
		*Weld metal					

IDENTIFICATION A. Firing record no. B. Date of test C. Plate no. D. Armor manufacturer E. Electrode mfgr. F. Armor fabricator	ARMOR DATA A. Plate thickness B. Type C. Carbon content D. BHN E. Process F. Heat treatment temp. time quench	ELECTRODE DATA A. Type B. Trade name C. Coating D. Current & polarity	JOINT DESIGN A. Groove. Included angle. Root face B. Root gap C. Plate preparation	WELDING PROCEDURE A. Backing B. Deposition size el. no. type amp. v. (Passes) 1. Root type 2. Body type 3. Crown type C. Total welding time & inter pass temperature D. Remarks	HEAT A. Pre B. Post	#	BALLISTIC RESULTS Vel. F/S	Location of # L.L.	R.L.	C.B.	Cracking Loc.	Type	Amt	REMARKS ON CRACKING RADIOGRAPHIC RESULTS, ETC.
A. AD 788 B. 8/16/42 C. H 98 D. Jones & Laughlin E. Harnischfeger Corp. F. Fisher Tank Division.	A. 1/2" B. R III 1.66Mn .26Si .39Mo C. .28C D. Face 311 Back 321 E. — F. 1600°F ½ hr water 875°F 1½ hr air	A. F .13C 1.54Mn .12Si .60Mo* B. AW-2-C C. Lime D. DC	A. 45° SV B. 3/8" C. Flame cutting. Grinding.	A. Mild steel B. 1. I 3/16" 1a 225 20 2. I 1/4" 3a 325 30 3. III 3/16" 3b 225 20 Three seal beads- 3/16" 225 20 C. 1:45 hours. 140°-185°F D. 3 minutes. chipping after each pass. 1 hour grinding to remove steel back up after flame gouging. Reinforcements removed.	A.None B.None	1 2	2577 2587 37mm HE M-54 projectile	 ½" R	½" R	2¼" U ½" D	IMP IMP IMP	I I V	1" 14½ 2½ 18" -	P Moderate amount of slag and porosity throughout the welds.
A. AD 788 B. 8/16/43 C. H 100 D. Jones & Laughlin E. Harnischfeger Corp. F. Fisher Tank Division	A. 1/2" B. R III 1.40Mn .25Si .52Mo C. .27C D. Face 363 Back 363 E. — F. 1600°F ½ hr water 875°F 1½ hrs air	A. F .13C 1.54Mn .12Si .60Mo* B. AW-2-C C. Lime D. —	A. 45° SV B. 3/8" C. —	A. Mild steel B. 1. I 3/16" 1a 200 21 2. I 1/4" 2a 325 21 3. I 1/4" 1a 325 21 C. 1:15 hours. 140°-200°F D. 3 minutes. chipping after each pass. 45 minutes of grinding after mild steel back-up was flame gouged out. Pass No. 1 was replaced by No. 5 1/4" 325 21 Reinforcements removed.	A.None B.None	1 2	2517 2556 37mm HE M-54 projectile	 X	¼" R	7¼" D 6¼" U	- IMP	- I	- 15½* -	P Moderate amount of slag and porosity in all the welds.
A. AD 788 B. 8/16/43 C. H 101 D. Jones & Laughlin E. Harnischfeger F. Fisher Tank Division.	A. 1/2" B. R III 1.40Mn .25Si .52Mo C. .27C D. Face 363 Back 363 E. — F. 1600°F ½ hr water 875°F 1½ hr air	A. F .13C 1.54Mn .12Si .60Mo* B. AW-2-C C. Lime D. DC	A. SV B. — C. Flame cutting. Grinding	A. Mild steel B. 1. I 3/16" 1a 200 21 2. I 1/4" 2a 325 21 3. III 5/32" 2b 165 21 1/4" 1b 325 21 Two seal beads- 5/32" 165 21 One seal bead- 1/4" 325 21 C. 1:28 hours 140°-200°F D. 45 minutes to grind out pass No. 1 after back-up strip was removed. 2 mins. of chipping after each pass. Reinforcements removed.	A.None B.None	1 2	2515 2521 37mm HE M-54 projectile	1" L	 ¼" L	4½" U 5" D	IMP IMP	I I	8" 11½ 19½* -	P Small amount of slag and porosity throughout the welds.
		*Weld metal												

IDENTIFICATION A. FIRING RECORD NO. B. DATE OF TEST C. PLATE NO. D. ARMOR MANUFACTURER E. ELECTRODE MFGR. F. ARMOR FABRICATOR	ARMOR DATA A. PLATE THICKNESS B. TYPE C. CARBON CONTENT D. BHN E. PROCESS F. HEAT TREATMENT TEMP. TIME QUENCH	ELECTRODE DATA A. TYPE B. TRADE NAME C. COATING D. CURRENT & POLARITY	JOINT DESIGN A. GROOVE. INCLUDED ANGLE. ROOT FACE B. ROOT GAP C. PLATE PREPARATION	WELDING PROCEDURE A. BACKING B. DEPOSITION SIZE EL. NO. TYPE AMP. V. (PASSES) 1. ROOT TYPE 2. BODY TYPE 3. CROWN TYPE C. TOTAL WELDING TIME & INTER PASS TEMPERATURE D. REMARKS	HEAT A. PRE B. POST	#	BALLISTIC RESULTS VEL. F/S	LOCATION OF # L.L.	R.L.	C B.	CRACKING LOC.	TYPE	AMT	REMARKS ON CRACKING RADIOGRAPHIC RESULTS, ETC.
A. AD 800 B. 6/25/43 C. H 105 D. Jones & Laughlin E. Harnischfeger Corp. F. Fisher Tank Division.	A. 1/2" B. R III 1.66Mn .2581 .39Mo C. .28C D. Face 311 Back 321 E. — F. 1600°F ½ hr water 875°F 1½ hr air	A. F .13C 1.54Mn .1231 .60Mo* B. AW-2-C C. Lime D. DC	A. 45° SV B. 3/8" C. Flame cutting. Grinding.	A. Mild steel B. 1. I 3/16" 1a 225 21 2. III 1/4" 1a 325 21 3/16" 2b 225 21 3. III 3/16" 2b 225 21 1/4" 1b 300 21 Two seal beads - 3/16" 225 21 One seal bead - 1/4" 300 21 C. 1.33 hours. 160°-180°F D. 4 minutes chipping after each pass; 32 minutes grinding to clean after removal of back-up. Weld reinforcement ground off.	A. None B. None	1	2500	1" L		3½" U	IMP	I	2"	F Excessive imperfect fusion and porosity.
						2	2533		½" R	8½" D	IMP	I	3½	
						3	2528		½" L	2¾" U	IMP	I	9"	
							2-7/8" x 3-1/8" opening after 2nd round. 3-3/8" x 3-1/2" opening after 3rd round.						14½"	
							37mm HE M-54 projectile						-	
A. AD 866 B. 9/3/43 C. H 111 D. Jones & Laughlin E. Harnischfeger Corp. F. Fisher Tank Division.	A. 1/2" B. R III 1.66Mn .2581 .25Mo C. .25C D. Face 311 Back 321 E. — F. 1600°F ½ hr water 875°F 1½ hr air	A. F .13C 1.54Mn .1231 .60Mo* B. AW-2-C C. Lime D. DC	A. 45°SV B. 3/8" C. Flame cutting. Grinding.	A. 1/4 x 1" Mild steel. B. 1. I 3/16" 1a 225 21 2. I 1/4" 2a 225 21 3. I 1/4" 1a 225 21 One seal bead- 1/4" 225 21 C. 1:12 hours. 120°-300°F D. 3 minutes chipping after each pass. 30 minutes grinding after back-up strip was removed. Weld reinforcements ground off.	A. None B. None	1	2522 (?)		1½" L	3½" U	-	-	-	F Excessive cracking and imperfect fusion in the welds; moderate amount of slag and porosity throughout the welds.
						2	2516	1½" R		6" D	-	-	-	
						3	2516		½" R	2¾" D	IMP	I	7"	
						4	2520	2¼" R		½" U	-	-	-	
													7"	
							37mm HE M-54 projectile						-	
A. AD 866 B. 9/3/43 C. H 114 D. Great Lakes Steel Corp. E. Harnischfeger Corp. F. Fisher Tank Division.	A. 1/2" B. R V 1.46Mn .2581 .33Cr .18Mo C. .25C D. Face 321 Back 311 E. — F. 1650°F ½ hr water 930°F ½ hr air	A. F .13C 1.54Mn .1231 .013Cr .60Mo* B. AW-2-C C. Lime D. —	A. 45° SV B. 3/8" C. —	A. 1/4 x 1" Mild steel B. 1. I 3/16" 1a 221 21 2. I 1/4" 2a 325 21 3. I 1/4" 1a 325 21 One seal bead- 1/4" 325 21 C. 1:09 hours. 120°-185°F D. 3 minutes chipping after each pass. 30 minutes grinding after removal of back-up strip. Weld reinforcements ground off.	A. None B. None	1	2513		1½" R	9" U	IMP	I	1½	F Excessive imperfect fusion slag and porosity.
						2	2516	½" R		7½" D	-	-	-	
						3	2565	2¼" L		6" U	-	-	-	
						4	2564		½" L	5" U	IMP	I	8"	
													9½"	
							37mm HE M-54 projectile						-	

*Weld metal

IDENTIFICATION A. Firing record no. B. Date of test C. Plate no. D. Armor manufacturer E. Electrode mfgr. F. Armor fabricator	ARMOR DATA A. Plate thickness B. Type C. Carbon content D. BHN E. Process F. Heat treatment temp. time quench	ELECTRODE DATA A. Type B. Trade name C. Coating D. Current & polarity	JOINT DESIGN A. Groove. Included angle. Root face B. Root gap C. Plate preparation	WELDING PROCEDURE A. Backing B. Deposition size el. / Passes: No. Type Amp. V. 1. Root type 2. Body type 3. Crown type C. Total welding time & inter pass temperature D. Remarks	HEAT A. Pre B. Post	R	BALLISTIC RESULTS Vel. F/S	Location of R L.L.	R.L.	C.B.	Cracking Loc.	Type	Amt	REMARKS ON CRACKING Radiographic results, etc.
A. AD 872 B. 9/7/43 C. H 115 D. Jones & Laughlin E. Harnischfeger Corp. F. Fisher Tank Division.	A. 1/2" B. R III 1.53Mn .18Si .35Mo C. .25C D. Face 341 Back 352 E. --- F. 1625°F ½ hr water 880°F ½ hr air	A. F .13C 1.54Mn .12Si .60Mo* B. AW-2-C C. Lime D. DC-REV	A. 45° SV B. 3/8" C. Flame cutting. Grinding.	A. Mild steel B. 1. I 3/16" 1a 250 21 2. III 1/4" 1a 2b 350 21 3. III 5/32" 2b 200 21 1/4" 1b 350 21 Two seal beads- 5/32" 200 21 One SB 1/4" 350 21 C. 1:33 hours 170°-380°F D. 3 minutes chipping after each pass. 19 minutes grinding after back-up strip was removed. Reinforcements removed.	A. None B. None	1	2513	1½" R		6¼" U	-	-	-	F 3/8" transverse crack in upper right leg weld; small amount of slag at both junctions.
						2	2518		1¾" R	9½" D	-	-	-	
						3	2518		1¾" R	5¾" U	-	-	-	
						4	2592	1½" R		5½" D	-	-	-	
							37mm HE M54 projectile						-	
A. AD 878 B. 9/11/43 C. H 116 D. Great Lakes Steel Corp. E. Harnischfeger Corp. F. Fisher Tank Division.	A. 1/2" B. R V 1.46Mn .25Si .33Cr .15Mo C. .23C D. Face 352 Back 352 E. --- F. 1650°F ½ hr water 930°F ½ hr air	A. F .13C 1.54Mn .12Si .013Cr .60Mo* B. AW-2-C C. Lime D. DC-REV	A. 45° SV B. 3/8" C. Flame cutting. Grinding.	A. Mild Steel B. 1. I 3/16" 1a 250 21 2. III 1/4" 1a 2b 350 21 3. III 5/32" 2b 200 21 1/4" 1b 350 21 One seal bead - 1/4" 350 21 Two seal beads- 5/32" 200 21 C. 1:31 hours 120° - 380°F D. 3 minutes chipping after each pass. 20 minutes grinding after back-up was removed. Reinforcement ground off.	A. None B. None	1	2511	¾" R		3½" U	IMP IMP	I V	6" 4½	P Small amount of slag throughout.
						2	2534		2½" R	8¼" D	-	-	-	
						3	2534		2"	7½" U	IMP O	I V	4¾ ½	
						4	2537	X		5½" D	O	V	½"	
													16¼"	
							37mm HE M54 projectile						-	
		*Weld metal												

IDENTIFICATION A. Firing record no. B. Date of test C. Plate no. D. Armor manufacturer E. Electrode mfgr. F. Armor fabricator	ARMOR DATA A. Plate thickness B. Type C. Carbon content D. BHN E. Process F. Heat treatment temp. time quench	ELECTRODE DATA A. Type B. Trade name C. Coating D. Current & polarity	JOINT DESIGN A. Groove. Included angle. Root face B. Root gap C. Plate preparation	WELDING PROCEDURE A. Backing B. Deposition size el. no. type amp. v. (Passes) 1. Root type 2. Body type 3. Crown type C. Total welding time & inter pass temperature D. Remarks	HEAT A. Pre B. Post	#	BALLISTIC RESULTS Vel. F/S	Location of # L.L.	Location of # R.L.	Location of # C B.	Cracking Loc.	Cracking Type	Cracking Amt	REMARKS ON CRACKING Radiographic results, etc.
A. AD 789 B. 8/17/43 C. U 44 D. Jones & Laughlin Steel Corp. E. Linde Air Products Co. F. Fisher Tank Division.	A. 1/2" B. R III 1.66Mn .2881 .39Mo C. .28C D. Face 311 Back 321 E. — F. 1600°F ½ hr water 875°F 1½ hr air	A. F. .17C .92Mn .6581 .42Mo* B. Oxweld #36 C. — D. —	A. 45° SV B. 1/32" C. Flame cutting. Grinding.	A. Yes B. Special Unionmelt. 3/16" 3a 650 30 3/16" 3a 600 38 C. 19.89 minutes. D. Weld reinforcement ground off.	A. None B. None	1	2515		1" R	3¼" U	-	-	-	P
						2	2513	¾" R		8¼" D	IMP	I	11¼"	Borderline amount of slag and porosity at left junction of crossbar.
							37mm HE M-54 projectile -							
A. AD 380 B. 3/19/43 C. Y-1 D. Great Lakes Steel Corp. E. Linde Air Products Co. F. General Motors Truck & Coach	A. 1/2" B. R IV .89Mn .6681 .66Cr .28Mo .09Zr C. .28C D. Face 363 Back 375 E. B.O.H. F. 1600°F ½ hr water 880°F 1½ hr air	A. F — B. Oxweld #36 C. # 20 (12 x 200) D. —	A. 45° SV B. 1/32" C. Flame cutting.	A. Copper B. Unionmelt 3/16" 630 30 3/16" 610 38 C. 5 hours. 10 °F D. Plates were tacked at 8" intervals with Fleetweld # 7 before Unionmelt welding.	A. None B. None	1	2600		½" R	9½" U	IMP	I	6½	P
											IMP	V	6½	Small star-shaped crater crack.
						2	2600	4" L		7½" D	-	-	-	
						3	2600	2½" L		3½" U	-	-	-	
						4	2600		3" L	9" D	O	I	1½	
						5	2600	1½ R		10" U	O	I	2	
													16½"	
							37mm HE M54 projectile -							
		*Weld metal												

RESTRICTED

TITLE: Report on Phase III Caribbean Area Shoran Project Part B - Results Volume III Atr Proving Ground Command Service Test 8 - 46-7	ATI- 38870
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ABSTRACT:

The Shoran method has made possibie for the first time the ttnking of Cuba and tslands in the Bahamas with the continentat datum of North America. The only limitation of the method is the length of tine which can be measured, which is a function of the attitude at which the Shoran piane flies. For the present, iines well in excess of 500 miles can be measured, and thts means that most of the istand bodies of the world and all continents can be placed on a uniform geodetic datum. It has been recommended that a requirement exists for Shoran geodetic surveys and that these shouid be continued and expedited.

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