WATERTOWN ARSENAL LABORATORY

EXPERIMENTAL REPORT

NO. WAL. 648/6

EVALUATION OF SHOCK PROPERTIES OF WELDED ARMOR JOINTS AT SUBNORMAL TEMPERATURES

Examination of Samples from 31 Commercially Welded "H" Plates Ballistically Shock Tested as Part of the 1942 - 1943 Canadian Cold Test Program

BY

S. A. Herres
1st Lt., Ord. Dept.

and

Anna M. Turkalo
Physical Science Aide

DATE 9 August 1944

WATERTOWN ARSENAL
WATERTOWN, MASS.

Watertown Arsenal Laboratory
Report No. WAL 648/6
Problem No. D-1.1

9 August 1944

EVALUATION OF SHOCK PROPERTIES OF WELDED ARMOR JOINTS AT SUBNORMAL TEMPERATURES

Examination of Samples from 31 Commercially Welded "H" Plates
Ballistically Shock Tested as Part of the
1942 - 1943 Canadian Cold Test Program

OBJECT

To establish conditions which contributed to inferior ballistic shock performance of subject plates.

SUMMARY OF RESULTS

1. It appears that a low temperature ballistic test of an armor weldment is more severe than the same test at normal temperature, but similar conditions lead to failure at low temperature as those causing poor or borderline performance at normal temperatures.

2. Geometry of the weld joint and location together with extent of macrodefects must be regarded as having considerable influence on both ballistic and laboratory test results. Inconsistencies in the ballistic test prevent strict comparisons between the various plates, and considerable caution must be exercised in drawing too definite conclusions on the basis of passing or failing of plates under these ballistic tests.

3. Nick-break and bend fracture tests (Figures 1 and 2) supplemented by notched bar impact tests and microscopic examination revealed the following as probable types of ballistic failure in the subject plates:

a. 1-1/2 inch thick austenitic hand welded rolled armor - predominantly fusion zone at bond line or in base metal immediately adjacent to bond line.

b. 1-1/2 inch thick austenitic hand welded cast armor - fusion zone at bond line or in base metal adjacent to bond line, fusion zone in weld metal adjacent to bond line, shock-deficient unaffected base metal, or shock-deficient austenitic weld metal.

c. 1-1/2 inch thick austenitic Unionmelt welded rolled armor - shock-deficient heat-affected zone or shock-deficient weld metal.

d. 1-1/2 inch thick austenitic Unionmelt welded cast armor - shock-deficient heat-affected zone or shock-deficient unaffected base metal.

e. 1 inch thick austenitic hand welded rolled armor - poor steel quality unaffected base metal and heat-affected zone, fusion zone at bond line or in base metal adjacent to bond line, fusion zone in weld metal adjacent to bond line, or shock-deficient austenitic weld metal.

f. 1/2 inch thick austenitic hand welded rolled armor - predominantly shock-deficient heat-affected zone near fusion line.

g. 1/2 inch thick austenitic Unionmelt welded rolled armor - shock-deficient austenitic weld metal or shock-deficient heat-affected zone.

h. 1/2 inch thick ferritic Unionmelt welded rolled armor - shock-deficient heat-affected zone, or shock-deficient ferritic weld metal.

4. The following conditions appear to have caused the above types of failure:

a. Fusion zone failure at bond line or in base metal immediately adjacent to bond line - associated with a precipitation of stable chromium carbides at bond line with resultant decarburization and deterioration of base metal properties for a distance usually not exceeding two-thousandths of an inch from weld metal bond line. The predominance of this type of failure is believed to be a result of the high interpass temperature used in welding certain of the plates.

b. Fusion zone failure in weld metal adjacent to the bond line - the usual type of fusion zone failure observed in austenitic hand welded plates previously examined. Believed to be associated with a linear precipitation of nonmetallics in weld metal adjacent to bond line.

c. Failure through shock-deficient unaffected base metal - believed to be a result of incomplete quench hardening (poor quenching practice, insufficient hardenability, or a combination of the two) as established by previous investigations (by the Armor Section of this Laboratory) of unwelded armor plate involved in the Canadian Cold Test Program.

d. Failure through shock-deficient austenitic weld metal - believed to be a result of dendritic metallic segregation in weld metal composition which was not properly balanced to remain wholly austenitic after dilution with base metal.

e. Failure through shock-deficient heat-affected zone - associated with heterogeneous microstructure caused by incomplete quench hardening of heat-affected base metal slowly cooled during the welding cycle. Avoided only by use of higher alloy armor plate or a welding procedure involving lower heat input in relation to the plate thickness.

f. Failure through heat-affected zone or unaffected base metal of poor steel quality armor - associated with severe laminations or concentration of nonmetallic inclusions into planes of weakness.

g. Failure through shock-deficient ferritic weld metal - associated with heterogeneous microstructure developed when weld metal has insufficient alloy to quench harden during the welding cycle.

5. These conditions, particularly the use of poor quality and inadequately quench-hardened armor and the use of electrodes and welding procedures which produced shock-deficient structures in the weld metal, at the fusion zone, or in the heat-affected base metal, are sufficient cause for the relatively very poor ballistic performance of the subject plates.

S. A. Herres
1st Lt., Ord. Dept.

A. M. Turkalo
Anna M. Turkalo
Physical Science Aide

APPROVED:

H. H. ZORNIG
Colonel, Ord. Dept.
Director of Laboratory

A-1

INTRODUCTION

Samples from thirty-one H plates commercially welded and ballistically tested as part of the 1942 - 1943 Cold Test Program were received at this laboratory during February 1944. Previously, all of the approximately 150 plates tested in the Cold Test Program were divided into three groups: (1) H plates welded by Unionmelt process; (2) H plates manually welded with Mn-modified austenitic electrodes; (3) H plates manually welded with Mo-modified austenitic electrodes; and representative plates selected from each group were apportioned to three industrial laboratories for investigation in conjunction with the NDRC project on Weldability of Commercial Armor Plate. NDRC reports[1,2] covering investigations of the first two groups have been issued and the third is expected shortly.

The subject samples include representative plates from each of the above three groups. The purpose of this report is to apply the nick-break weld joint fracture and bend fracture tests, as developed in connection with a recent examination of thirty-three commercially welded H plates ballistically tested at normal temperatures[3], as a means of clarifying the principal conditions which contributed to inferior ballistic performance of the subject plates. It was desired to hold metallographic work to a minimum, avoiding duplication of work carried out in the previous investigations, but investigating by means of notched bar impact tests and microscopic examination any deleterious metallurgical conditions not previously observed.

TEST MATERIALS AND TEST PROCEDURE

Samples, 12 inches x 12 inches x thickness of plate were flame-cut from a portion of undamaged leg weld of the following groups of H welded ballistic test plates:

Plate		Location of Sample
1-1/2 inch Thick Austenitic Hand Welded Rolled Plates		
Fisher	CTF3A	Upper right leg
"	CTF6	Lower left "
"	CTF11	" " "
"	CTF14	" right "
"	CTF16	Upper left "
"	CTF21	Lower right "

1 "Weldability of Commercial Armor Plate (OD-82): Investigation of Welded H-Plates from the 1942-1943 Canadian Cold Test. Part I. H-Plates Welded by the Unionmelt Process," U.S.Steel Corp., Research Laboratory, April 30, 1944.

2 "Weldability of Commercial Armor Plate (OD-82): Investigation of Welded H-Plates from the 1942-1943 Canadian Cold Test. Part II. H-Plates Manually Welded with Austenitic Cr-Ni-Mn Electrodes," The International Nickel Co. Research Laboratory, June 14, 1944.

3 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," 10 June 1944, S. A. Herres and A. M. Turkalo.

Plate	Location of Sample
1-1/2 inch Thick Austenitic Hand Welded Cast Plates	
Baldwin 40	Upper left leg
Briggs M34	Lower " "
Chrysler CP47	" " "
Chrysler CP51	Upper right "
Fisher CTF22	Lower " "
Fisher CTF28	Upper " "
Ford W51	Lower " "
International 39	" left "
1-1/2 inch Thick Austenitic Unionmelt Welded Rolled Plates	
Briggs UM30	Upper right leg
Fisher UCTF1A	Lower " "
" UCTF5	" " "
" UCTF8	" " "
1-1/2 inch Thick Austenitic Unionmelt Welded Cast Plates	
Midland CO3	Lower left leg
1 inch Thick Austenitic Hand Welded Rolled Plates	
Cadillac 94	Lower left leg
" 96	" " "
" 97	" " "
Ternstedt TH68	" " "
1/2 inch Thick Austenitic Hand Welded Rolled Plates	
Gen. Motors Truck C11	Lower left leg
" " " C14	Upper right "
" " " C17	" left "
" " " C21	" right "
1/2 inch Thick Austenitic Unionmelt Welded Rolled Plates	
Gen. Motors Truck C7	Lower left leg
" " " C10	Upper right "
1/2 inch Thick Ferritic Unionmelt Welded Rolled Plates	
Gen. Motors Truck C3	Upper left leg
International D5-45-22	" right "

Firing record data including fabricator, armor type, composition, and manufacturer; electrode type, composition, and manufacturer; joint preparation; welding procedure; and ballistic test results have been tabulated on Charts 1 through 13 of Appendix A.

Samples were notched and broken as indicated in Figure 1 to develop fibre characteristics of plate metal, heat-affected zone and weld metal on fractured surface through weld joint.

Two bend bars, one for testing at room temperature and another for testing at -40° F., were taken transversely through weld joint on one-half of broken fracture sample. Bars from 1 inch and 1-1/2 inch plates were broken in a steam press and bars from 1/2 inch thick plates by a single drop of a 110-lb. weight from a height of 15 feet. Bars broken at the cold temperature were immersed in an acetone dry ice bath at -40° F. for one-half hour prior to testing.

To supplement fracture and bend test data Charpy bars and samples for microscopic examination were taken from some of the test plates. Standard Charpy bars with V-notch located in center of weld metal were taken at midwall transversely through weld joint of plates Fisher CTF3A, CTF11, UCTF5, and CTF22. Two bars from each plate were broken at 70° F. and one at each of the following temperatures: 0°, -20°, -40°, and -100° F. All-plate metal Charpy bars, midwall and perpendicular to the weld, were taken from plates Fisher CTF3A, Chrysler CP51, General Motors 94 and 96, and Ternstedt TH68. Two bars from each plate were broken at 70° F. and one at each of the following temperatures: 0°, -20°, and -40° F. Charpy bars broken at subnormal temperatures were held in an acetone dry ice bath for fifteen minutes at the testing temperature prior to breaking.

Samples for microscopic examination were taken transversely through weld joints of plates Fisher CTF3A, CTF11, CTF14, CTF21, CTF22, UCTF5, Chrysler CP47, and General Motors plates C11 and C17. In addition, samples for microexamination were taken from some of the broken weld Charpy bars.

GENERAL COMMENTS

1. Ballistic Shock Tests

Results of ballistic tests of subject plates are given in Charts 1 through 13 (Appendix A) which are abstracts of the original firing records. A summary of the ballistic shock test specification requirements in force at the present time and those in force at the time of the Camp Shilo cold tests is also included in Appendix A. Ballistic shock test results of the subject plates are further summarized in Table I.

In order to provide a proper perspective of the ballistic performance of the H plates from which the subject samples were selected, eight tables summarizing the ballistic tests of all welded H plates for the Canadian Cold Test Program are included in Appendix B. These tables were abstracted from Report No. WAL 642/117[4]. Plate groups for International D5-45-22, welded in Canada, and Fisher CTF22, welded with special 12% Cr, 6% Ni, 6% Mn electrode are not included in these general summary tables.

---

(4) Report No. WAL 642/117, "Arc Welding of Armor - Summary of Ballistic Tests of Welded 'H' Plates in Rolled and Cast Homogeneous Armor Plate at Sub-Zero Temperatures at Camp Shilo, Canada, during the Winter of 1942-1943," W. L. Warner.

It is readily apparent that inconsistencies of velocity, eccentricity, and number of ballistic impacts prevent strict comparison of the shock properties of the various plates. Many plates which were judged passing or failing on the basis of one round were neither good nor bad but borderline, as often shown by inconsistent performance on later impacts. Considerable caution should be exercised in drawing too definite conclusions on the basis of passing or failing of ballistic shock test.

Location of ballistic cracking as reported in firing records is based on surface appearance only. We are indebted to Dr. Aborn for a summary of his investigation of the actual path of ballistic failure for a number of the cold test H plates (Table IX, Appendix B).

2. Low Temperature Shock Resistance of Armor Plate

It has been known for many years that "Steel is far more brittle under shock when very cold (say 0° F.) than at ordinary temperatures"[5]. Gillett[6] in a review "On Properties of Metals at Subatmospheric Temperatures," says, "The correlation of deoxidation practice, heat-treatment and the resulting grain size with low-temperature impact resistance was clearly brought out in the classical work of Herty and McBride published in 1934. Since that time there has been no excuse for neglecting to consider these factors in relation to low-temperature behavior."

Two Watertown Arsenal Reports[7,8] correlate low temperature ballistic shock performance with metallurgical properties of 1 to 2-inch unwelded, rolled and cast armor tested at Camp Shilo. The general conclusions of these investigations are:

(1) Low temperature (-10° to -40° F.) ballistic shock tests are more severe than the same test conducted at normal temperature and may reveal the poor shock characteristics of borderline quality armor.

(2) The most important cause of poor performance was the heterogeneous microstructure resulting from incomplete quench hardening (poor quenching practice, insufficient hardenability, or a combination of the two).

---

(5) "The Metallurgy of Steel," H.M. Howe, The Engineering and Mining Journal, New York and London, 1904, Vol. 1, p.70.

(6) "Impact Resistance and Tensile Properties of Metals at Subatmospheric Temperatures," H.W. Gillett, American Society for Testing Materials, 1941, p.26.

(7) Report No. WAL 710/534, "Correlation of Metallurgical Properties with the Low Temperature Ballistic Shock Characteristics of 1 in. to 2-in. Low Alloy Cast Armor Tested at Camp Shilo," P.V. Riffin.

(8) Report No. WAL 710/662, "Correlation of Metallurgical Properties with Low Temperature Ballistic Performance of 1 in., 1-1/2 in., and 2-in. Rolled Armor Tested at Camp Shilo, Canada," M. Bolotsky.

testing, and the constraint due to thickness of plate, weld joint geometry, and presence of macrodefects. Experience has shown that a slowly applied load at room temperature provides a suitable test for 1-1/2 inch thick bars but for bars of less than 1 inch thickness the situation is not so clear. The rate of loading can be advanced to that of a freely falling weight dropped from a height of approximately 15 feet and the temperature of testing lowered to approximately -100° F. by immersing in a bath of dry ice and acetone. However, even at -100° F. it may not be possible with the drop weight to produce a brittle fracture in an unnotched bend bar of 1/2 inch thick slack-quenched armor plate.

DATA AND DISCUSSION

1-1/2 inch Thick Austenitic Hand Welded Rolled Plates

Tables III, IV, and VIII (Appendix B) indicate generally very poor ballistic shock performance of this group. Thirty-two plates were tested cold and one at normal temperature (after return to Aberdeen Proving Ground). Although 14 of the plates withstood one impact at velocity of specification in force at the time of testing without excessive cracking, the narrow margins of success and the inconsistent performance on additional impacts indicate borderline performance for the passing plates without exception. Table IX (Appendix B) indicates that about 75% of the ballistic fracture was in the fusion zone.

Nick-break test results for the six samples from these plates (Table II) reveal no tendency for low impact energy failure of weld metal, weld heat-affected zone, or unaffected plate. The path of failure in the bend fracture tests (Table III) is predominantly in the fusion zone. Typical fractured specimens are shown in Figure 3.

Three conditions which may lead to fusion zone failure in austenitic hand welded plates have been recognized: (1) Incomplete fusion and fusion zone cracks; (2) Linear precipitation of nonmetallics in weld metal adjacent to fusion line; (3) Precipitation of carbides at weld-plate interface.

Examples of the latter two types of fracture are shown in Figure 4. The upper left photograph shows the fractured surface of a bend bar from a butt weld made in 1-1/2 inch thick Carnegie-Illinois armor plate with a typical austenitic electrode welding procedure. The characteristic scaled appearance of the fracture surface is representative of the majority of the failures observed in austenitic hand welded plates previously examined[10]. The center left photomicrograph is a typical view of an unbroken section of the plate-weld junction showing the precipitation of nonmetallic inclusions lined up parallel to the fusion line. The lower left photomicrograph is a section through a nickel-plated fracture edge showing the path of failure in the bend fracture bar. The type of fracture represented by these three pictures is predominantly through the weld metal at a distance from the fusion line which coincides with the usual location of the inclusions.

---

(10) See footnote 3, page 3.

The upper right photograph of Figure 4 shows the fractured surface of a bend bar taken from the same weld and given a heat treatment of 1100° F. for 1 hour. The heat treatment caused a change in the appearance and path of fracture. Instead of having a dull scale of weld metal, the fracture surface now has a bright crystalline appearance. The center right and lower right photomicrographs are sections through nickel-plated fracture edges showing the path of failure in reheated bend fracture bars. The fracture represented by these last pictures is for the most part either along the carbides precipitated in the plate-weld bond line or in the plate metal adjacent to this line. Apparently, upon reheating, carbon diffuses from the base metal to the weld interface where a stable chromium carbide is formed, a phenomenon very similar to intergranular carbide precipitation in stainless steels. This results in decarburization with consequent softening and loss of strength of the base metal adjacent to the fusion line.(11)

The softening is demonstrated in the upper left photomicrograph of Figure 5 which shows Knoop microhardness indentations in the Carnegie armor plate weld reheated to 1100° F. for 1 hour. Relative hardnesses were 308* for austenitic weld metal, 275 for decarburized base metal, and 347 for tempered heat-affected zone.

The type of failure observed in the bend fracture of the austenitic hand welded 1-1/2 inch rolled plates (Table III and Figure 3) is similar to that observed in the reheated bend bars. While the cold test H plates were not tempered after welding, the interpass temperature was permitted on a number of the plates to exceed by several hundred degrees the present specification limit of 100° F. above the initial plate temperature (see welding data, Appendix A). The upper right and center left photomicrographs of Figure 5 show that the interpass heat has been sufficient to cause carbide precipitation with adjacent base metal decarburization in cold test plates. The center right photomicrograph shows the carbides etched with Murakami reagent. The lower left photomicrograph shows a typical section of the fractured edge of a bend bar from a cold test plate.

Occasionally the path of fracture in these plates extends into the heat-affected base metal beyond the decarburized zone, often at a lamination. If the interpass temperature is very high the rate of cooling will be retarded and a shock-deficient slack-quenched structure (see discussion of Unionmelt welds) is observed. The extent of such a structure is limited in the 1-1/2 inch plates, but is more prevalent in lighter gage plates. The lower right photomicrograph of Figure 5 shows the path of a bend bar fracture through a slack-quenched area in a 1/2 inch thick plate at a location which has not been reheated sufficiently to precipitate carbides. Very little intergranular failure was observed.

There appears to be a greater tendency for failure through the decarburized zone in bars from the cold test plates when broken at cold temperature. Geometry of the weld may be demonstrated to influence amount

---

(11) See also, "Welding Handbook," American Welding Society, 1942 edition, page 795.

* Average Knoop hardness number. Values are erratic and higher where slight amount of tempered martensite is present.

of fusion zone failure in bend fracture tests. Liberal root gaps and included angles and the use of heavy beads at the side of the crown (so-called annealing beads) tend to throw fracture into ductile weld metal where its propagation may be somewhat more difficult. In this connection it should be noted that the location of the ballistic impact or the point of application of load in the bend-fracture test will have a very important effect on the path, and hence the extent of fracture. In the present bend tests the load was applied at the center of the weld, but it has been demonstrated that there is a tendency for fusion zone failure if the load is applied at the edge of the weld. The variation of location of ballistic impacts with respect to weld geometry and location of macro-defects very easily accounts for the inconsistencies of ballistic shock testing.

Plate CTF11 showed a large proportion of bend fracture in weld metal which had a peculiar brittle dendritic appearance. This type of failure will be discussed in connection with similar fractures observed in the next group of plates.

1-1/2 inch Thick Austenitic Hand Welded Cast Plates

Tables V, VI and VIII (Appendix B) indicate that six of the thirty-three plates in this group passed ballistics. However, comparison of the results with either the current or the old specification requirements shows that none of the plates showed satisfactory ballistic performance and that probably twenty-four plates should be regarded as "no test" of the weld because of excessive cracking of the unaffected base metal.

Nick-break test results (Table 11) reveal crystallinity in unaffected plate for all of the eight cast armor samples. Table IX (Appendix B) indicates that about 28% of the ballistic fracture was in unaffected base metal and 46% in fusion zone. Bend fracture tests of the eight samples showed similar tendencies except for plates CTF22 and CTF28 which broke brittlely through center of weld metal. Figures 6 and 7 show typical nick-break and bend fractures including the two plates which developed brittle failure in the weld metal.

Failure through the unaffected base metal appears to be a result of incomplete quench hardening as established in previous investigations by the armor section (see General Comments - low temperature shock resistance of armor plate). Fusion zone failure is believed to be caused by the same conditions discussed in the section on 1-1/2 inch thick hand welded rolled plates.

Since austenitic weld metal generally remains ductile and tough even at extremely low testing temperatures, the brittle austenitic weld metal condition, which was also observed to some extent in 1-1/2 inch austenitic hand welded rolled armor plate No. CTF11 and Unionmelt welded plate UCTF5, was investigated. Plate CTF22 was welded with an electrode of the 12% Cr, 6% Ni, 6% Mn type. V-notch Charpy impact tests of this weld metal (bar transverse to weld with notch located at center and midwall of weld) showed 49-69 ft.lbs. at room temperature with a drop to 21 ft.lbs. at 0° F. and lower testing temperatures. Weld metal specimens from plates CTF11 and UCTF5 showed similar, but less severe decrease (76-88 ft.lbs. at room temperature to 45-49 ft.lbs. at -100° F. - most of the loss in impact energy below -40° F.). Specimens from 1-1/2 inch thick austenitic rolled armor H plate CTF3A which showed no tendency to develop brittle weld metal failure maintained a V-notch Charpy impact level of 73 ft.lbs. to -100° F. testing temperature.

Photomicrographs (Figure 8) of these four weld metals (taken on polished section from Charpy bars midwall and center of weld) showed no significant results upon etching with aqua regia glycerol. Nor were there any large differences in weld metal hardnesses as measured by Vickers-Brinell indentations. But, a pronounced dendritic pattern was revealed by use of an alkaline ferricyanide etch. It is believed that the dark constituent is high Cr ferrite which formed as a result of dendritic metallic segregation in weld metal composition which was not properly balanced in alloy elements to remain wholly austenitic after dilution with base metal. This distribution of ferrite would tend to promote brittle failure of the type observed. Very little of this constituent was observed in the midwall of plate CTF3A; however, the root passes of all 18/8 austenitic welds, which are heavily diluted with base metal, tend to develop this structure. In some limited application the use of higher alloy (25% Cr, 20% Ni) might be advantageous for root passes, but there is no evidence to indicate that this would overcome the tendency for fusion zone failures in 1-1/2 inch thick hand welded plates.

1-1/2 inch Thick Austenitic Unionmelt Welded Rolled Plates

Table VII (Appendix B) indicates that all twelve plates in this group failed ballistic shock test by large margins. Table IX (Appendix B) indicates that 85% of ballistic fracture was in heat-affected base metal.

Nick-break test results (Table II) reveal crystalline heat-affected zone fracture for all samples. Bend fracture tests (Table III and Figure 9) show preponderance of failure to be in heat-affected base metal. As discussed in a previous report[12], this condition is brought about by the high heat input of the Unionmelt process. The base metal adjacent to the weld is heated to a high temperature and slowly cooled. The result is a slack-quenched heat-affected zone which can be avoided only by use of very high alloy armor plate or by use of a procedure involving much lower weld heat input.

The brittle failure through a portion of the weld metal of plate UCTF5 was discussed in the preceding section.

---

(12) See footnote 3, page 3.

1-1/2 inch Thick Austenitic Unionmelt Welded Cast Plates

These plates combined the bad features of slack-quenched cast armor plate and Unionmelt heat-affected zones. As indicated by Table VII (Appendix B) all three plates of this group failed ballistic shock test very badly.

Nick-break fracture test of sample plate (Table II) showed crystallinity of both unaffected and heat-affected base metal. Bend tests (Table III) indicate failure through plate and heat-affected zone at room temperature, with some fusion zone failures at -40° F.

1 inch Thick Austenitic Hand Welded Rolled Plates

Tables II and VIII (Appendix B) show that all of the thirteen plates in this group which were tested at cold temperature failed to meet the ballistic shock specification in force at the time. Of seven plates tested at normal temperature (after return to Aberdeen), four failed ballistics and three passed by a narrow margin. Table IX (Appendix B) indicates that about 45% of ballistic failure was in weld metal, 38% in bond zone, and 17% in heat-affected base metal.

Nick-break tests (Table II) revealed fibrous fractures, but three of the four samples are severely laminated. Bend tests (Table III and Figures 10 and 11) showed fractures through weld metal (associated with weld metal cracks and incomplete fusion - Plate TH68), fusion zone, heat-affected and unaffected base metal. The poor steel quality of plates 94, 96, and 97 lead to the belief that the plate and heat-affected zone ballistic cracking of these plates might be associated with directional properties in the fairly dirty steels. V-notch Charpy impact bars, therefore, were taken in unaffected plate metal midwall and perpendicular to weld. Impact values were as follows:

	Temperature of Testing			
Plate No.	70°F.	0°F.	-20°F.	-40°F.
94	18, 20	20	18	17
96	19, 18	14	15	15
TH68	32, 33	31	32	30

The very low Charpy impact values for plates 94 and 96 are the effect of nonmetallic inclusions elongated in the principal rolling direction which is always supposed to be parallel to the leg welds in an H plate. The impact values for these same plates would have been very high if the Charpy bars had been taken parallel to the principal rolling direction. Plate TH68 while fairly dirty has apparently been cross-rolled to a greater extent, and has impact values of almost twice those of plates 94 and 96, but some 10 to 15 ft.lbs. lower than good quality current armor at the same hardness level (300 Brinell). The absence of crystallinity in the fractured specimens (Figures 10 and 11) and the fact that there was no real decrease in the Charpy impact energy with temperature lead to the conclusion that the proportion of heat-affected and unaffected base metal failure in this group of plates was due to dirty steel and poor rolling mill practice rather than to inadequate heat treatment or poor welding procedure.

The bond zone failure of plate 97 and the weld metal failure of plate TH68 (Figure 11) probably are caused by precipitation of carbides at bond zone (see section on 1-1/2 inch Thick Austenitic Hand Welded Rolled Plates) and weld defects (root bead cracking and incomplete fusion) respectively.

1/2 inch Thick Austenitic Hand Welded Rolled Plates

Tables I and VIII (Appendix B) show that six plates were tested cold and one at normal temperature (after return to Aberdeen). These plates were tested with a 37 mm. high explosive test projectile at a velocity 75 f/s above that of the current specification. A large proportion of the rounds struck outside the 2-inch limit for fair hits and it is very difficult to judge the ballistic quality of this group of plates. However, the plates welded with Jones and Laughlin armor and either Mn or Mo modified electrodes appear to be ballistically acceptable, and the plates welded from two other armor types unsatisfactory. The large amount of ballistic cracking in the unaffected plate metal with the latter two armor types suggests poor steel quality.

Nick-break tests (Table II) indicate fibrous fractures, but two of the four samples (C17 and C21) were severely laminated. Bend tests (Table III and Figure 12) show a high proportion of fusion zone failure in plates C17 and C21 which were very poor ballistically. There was less of this type failure in plates C11 and C14 probably because of a more favorable weld geometry (see section from plate C11 - Figure 12 - which did not break in the room temperature drop weight test).

Microscopic examination of specimens from plates C17 and C11 revealed some precipitation of carbides at the fusion line and a considerable amount of high temperature transformation carbides in the heat-affected base metal bordering the weld, as illustrated in Figure 5 and discussed in connection with the 1-1/2 inch thick austenitic hand welded rolled armor plates. These conditions are caused by reheating and slow cooling of this zone during welding and made worse by the high interpass temperature.

1/2 inch Thick Austenitic Unionmelt Welded Rolled Plates

Tables VII and VIII (Appendix B) show that of six plates tested, four failed ballistic shock test at subnormal temperature, while two passed the test at normal temperature (after return to Aberdeen). Table IX (Appendix B) lists 80% of ballistic failure as occurring in heat-affected base metal.

Nick-break tests of the two samples examined (Table II) reveal crystalline slack-quenched, heat-affected base metal fractures and brittle columnar dendritic fractures through austenitic weld metal. Bend fractures (Table III and Figure 13) show fracture with little or no deformation through weld metal and heat-affected base metal. These tests indicate that the 1/2 inch thick austenitic Unionmelt welded plates have very poor shock properties. Cold temperature ballistic shock tests produce severe failures, but the plates may pass the normal temperature shock test.

It is interesting to note that in the absence of cracks or notches, an amount of brittle, low energy of impact, constituent which would produce severe failure in welded plates of heavier gages, is acceptable under the present normal temperature ballistic shock test for 1/2 inch thick or lighter gage plates. However, at low temperatures of testing these constituents, which break with little or no deformation in the fracture test, may lead to severe ballistic failure.

1/2 inch Thick Ferritic Unionmelt Welded Rolled Plates

Tables VII and VIII (Appendix B) show ballistic failure of all seven plates tested cold and one failure in two plates listed at normal temperature (after return to Aberdeen). Table IX (Appendix B) lists 70% of failure as occurring in the heat-affected base metal.

One sample of a plate which failed the ballistic test at cold temperature was received. The second sample, International Harvester of Canada (plate D5-45-22), was not included in the Cold Test Program but was a duplicate of plates tested cold. It was tested at normal temperature at Aberdeen and passed the ballistic shock test. Weld reinforcements were ground flush with plate surface on back face prior to ballistic testing of both these plates. As previously discussed[13], this practice removes notch at junction of plate surface and weld metal, considerably improving shock resistance in ballistic or bend fracture tests, but is not regarded as representative of fabrication armor weldments.

Nick-break tests of the two samples (Table II reveal crystalline, slack-quenched, fracture of heat-affected base metal. Weld metal fracture of plate C3 of the low alloy Unionmelt ferritic type previously found to have Charpy impact values of approximately 15 ft.lbs. at room temperature and 7 ft.lbs. at 0° F. showed large crystalline patches. Nick-break weld fracture of plate D5-45-22 (Figure 13), of a higher alloy analyses, showed only slight amount of crystallinity.

In the absence of notches or weld defects it is not usually possible to fracture 1/2 inch thick bend bars with the drop weight test. When bend fracture tests were made on four bars from these two plates (Table III and Figure 13) with the face of the weld, which had been ground flush, on the tension side of the bend bar, only one failure through the slack-quenched heat-affected zone was obtained. However, when additional bars were tested with the unground face down, they all fractured brittlely through the slack-quenched heat-affected zone.

---

(13) See footnote 3, page 3.

It appears that the same situation applies in ballistic testing of these plates. If the weld is free of defects and notches are carefully removed from ballistic back face, the plate may pass (plate D5-45-22 at normal temperature - see Table I). If failure is started at a notch, weld defect, or by sufficient increase in velocity of testing, very severe failure may occur, particularly at low temperature, through the slack-quenched, low impact energy level, heat-affected base metal (plate C3 at cold temperature - see Table I). Unless there is assurance that notches can be avoided in fabrication welding, qualification testing of plates with reinforcement removed does not appear justified.

GENERAL COMMENTS

The results of nick-break and bend fracture tests supplemented by notched bar impact tests and microexamination revealed various conditions which contributed to inferior ballistic performance of certain of the H welded plates which were ballistically shock tested as part of the 1942 - 1943 Canadian Cold Test Program. The various types of failure and the conditions which appear to have caused them are tabulated in the Summary of Results at the beginning of this report.

The relatively very poor ballistic performance of the majority of the subject plates appears to be a result of the use of electrodes or welding procedures which produced shock-deficient structures in the weld metal, at the fusion line, or in the heat-affected base metal, or the use of poor quality or inadequately quench-hardened armor plate. The futility of welding H plates from poorly made or improperly heat-treated armor plate has been repeatedly demonstrated(14).

The geometry of the weld joint, particularly with respect to its influence on the initiation and ease of propagation of fusion zone failures, must be regarded as a major factor affecting results of both ballistic and laboratory tests.

It appears that a low temperature ballistic test of an armor weldment is more severe than the same test at normal temperature, but that similar conditions lead to failure at low temperature as those causing poor or borderline performance at normal temperature.

---

(14) Report No. WAL 640/89, "Welding of Armor - Summary of Ballistic Shock Test Results on 1 Inch and 3/4 Inch Homogeneous Armor 'H' Plates Welded with Austenitic Electrodes and Tested at Aberdeen Proving Ground during the Period from 1 October 1942 through 31 March 1943," A. M. Turkalo and S. A. Herres.

TABLE I

Ballistic Shock Test Results

Plate Number	Projectile	Round No.	Eccentricity (center impact to center weld) in.	Velocity f/s	Weld Cracking (within 1/8 in. of weld) in.	Plate Cracking (outside 1/8 in. of weld) in.	Temperature of testing °F.
1-1/2 inch Thick Austenitic Hand Welded Rolled Plates							
Fisher CTF3A	75 mm. T21	1	1/4	1091	10	0	-18.5
		2	3	1089	29	0	
Fisher CTF6	"	1	1	1100	23	4	-30
		2	3/4	1098	9	2-1/4	
Fisher CTF11	"	1	1-1/4	1097	27-1/2	0	-18.8
Fisher CTF14	"	1	1/2	1110	36	0	-15
Fisher CTF16	"	1	3/4	1094	37	0	-18
		2	2	1095	26	4	
Fisher CTF21	"	1	1/4	1098	36	0	-15
1-1/2 inch Thick Austenitic Hand Welded Cast Plates							
Baldwin 40	75 mm. T21	1	1-3/4	818	0	0	-19
		2	1/2	896	0	0	
		3	2	1002	0	0	
		4	1	1048	9	16	
Briggs M34	"	1	2-1/2	822	0	0	-20
		2	2-3/4	823	0	0	
		3	1-3/4	920	0	0	
		4	3/4	1001	18-1/4	25-1/2	
Chrysler CP47	"			prior to testing	6		-20
		1	1-1/2	809	8	0	
		2	1-3/8	911	1-3/4	44-3/4	
Chrysler CP51	"	1	2-1/2	802	11	38-7/8	-20
		2	0	907	2-3/4	15-1/2	
Fisher CTF22	"	1	6-1/2	792	0	0	-20
		2	1/2	909	4-1/2	4-1/4	
		3	0	1058	17-1/2	16-1/4	

TABLE I (Cont. - p.2)

Plate Number	Projectile	Round No.	Eccentricity (center impact to center weld) in.	Velocity f/s	Weld Cracking (within 1/8 in. of weld) in.	Plate Cracking (outside 1/8 in. of weld) in.	Temperature of testing °F.
Fisher CTF28	75 mm. T21	1	2	805	12	0	-29
		2	0	903	9-1/4	1-3/8	
		3	3/4	1001	30-1/4	0	
Ford W51	"			prior to testing	7-3/8		-20
		1	2-3/4	812	4-1/8	0	
		2	3/4	900	16-1/2	0	
International 39	"	1	4	779	0	0	-22
		2	0	899	7-1/2	11-1/2	
1-1/2 inch Thick Austenitic Unionmelt Welded Rolled Plates							
Briggs UM30	75 mm. T21	1	3-1/2	1110	0	0	+20
		2	0	1083	36-1/2	0	
Fisher UCTF1A	"	1	1	823	36	0	-15
Fisher UCTF5	"	1	3-1/2	651	35	0	-13
Fisher UCTF8	"	1	0	772	36	0	-13
1-1/2 inch Thick Austenitic Unionmelt Welded Cast Plates							
Midland CO3	75 mm. T21	1	1/2	865	36	10-1/2	-20
1 inch Thick Austenitic Hand Welded Rolled Plates							
Cadillac 94	75 mm. T21	1	0	804	24	0	-19
Cadillac 96	"	1	1	784	32	0	-17
Cadillac 97	"	1	2-1/4	774	0	0	-17
		2	2	775	8-1/2	8-1/2	
		3	1-1/4	782	9-3/4	15-1/2	
Ternstedt TH68	"	1	1-1/4	782	22-1/2	0	-15

TABLE I (Cont. - p.3)

Plate Number	Projectile	Round No.	Eccentricity (center impact to center weld) in.	Velocity f/s	Weld Cracking (within 1/8 in. of weld) in.	Plate Cracking (outside 1/8 in. of weld) in.	Temperature of testing °F.
1/2 inch Thick Austenitic Hand Welded Rolled Plates							
Gen. Motors Truck C11	37 mm. HE M54	1	6	2600	0	0	-17
		2	6	2600	0	0	
		3	6-1/2	2600	0	0	
		4	1-3/4	2600	9-1/2	1-1/2	
		5	6-1/2	2600	0	0	
		6	3-1/4	2600	0	0	
Gen. Motors Truck C14	"	1	4	2600	0	0	-15
		2	1-1/2	2600	13	0	
		3	1-3/4	2600	2-1/2	0	
		4	2-3/4	2600	4	0	
Gen. Motors Truck C17	"	1	3	2600	0	0	-21
		2	2-1/2	2600	4	0	
		3	1	2600	25	12	
Gen. Motors Truck C21	"	1	0	2600	12-1/2	0	-20
		2	3-1/4	2600	40-1/2	0	
1/2 inch Thick Austenitic Unionmelt Welded Rolled Plates							
Gen. Motors Truck C7	37 mm. HE M54	1	7	2600	0	0	-17
		2	2-1/2	2600	14-1/2	1-3/4	
		3	3-1/2	2600	6-1/2	2	
Gen. Motors Truck C10	"	1	1-1/4	2600	8	-	+70
		2	1-1/4	2600	10	-	
		3	3/4	2600	26	-	
1/2 inch Thick Ferritic Unionmelt Welded Rolled Plates							
Gen. Motors Truck C3	37 mm. HE M54	1	2-1/2	2600	17	0	-17
		2	5	2600	0	0	
		3	1	2600	23	8-1/2	

TABLE I (Cont. - p.4)

Plate Number	Projectile	Round No.	Eccentricity (center impact to center weld) in.	Velocity f/s	Weld Cracking (within 1/8 in. of weld) in.	Plate Cracking (outside 1/8 in. of weld) in.	Temperature of testing °F.
International D5-45-22	37 mm. HE M54	1	1-3/8	2600	0	0	+50
		2	2-1/8	2600	0	0	
		3	7-1/2	2600	0	0	
		4	1	2600	0	0	
		5	1-1/4	2600	3/4	0	
		6	0	2600	0	0	

TABLE II

Nick-Break Fracture Test Results

Plate No.	Plate	Heat-Affected Zone	Weld	Remarks
1-1/2 inch Thick Austenitic Hand Welded Rolled Plates				
Fisher CTF3A	F	F	F	Incomplete fusion at root
" CTF6	F	F	F	
" CTF11	F	F	F	Incomplete fusion at root
" CTF14	F	F	F	
" CTF16	F	F	F	Laminated plate
" CTF21	F	F	F	Laminated plate
1-1/2 inch Thick Austenitic Hand Welded Cast Plates				
Baldwin 40	C	F	F	Incomplete fusion at root
Briggs M34	Cf	Fc	F	Incomplete fusion at root; gas holes
Chrysler CP47	C	F	F	Incomplete fusion at root
Chrysler CP51	C	Fc	F	Incomplete fusion at root
Fisher CTF22	FC	Fc	D	
Fisher CTF28	C	Fc	Fd	
Ford W51	C	Fc	F	
International 39	C	F	F	
1-1/2 inch Thick Austenitic Unionmelt Welded Rolled Plates				
Briggs UM30	F	C	F	
Fisher UCTF1A	F	C	F	
" UCTF5	F	C	FD	
" UCTF8	F	C	FD	
1-1/2 inch Thick Austenitic Unionmelt Welded Cast Plates				
Midland CO3	C	C	F	
1 inch Thick Austenitic Hand Welded Rolled Plates				
Cadillac 94	Fc badly laminated	F	F	
" 96	Fc badly laminated	Fc	F	Incomplete fusion at root
" 97	Fc badly laminated	Fc	F	Incomplete fusion at root
Ternstedt TH68	F	F	Fd	

NOTES:

F = fibrous fracture
C = crystalline fracture
FC = mixed fibrous and crystalline
Fc = mixed fracture, mostly fibrous
Cf = mixed fracture, mostly crystalline
D = brittle dendritic weld metal fracture
Fd = mixed fibrous and brittle dendritic fracture

TABLE II (Cont. - p.2)

Plate No.	Plate	Heat-Affected Zone	Weld	Remarks
1/2 inch Thick Austenitic Hand Welded Rolled Plates				
Gen.Motors Truck C11	F	F	F	
" " " C14	F	F	F	
" " " C17	F laminated	F	F	
" " " C21	F laminated	F	F	
1/2 inch Thick Austenitic Unionmelt Welded Rolled Plates				
Gen.Motors Truck C7	F	C	D	
" " " C10	F	C	D	
1/2 inch Thick Ferritic Unionmelt Welded Rolled Plates				
Gen.Motors Truck C3	F	C	Fc	Crystalline patches in weld
International D5-45-22	F	C	Fc	Slight crystallinity in weld

TABLE III

Summary of Bend Test Results

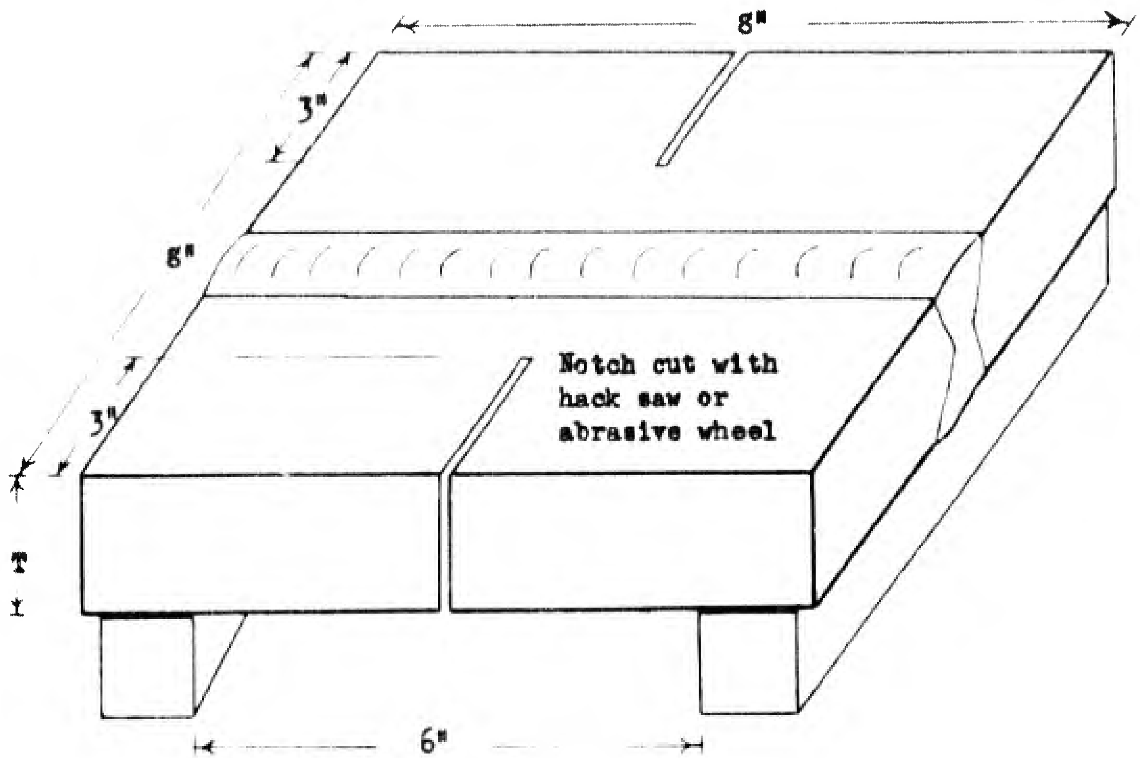
Plate No.	crn.	Path of Fracture at Room Temperature body	root	body	crn.	crn.	Path of Fracture at -40° F. body	root	body	crn.	Remarks
1-1/2 inch Thick Austenitic Hand Welded Rolled Plates											
Fisher CTF3A	W	FZ	FZ	W, FZ	W	W	W, W-D	FZb	FZb	FZb	Lack of fusion at root
" CTF6	W	W, FZ	FZ, P, HAZ	FZ, HAZ	W, FZ	W	W, FZ	FZb	FZb	FZb	Lack of fusion in upper body of cold spec.
" CTF11	W	W, W-D	W-D	W, W-D	W-D	W	W-D	W-D, FZb	FZb	FZ	Inc. fusion at root
" CTF14	W	W	W-F	FZ	W	FZb	FZb	FZb	FZb	FZb	Inc. fusion in lower body of RT bar
" CTF16	W	W, FZ, P	W, FZ, P	W-D	W	W	W-D, FZb	FZb	FZb	W	Inc. fusion at root of room temperature bar
" CTF21	W, FZb	W, FZb	FZb	FZb	W	W, FZb	FZb, P	FZb	FZb	FZb	Lack of fusion at root and bodies
1-1/2 inch Thick Austenitic Hand Welded Cast Plates											
Baldwin 40	W	W	W-D	W	W	FZ	HAZ-C FZb	P-C	P-C	HAZ	Inc. fusion at root; gas holes
Briggs M34	FZ	HAZ-C P-FC	P-FC	HAZ-C P-FC	W	FZ	HAZ-C	P-C	HAZ-C FZb	W	
Chrysler CP47	W	W, FZ	FZ	W, FZ	W	FZb	FZb	FZb	FZb	W	Inc. fusion in upper body and root
" CP51	W, FZ	FZ	FZ	FZ	W, FZ	FZ	FZb, P-C	P-C	FZ	FZ, W	
Fisher CTF22	W-D	W-D	W-D	W-D	W-D	W-D	W-D	W-D	W-D	W-D	Inc. fusion at root
" CTF28	W	W-D	W-D, FZ	W-D	W	W	W-D	FZb, W-D	FZb, W-D	W	Inc. fusion upper body and root
Ford W51	W	FZ	FZ	W-D	W	W	FZb	FZb	W-D, FZ	W	Inc. fusion root and body
International 39	FZ	FZ	P-C	FZ	FZ, W	FZb	FZb	P-C	FZb, P-C	FZb	Inc. fusion at root

P = fibrous unaffected base metal fracture
HAZ = fibrous heat-affected base metal fracture
W = fibrous weld metal fracture
W-D = brittle dendritic weld metal fracture
FZ = fusion zone fracture with weld metal scale
FZb = fusion zone fracture at bond line or plate adjacent to fusion line
C = crystalline fracture
FC = mixed crystalline and fibrous fracture
Fc = mixed fracture, mostly fibrous
Cf = mixed fracture, mostly crystalline

TABLE III (Cont. - p.2)

Plate No.	Path of Fracture at Room Temperature: crn.	body	root	body	crn.	Path of Fracture at -40° F.: crn.	body	root	body	crn.	Remarks
1-1/2 inch Thick Austenitic Unionmelt Welded Rolled Plate											
Briggs UM30	W	W	W, FZ	W	W	W	HAZ-C	P-F	HAZ-C	FZb	Weld defect in room temperature bar
Fisher UCTF1A	W	HAZ-C	HAZ-C	HAZ-C	HAZ-C	FZb	HAZ-C	HAZ-C	FZb	HAZ-C, W	Undercut at upper crown of cold bar
" UCTF5	W	HAZ-C	HAZ-C	HAZ-C	HAZ-C	W	HAZ-C	HAZ-C	W-D	W-D	
" UCTF8	HAZ-C	HAZ-C, P	P	HAZ-C	W	FZb	HAZ-C	HAZ-C, P	HAZ-C	HAZ-C	
1-1/2 inch Thick Austenitic Unionmelt Welded Cast Plates											
Midland C03	HAZ-C	HAZ-C	P-C	HAZ-C	HAZ-C	HAZ-C	HAZ-C	HAZ-C, P-C	HAZ-C	HAZ-C	
1 inch Thick Austenitic Hand Welded Rolled Plates											
Cadillac 94	W, FZ	FZ	P	FZ	W, FZ	W	P	P	P, W	W	
" 96	W	W, FZb	P	P	P, W	FZb	HAZ-C, P-CT	P-C	P-C	FZb	
" 97	W, FZ	P	FZb, P	FZ	W, FZ	W	FZb, HAZ	FZb	FZb	FZ, W	Inc. fusion at root and body
Ternstedt TH68	W	W-D	W-D	W-D	W	W	W-D	W-D	W-D	W	Weld metal crack in root pass and inc. fusion in body
1/2 inch Thick Austenitic Hand Welded Rolled Plates											
Gen. Motors Truck C11	did not break					W, FZb	FZb	W, FZb			
" " " C14	W	FZb, HAZ	W			W	FZb, HAZ	W			
" " " C17	FZb	FZb	FZb			FZb	FZb	FZb			
" " " C21	FZb	FZb	FZb, W			FZb	FZb	FZb, W			
1/2 inch Thick Austenitic Unionmelt Welded Rolled Plates											
Gen. Motors Truck C7	W-D	W-D	W-D			W-D	W-D	W-D			Large gas hole in cold test bar
" " " C10	W-D	HAZ-C	W-D			W-D	HAZ-C	W-D			Inc. fusion at root
1/2 inch Thick Ferritic Unionmelt Welded Rolled Plates											
Gen. Motors Truck C3	did not break					did not break					Reinforcement removed from both sides
D-5-45-22	"	"	"			HAZ-C	HAZ-C	HAZ-C			Rein. removed from ballistic back face

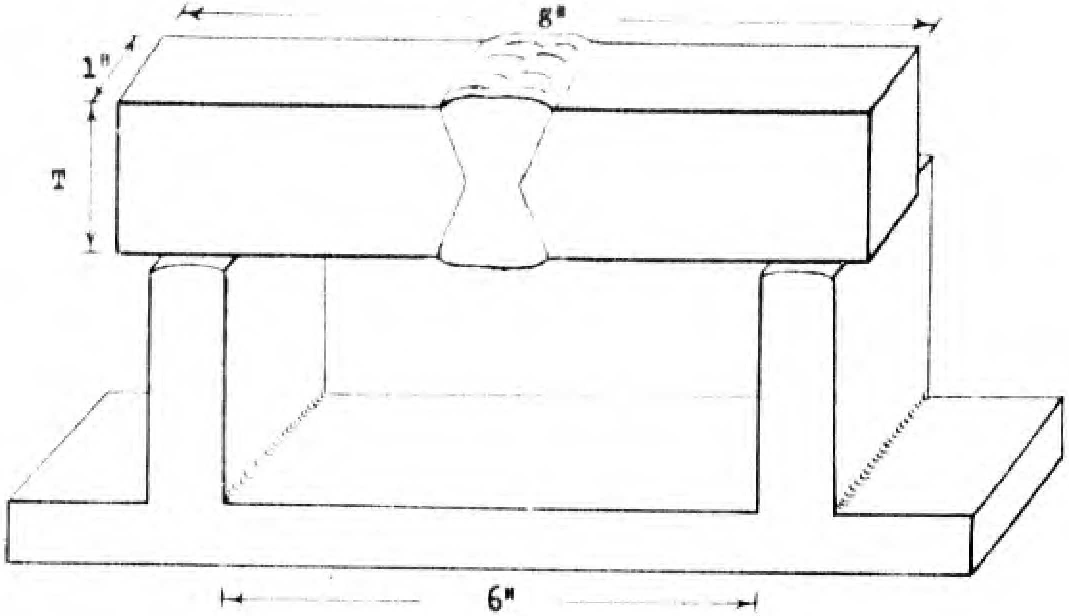
1/2 x 1/2 x 4 inch bar used as striking block. 1 x 6 x 6 inch plate placed on top of bar to prevent damage to steam hammer or drop weight.



Supported on six-inch span; broken with one blow of drop weight or steam hammer

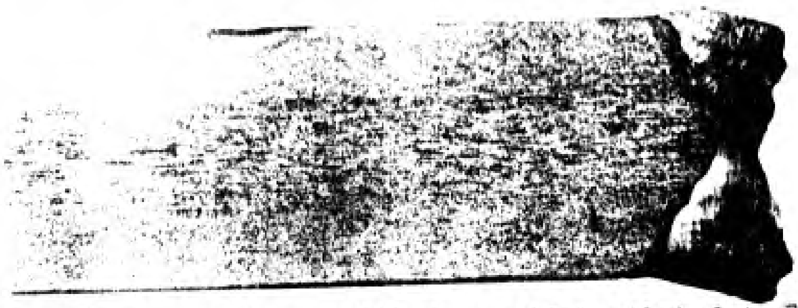
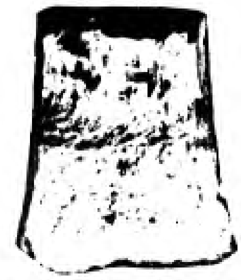
Figure 1. Nick-Break Fracture Test of Weld Joint

Load applied to center of weld



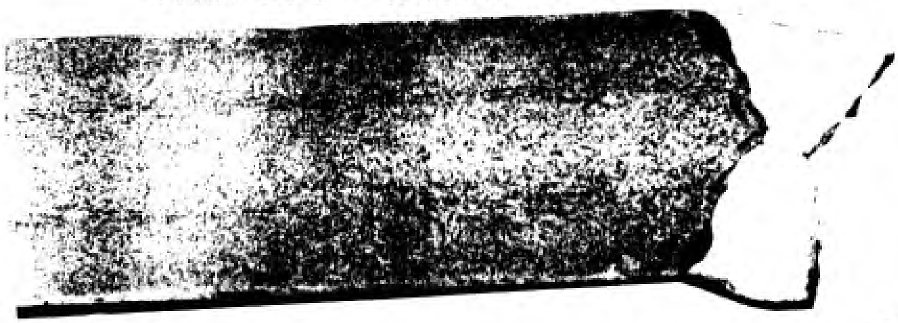
Supported on six-inch span; bars of 1 inch and 1 1/2 inch thickness broken in a steam press; bars of lesser thickness broken with one blow of drop weight

Figure 2. Bend Fracture Test of Weld Joint

1 1/2 inch thick austenitic hand welded rolled plate Fisher CTF 14 - broken at room temperature


Fisher CTF 14 - broken at -40° F.




1 1/2 inch thick austenitic hand welded rolled plate Fisher CTF 21 - broken at room temperature


Fisher CTF 21 - broken at -40° F.

BEND BAR FRACTURES


Plate Fisher CTF 14 Plate Fisher CTF 21

NICK-BREAK FRACTURES

Figure 3

-A-

X1

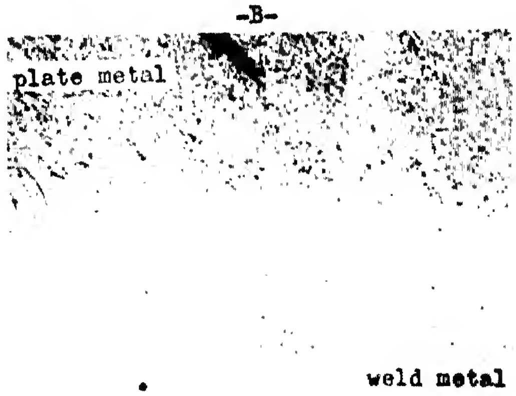
Fusion zone failure in bend bar from as-welded joint in Carnegie-Illinois armor.

-D-

X1

Fusion zone failure in bend bar from same weld joint as "A" after 1100° F draw for one hour.

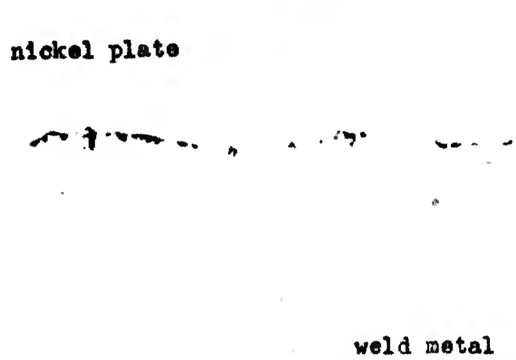
-B-



X500 Picral

Linear precipitation of non-metallics in austenitic weld metal near fusion line of weld joint.

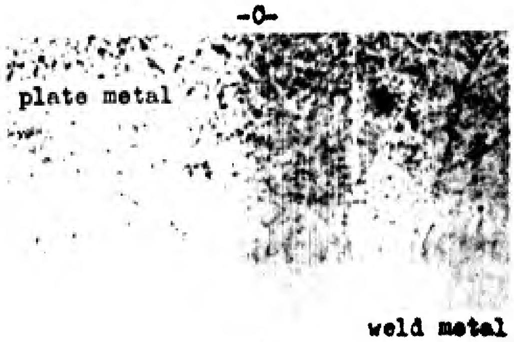
-E-



X500 Picral

Path of failure through precipitated carbides along fusion line in reheated bend bar.

-C-

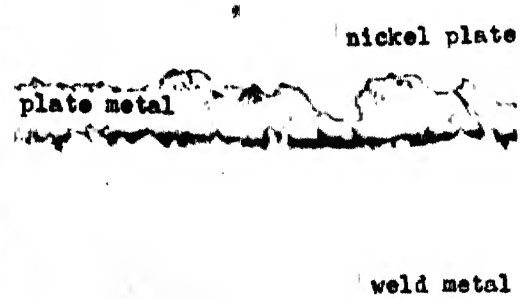


nickel plate

X500 Picral

Bend bar fracture path through area of non-metallics in as-welded joint.

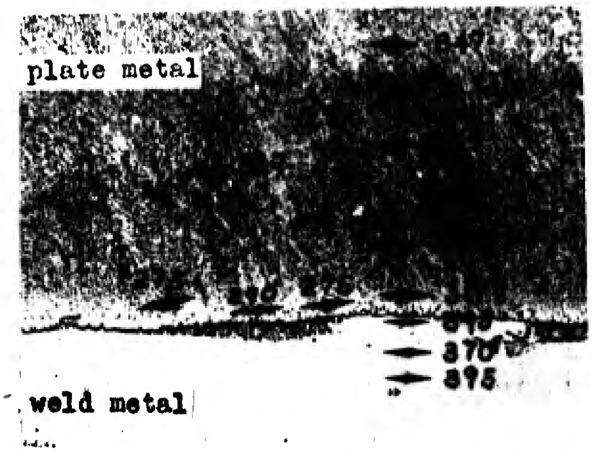
-F-



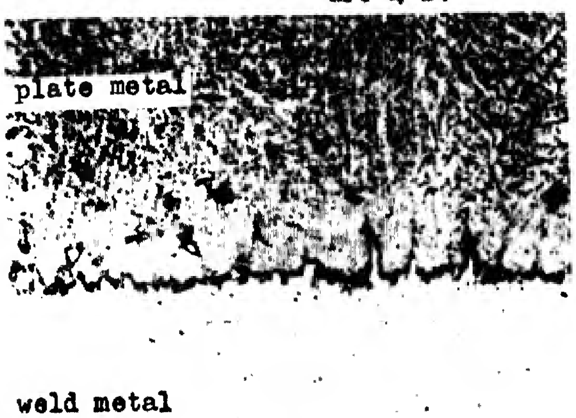
X500 Picral

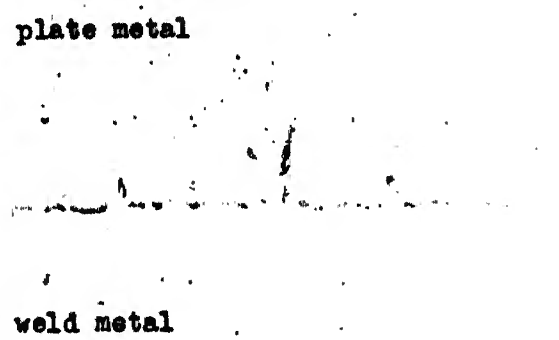
Path of failure through decarburized area in fusion zone in reheated bend bar.

Figure 4

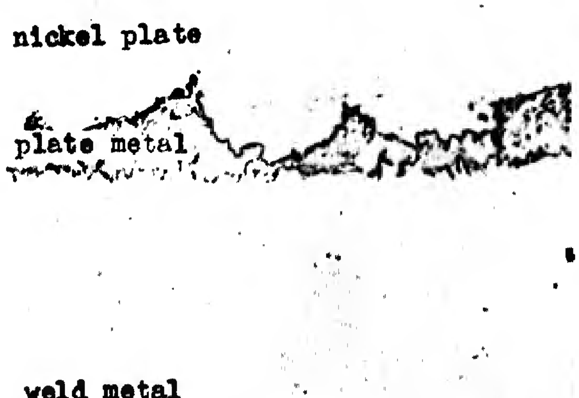


X100 Picral
Knoop microhardness indentations in fusion zone of reheated bend bar Figure 4-D.

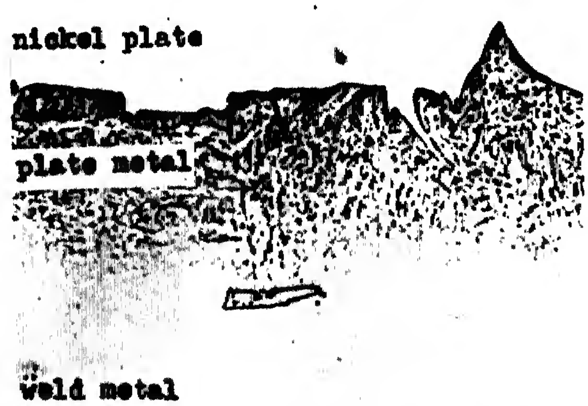




X500 Etched in Picral X500 Etched in Murakami's Reagent
Precipitated carbides and decarburized area at fusion line in 1 1/2 inch thick austenitic hand welded rolled plate Fisher CTF 21.

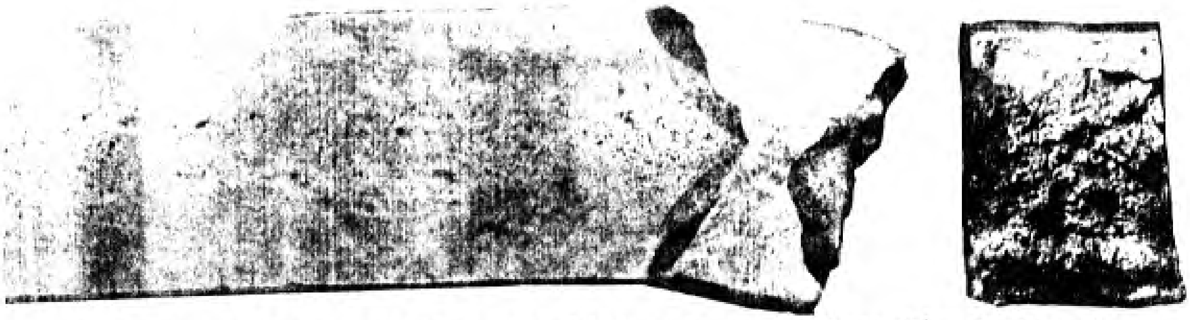


X500 Picral
Fusion zone bend bar failure through decarburized area at fusion line in 1 1/2 inch thick austenitic hand welded plate Fisher CTF 11.



X500 Picral
Failure through slack quenched structure near fusion line in 1/2 inch thick austenitic hand welded plate Gen. Motors Truck C 11.

Figure 5



1 1/2 inch thick austenitic hand welded cast plate Briggs M34 - broken at room temperature

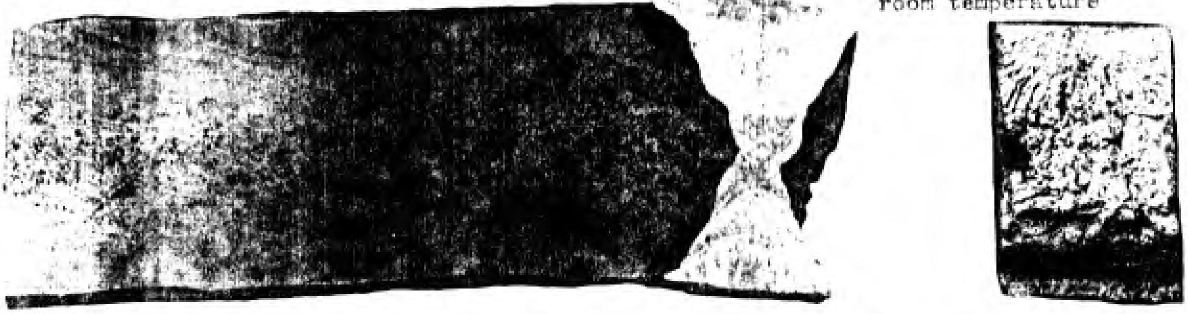
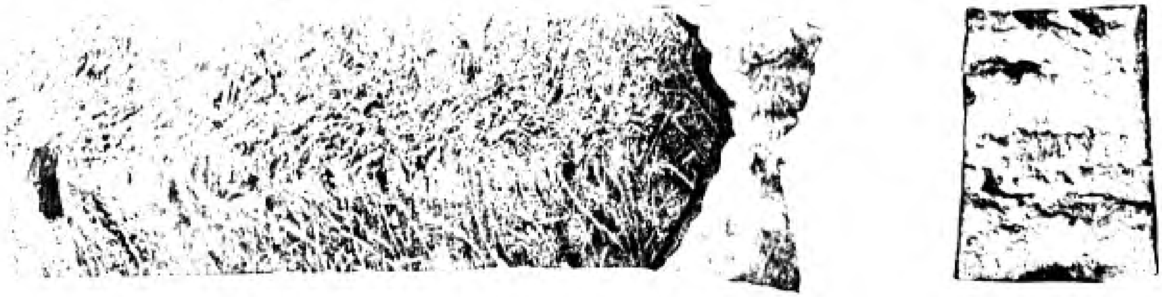


Plate Briggs M34 - broken at -40° F.



1 1/2 inch thick austenitic hand welded cast plate Chrysler CP 51 - broken at room temperature

Plate Chrysler CP 51 - broken at -40° F.

BEND BAR FRACTURES

Plate Briggs M34

Plate Chrysler CP 51

NICK-BREAK FRACTURES

Figure 6

1 1/2 inch thick austenitic hand welded cast plate Fisher CTF 22 - broken at room temperature

Plate Fisher CTF 22 - broken at -40° F.

1 1/2 inch thick austenitic hand welded cast plate Fisher CTF 28 - broken at room temperature

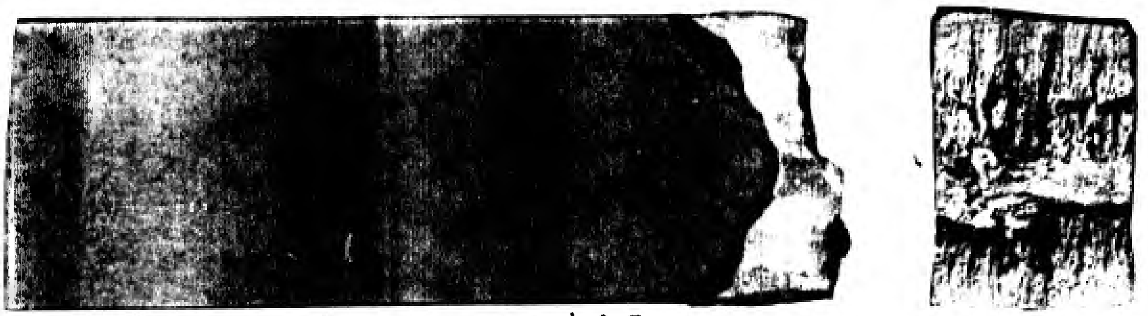


Plate Fisher CTF 28 - broken at -40° F.

BEND BAR FRACTURES

WTN.639-7067

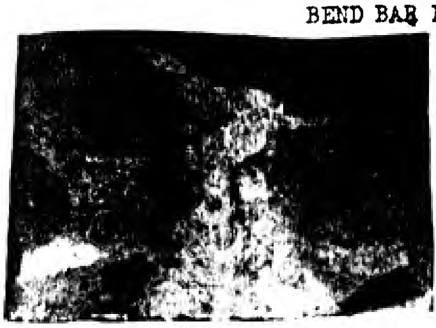


Plate Fisher CTF 22

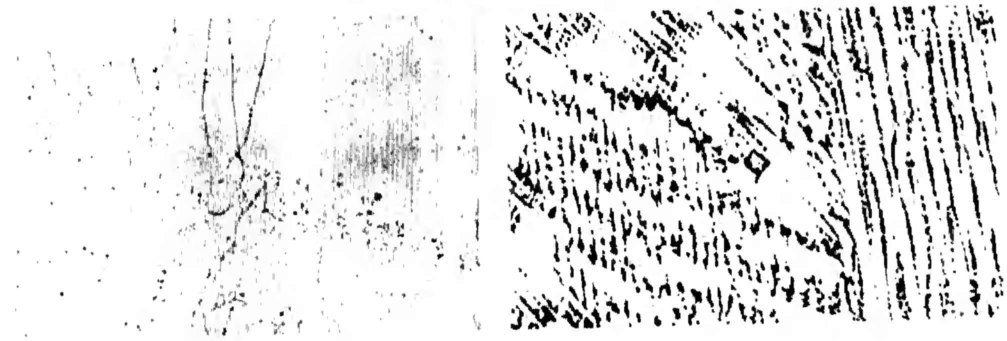
Plate Fisher CTF 28

NICK-BREAK FRACTURES

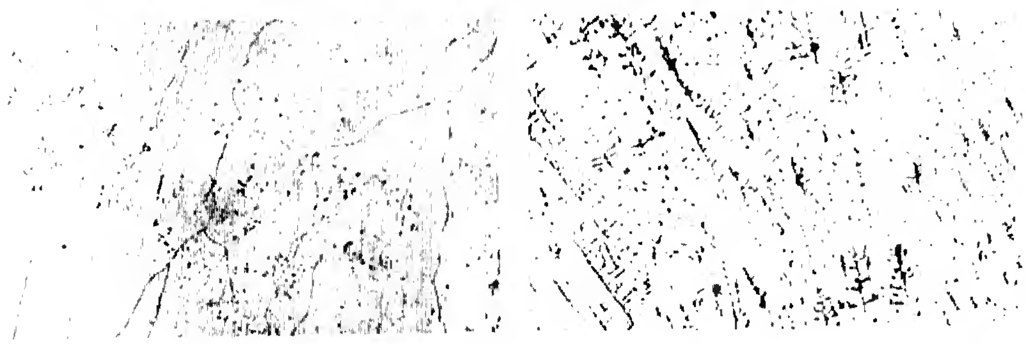
Figure 7

Etched in aqua regia glycerol   Etched in modified Murakami's reagent

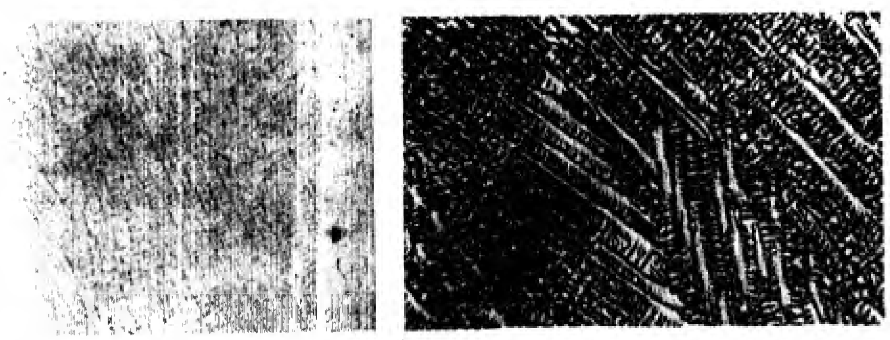
Hand weld -- 18% Cr - 8% Ni electrode -- Plate Fisher CTF 3A



Hand weld -- 18% Cr - 8% Ni electrode -- Plate Fisher CTF 11



Unionmelt weld -- Plate Fisher UCTF 5



WTN.639-7088

Hand weld -- 12% Cr - 6% Ni - 6% Mn electrode -- Plate Fisher CTF 22

MICROSTRUCTURE OF VARIOUS STAINLESS WELD METALS
(Photomicrographs taken at midwall center of weld - X100)

Figure 8

1 1/2 inch thick austenitic Unionmelt welded rolled plate Fisher UCTF 1A - broken at room temperature

Plate Fisher UCTF 1A - broken at -40° F

1 1/2 inch thick austenitic Unionmelt welded rolled plate Fisher UCTF 5 - broken at room temperature

Plate Fisher UCTF 5 - broken at -40° F

BEND BAR FRACTURES

WT.539-7083

Plate Fisher UCTF 1A

Plate Fisher UCTF 5

NICK-BREAK FRACTURES

Figure 9

1 inch thick austenitic hand welded rolled plate Cadillac 94 - broken at room temperature

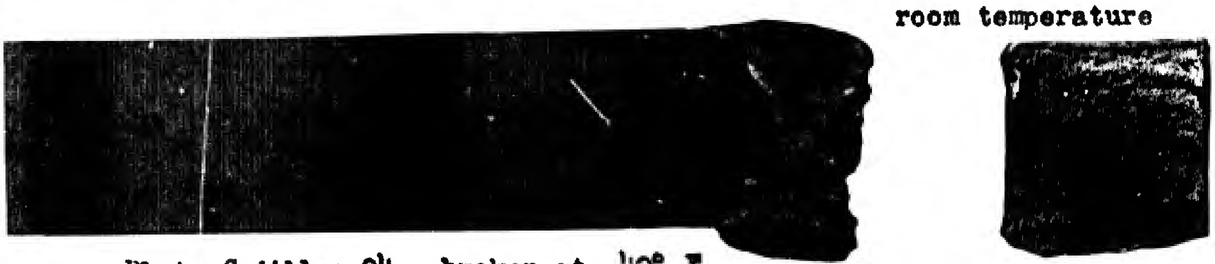


Plate Cadillac 94 - broken at -40° F

1 inch thick austenitic hand welded rolled plate Cadillac 96 - broken at room temperature

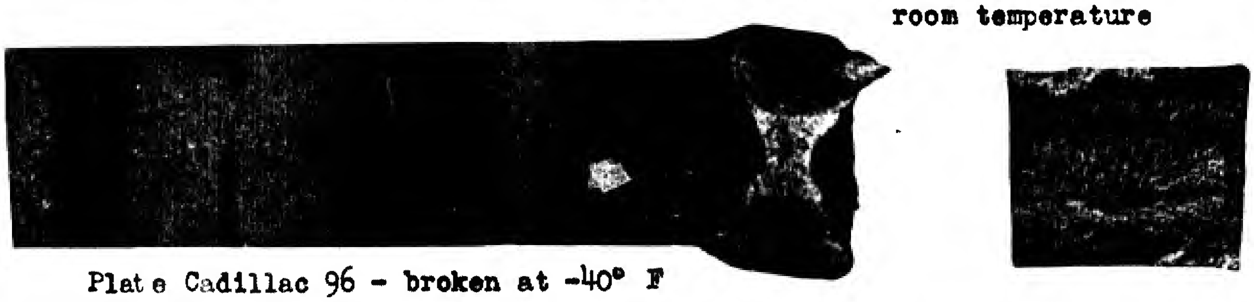


Plate Cadillac 96 - broken at -40° F

BEND BAR FRACTURES

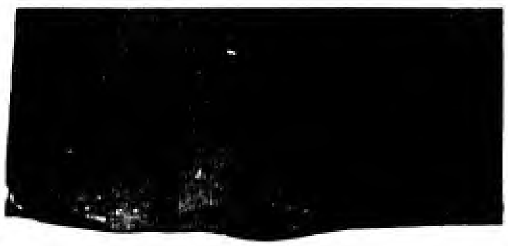


Plate Cadillac 94

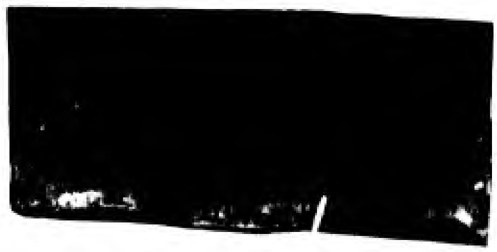
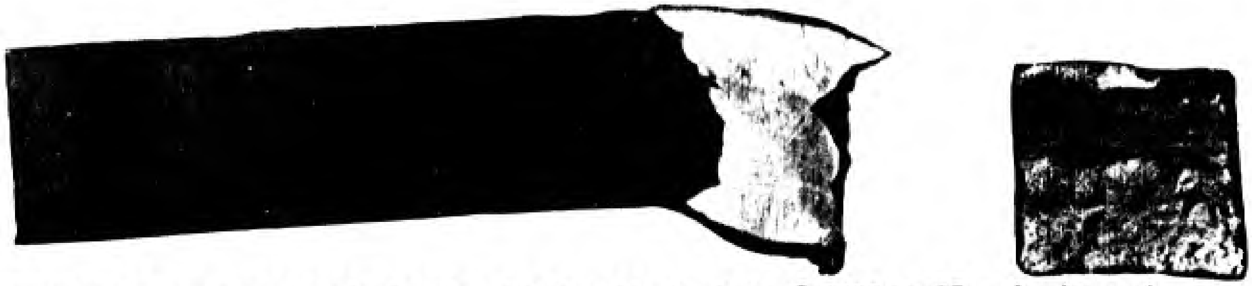


Plate Cadillac 96

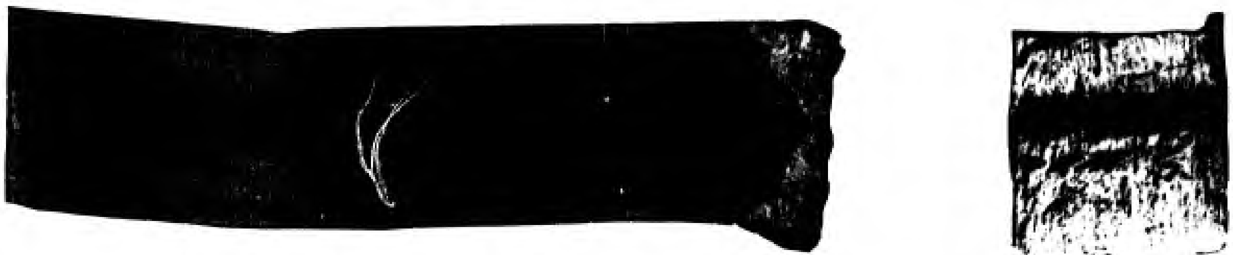
NICK-BREAK FRACTURES

Figure 10



1 inch thick austenitic hand welded rolled plate Cadillac 97 - broken at room temperature

Plate Cadillac 97 - broken at -40°F.



1 inch thick austenitic hand welded rolled plate Ternstedt TH 68 - broken at room temperature

Plate Ternstedt TH 68 - broken at -40°F.

BEND BAR FRACTURES

WTN.639-7091

Plate Cadillac 97

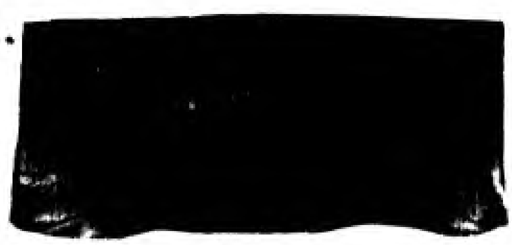


Plate Ternstedt TH 68

NICK-BREAK FRACTURES

Figure 11

1/2 inch thick austenitic hand welded rolled plate General Motors Truck C 11 - tested at room temperature

1/2 inch thick austenitic hand welded rolled plate General Motors Truck C 17 - broken at room temperature

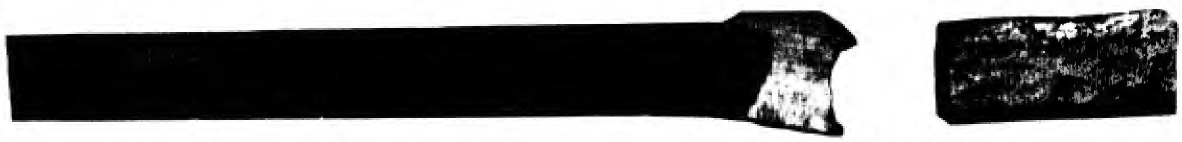


Plate General Motors Truck C 17 - broken at -40° F.

1/2 inch thick austenitic hand welded rolled plate General Motors Truck C 21 - broken at room temperature

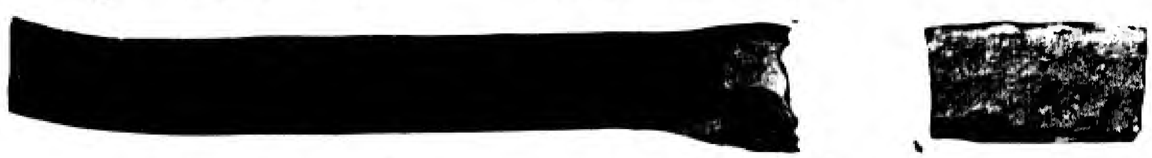


Plate General Motors Truck C 21 - broken at -40° F.

BEND BAR FRACTURES

Plate Gen. Motors Truck C 11

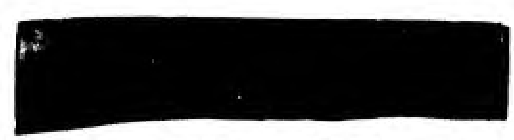


Plate Gen. Motors Truck C 17

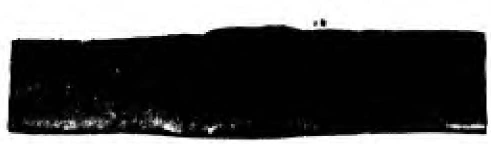
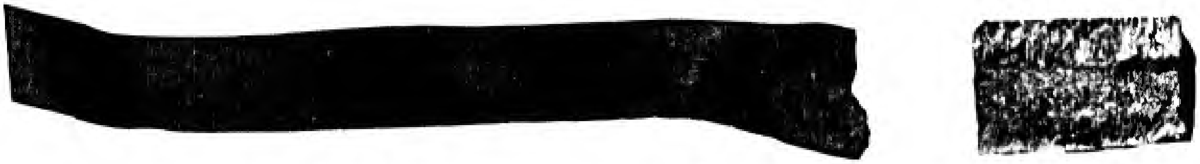


Plate Gen. Motors Truck C 21

NICK-BREAK FRACTURES

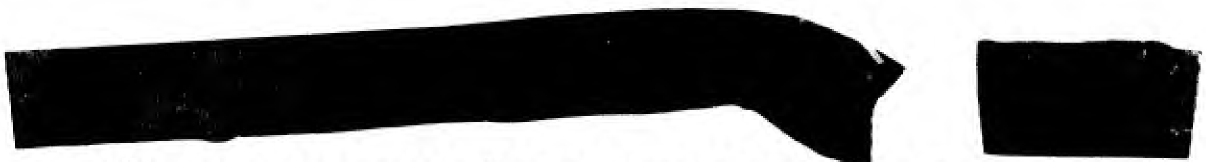
Figure 12



1/2 inch thick austenitic Unionmelt welded rolled plate
General Motors Truck C 10 - broken at room temperature

Plate General Motors Truck C 10 - broken at -40° F.

1/2 inch thick ferritic Unionmelt welded rolled plate
General Motors Truck C 3 - tested at room temperature



1/2 inch thick ferritic Unionmelt welded rolled plate
International D5-45-42 - broken at -40° F.

BEND BAR FRACTURES

Plate Gen. Motors Truck C 10

Plate Gen. Motors Truck C 3

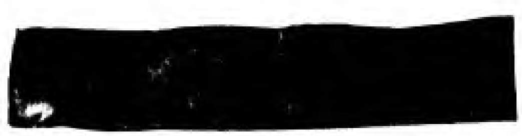


Plate International D5-45-42

NICK-BREAK FRACTURES

Figure 13

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 subject 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 from 1/2 inch to 1-1/2 inches.

B. Type Armor

Armor compositions are typed as follows:

R (Rolled)

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

C (Cast)

I	Mn-Ni-Cr-Mo	.32	.80	.35	.55	.40	.45
II	Mn-Cr-Mo	.28	1.55	.45	.40	.12	
III	Mn-Mo	.30	1.58	.40	--	.30	
IV	Special	(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.

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 (RI

B. [illegible]t 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 strip 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" PLATES WELDED WITH AUSTENITIC ELECTRODES

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

The requirements for the shock test at normal temperature as given by Specification AXS-497, Rev. 3, August, 1942, were as follows:

Armor	Projectile	Striking Velocity (±25 f/s)	Maximum Allowable Cracking Weld (inches)	Plate
1-1/2" rolled	75 mm. T21	1100	15	8
1-1/2" cast	"	1050	15	8
1" rolled	"	775	18	8

There were no requirements specified for 1/2 inch plate, but for these cold tests the 37 mm. M54 H.E. projectile at 2600 f/s velocity was used. A limit of 12 inches of weld cracking was used as a criterion of acceptability of the welded joint. The limit on plate cracking was 8 inche

From 3 May 1944 to the present the following requirements have been 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	15

"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."

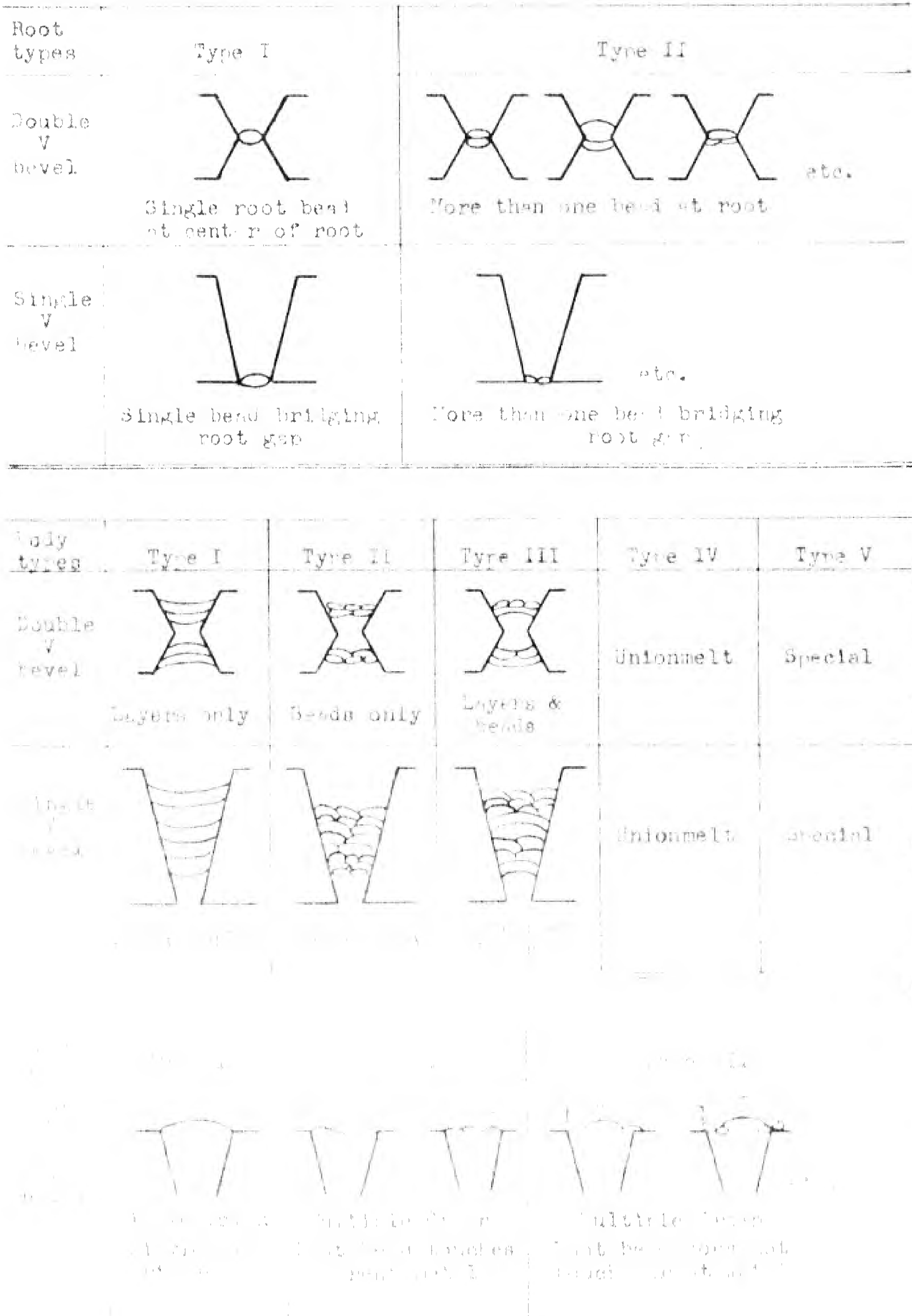
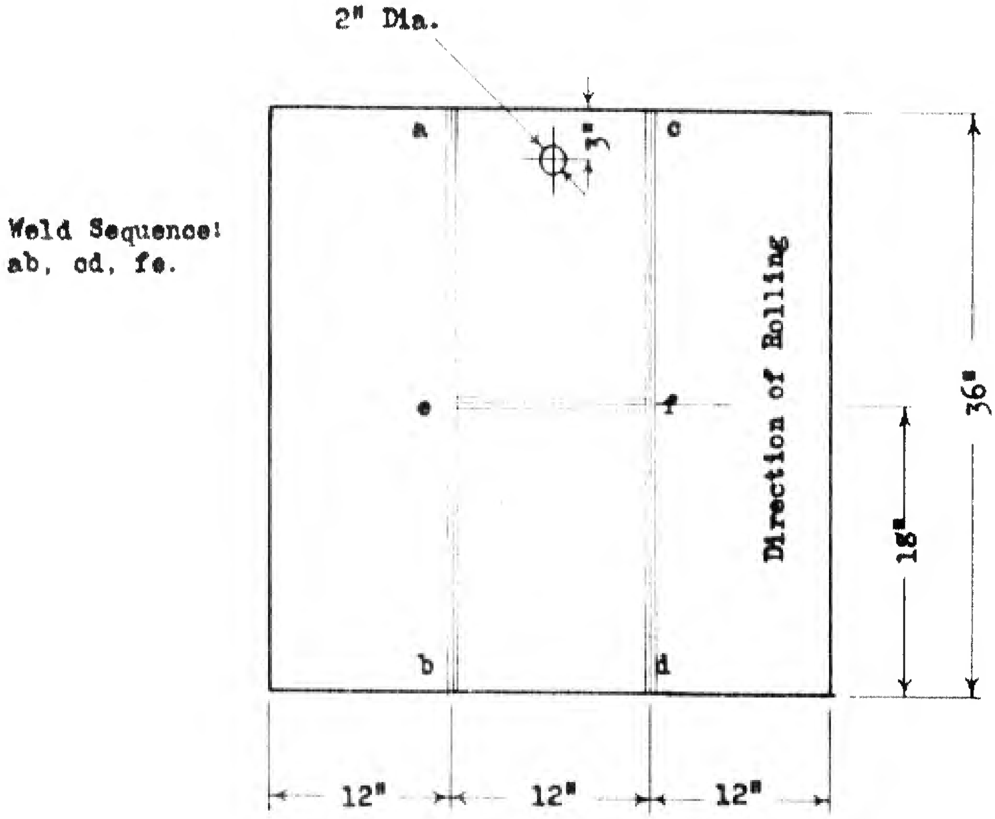
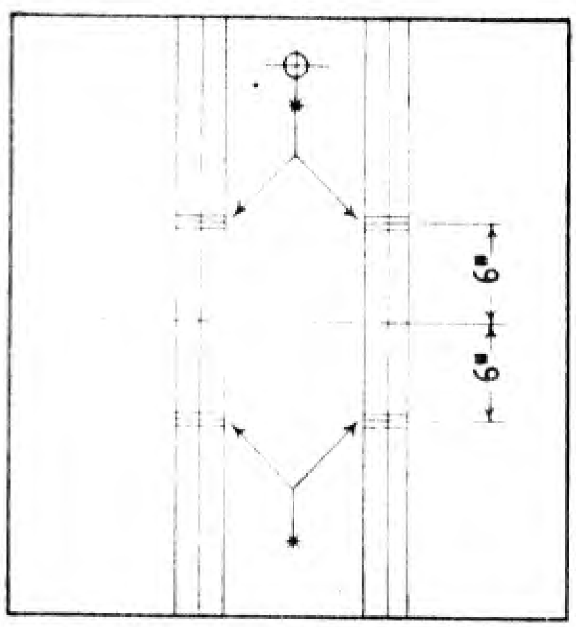


Fig. 1 Weld [illegible] Deposition types



QUALIFICATION SHOCK TEST PLATE



* Intended Aiming Points

FIG. 11

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 2128 B. 1/21, 22, 23/43 2/23, 24/43 C. CTF 3A D. Republic Steel Corp. E. Alloy Rods Co. F. Fisher Tank Division.	A. 1-1/2" B. R I .87Mn .27Si .018S .017P .69Cr .95Ni .49Mo C. .27C D. - - E. Basic F. 1650°F water spray quench 1200°F draw	A. A II .08C 3.60Mn .035Si .005S .019P 19.35Cr 10.2Ni .012Mo B. Armorarc C. Titania D. AC DC-REV	A. 45° DV B. 5/16" C. Flame cutting. Grinding.	A. Copper B. 1. I 3/16" 1a 185 22 2. I 1/4" 2a 250 40 5/16" 4a 360 40 3. I 5/16" 2a 360 40 C. 2 hours 11 minutes. 240°-520°F D. Grinding time 3 hours.	A. 150°F B. None	1 2	1091 1089	¼" R	 3" L	5" U 4½" D	IMP IMP	I I	10" 29 39"	F Crossbar was badly cracked before repairs. 2-1/4" crack still present after repairs. Temp. at time of testing: -18.5°F 75mm T21 projectile
A. AD 2128 B. 1/21, 22, 23/43 2/23, 24/43 C. CTF 6 D. Republic Steel Corp. E. Reid Avery F. Fisher Tank Division	A. 1-1/2" B. RI .92Mn .29Si .017S .02P 1.04Cr 1.21Ni .66Mo C. .288C D. Face 260 Back 260 E. Basic F. 1650°F water spray quench 1200°F drawn	A. A I .09C 1.79Mn .03Si .004S .051P 19.3Cr 10.1Ni 1.24Mo B. Raco C. Titania D. AC DC-REV	A. 45° DV B. 5/16" C. Flame cutting. Grinding.	A. Copper B. 1. I 3/16" 1a 285 22 2. I 1/4" 2a 250 40 5/16" 4a 360 40 3. I 5/16" 2a 360 40 C. 1 hour 54 minutes. 240°-520°F D. Grinding time 5 minutes.	A. 150°F B. None	1 2	1100 1098	 ½" L	1" R	1½" D 4½" U	IMP IMP IMP IMP	I V I V	23" 4 9 2¼ 38¼"	P 75mm T21 projectile Temp. at time of testing -30°F
A. AD 2135 B. 1/21, 22/43 2/23, 24/43 C. CTF 11 D. Jones & Laughlin E. Alloy Rods Co. F. Fisher Tank Division.	A. 1-1/2" B. R III 1.59Mn .25Si .016S .021P .41Mo C. .27C D. - - E. Basic F. Not known	A. A II .08C 3.60Mn .035S .005S .019P 19.35Cr 10.2Ni .012Mo B. Armorarc C. Titania D. AC DC-REV	A. 45° DV B. 5/16" C. Flame cutting. Grinding.	A. Copper B. 1. I 3/16" 1a 185 22 2. I 1/4" 2a 250 40 5/16" 4a 360 40 3. I 5/16" 2a 360 40 C. 1 hour 55 minutes. 220°-530°F D. Grinding time 1 hour.	A. 150°F B. None	1	1097		1¼" L	3" U	IMP	I	27½"	P Temp. at time of testing: -18.8°F. 75mm T21 projectile

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 2135 B. 1/21,22/43 2/23,24/43 C. CTF 14 D. Jones & Laughlin E. Reid Avery F. Fisher Tank Division	A. 1-1/2" B. R III 1.59Mn .25Si .016S .021P .41Mo C. .27C D. - - E. F. not known	A. A I .09C 1.79Mn .035Si .004S .051 19.31Cr 10.13Ni 1.24Mo B. Raco C. Lime D. AC DC-REV	A. 45° DV B. 5/16" C. Flame cutting. Grinding	A. Copper B. 1. I 3/16" 1a 185 22 2. I 1/4" 2a 250 40 5/16" 4a 380 40 3. I 5/16" 2a 380 40 C. 2 hours 2 minutes. 280°F - 460°F D. Grinding time, none.	A. 150° F B. None	1	1110	½" L		4" D	IMP	I	36"	P
							Temp. at time of testing -15°F. 75mm T21 projectile							
A. AD 2126 B. 1/21,22,23/43 2/23/43 C. CTF 16 D. Great Lakes Steel Corp. E. Alloy Rods Co. F. Fisher Tank Division	A. 1-1/2" B. R IV .95Mn .72Si .025S .023P .64Cr .16Mo .10Zr C. .29C D. — E. F. Not known	A. A II .08C 3.60Mn .035Si .005S .019P 19.35Cr 10.2Ni .012Mo B. Armorarc C. Titania D. AC DC-REV	A. 45° DV B. 5/16" C. Flame cutting. Grinding.	A. Copper B. 1. I 3/16" 1a 185 22 2. I 1/4" 2a 250 40 5/16" 4a 380 40 3. I 5/16" 2a 380 40 C. 2 hours 16 minutes. 300°-500°F D. Grinding time, none.	A. 150° F B. None	1	1094		½" L	2½" U	IMP	I	37"	P
						2	1095	2" L		3" D	IMP IMP	I V	26 4 67"	
							75mm T21 projectile Temp. at time of testing -10°F.							
A. AD 2126 B. 1/21,22,23/43 2/23/43 C. CTF 21 D. Great Lakes Steel Corp. E. Reid Avery F. Fisher Tank Division	A. 1-1/2" B. R IV .95Mn .72Si .025S .023P .64Cr .16Mo .10Zr C. .29C D. - - E. F. not known	A. A I .09C 1.79Mn .035Si .004S .051P 19.31Cr 10.13Ni 1.24Mo B. Raco C. Titania D. AC DC-REV	A. 45° DV B. 5/16" C. Flame cutting. Grinding.	A. Copper B. 1. I 3/16" 1a 185 22 2. I 1/4" 2a 250 40 5/16" 4a 380 40 3. I 5/16" 2a 380 40 C. 2 hours 11 minutes. 300°-460°F D. Grinding time, none.	A. 150° F B. None	1	1098	½" R		5½" U	IMP	I	36"	P 8" of incomplete fusion in upper left leg.
							75mm T21 projectile Temp. at time of testing -15°F.							

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 OR CRACKING Radiographic Results, etc.
A. AD 2134 B. 1/24, 28/43 2/24/43 C. 40 D. Symington Gould Corp. E. Alloy Rod Co. F. Baldwin Locomotive Works	A. 1-1/2" B. Cast I .98Mn .35Si .016S .032P .45Cr .56Ni .46Mo C. .25C D. Face 272 Back 285 E. Elec. Basic F. Not given	A. A I .13C 4.5Mn .70 Si .03S .03P 21.0Cr 10.5Ni B. Armorarc B C. T1 D. DC-REV	A. DV B. 3/16" C. Flame cutting.	A. B. 1. II 3/16" 1a 135 30 1/4" 1a 300 30 2. I 1/4" 5a 300 30 3/16" 1a 200 30 3. II 1/4" 4b 300 30 C. 8 hours. D. Grinding time, none.	A. None B. None	1 2 3 4 75mm T21 projectile Temp. at time of testing -19°F	818 896 1002 1048	1 3/4" L 3" R	 1/2" R 1" R	2 1/2" D 5" U 2" U 3 1/2" D	 - - - IMP IMP	 - - - I V	 - - - 9" 16" 25"	F Plate is unsound.
A. AD 2131 B. 1/24, 25/43 2/24/43 C. M 34 D. American Steel Fdry. E. McKay Company F. Briggs Mfg. Co.	A. 1-1/2" B. Cast II 1.56Mn .47Si .021S .017P .37Cr .15Mo C. .279C D. Face 241 Back 241 E. O.H. F. Not given	A. A II .077C .404Mn .62 .02S .02P 19.06Cr 9.06Ni B. Armorloy C. Titania D. DC-REV	A. 45° DV B. 5/16" C. Flame cutting.	A. Copper B. 1. II 1/4" 2a 220 27 2. I 1/4" 2a 220 27 5/16" 2a 300 32 3. I 5/16" 2a 300 32 C. 3-1/2 hours. 155°-410°F D. Grinding time 15 minutes.	A. None B. None	1 2 3 4 75mm T21 projectile Temp. at time of testing -20°F	822 823 920 1001	2 1/2" L 1 1/4" L	 2 3/4" L 3/4" R	2 1/2" " 5 1/2" D 2 1/2" D 4" U	 - - - IMP IMP	 - - - I V	 - - - 18 1/2 25 1/2 43 3/4"	P Traces of porosity and slag.
A. AD 2136 B. 1/23, 24, 25/43 2/3/43 C. CP 47 D. Continental Roll & Steel Foundry E. McKay Company F. Chrysler Plymouth	A. 1-1/2" B. Cast I .77Mn .35Si .042S .040P .52Cr .59Ni .4Mo C. .27C D. Face 229 Back 248 E. B.O.H. F. 1650°F 8 hrs. air 1550°F 8 hrs. water 1180°F 10 hrs. furnace 1000°F water	A. A I .077C 4.04Mn .62Si .02S .02P 19.06Cr 9.06Ni B. Armorloy C. Lime & T1 D. DC-REV	A. 45° DV B. 3/16" C. Flame cutting.	A. Copper B. 1. I 3/16" 1a 165 25 2. I 3/16" 2a 165 25 1/4" 2a 200 25 5/16" 4a 280 30 3. III 3/16" 4b 165 25 1/4" 2b 200 25 C. 8 hours 115°-250°F D. Grinding time 4 hours. Repair welds on both legs.	A. None B. None	Before Test 1 2 Temp. at time of testing -20°F 75mm T21 projectile	 809 911	- 1 1/2" L	- 1-3/8" L	- 4" D 8" 3" U	- O IMP IMP	I I I IV	8" 8 1 1/2 44 1/2 60 1/2"	P after repair welded.

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	N	BALLISTIC RESULTS VEL. F/S	LOCATION OF B L.L.	R.L.	C.B.	CRACKING LOC.	TYPE	AMT	REMARKS ON CRACKING RADIOGRAPHIC RESULTS, ETC
A. AD 2136 B. 1/23,24/43 25 2/3/43 C. CP 51 D. Continental E. Crucible Steel Corp. F. Chrysler P. mouth	A. 1-2/2" B. Cast I .37Mn .35Si .042S .040P .52Cr .59Ni .4Mo C. .27C D. Face 229 Back 248 E. O.H. Acid F. 1650°F air 1550° water 1180°F furnace 1000°F water	A. A I .12C 1.70Mn .50Si .030S .030P 18.5Cr 9.25Ni 1.85Mo B. Armorize C. Ti D. DC-REV	A. 45° DV B. 3/16" C. Flame cutting.	A. Copper B. 1. II 3/16" 2a 165 25 2. III 5/16" 2a 280 30 1/4" 4b 200 25 3. III 3/16" 4b 165 25 1/4" 2b 200 25 C. 8 hours. 125°-250°F D. Grinding time 4 hours. Repair weld in cross bar	A. None B. None	1 2	902 907 75mm T21 projectile Temp. at time of testing -20°F	 X	2½" L	5½" D 4½" U	 IMP IMP IMP IMP	 I IV I IV	 11" 38-7/8" 2¾" 15¼ 68-1/8"	Passed after Repair Welded
A. AD 2141 B. 2/10,11/43 C. CTF 22 D. American Steel Fdry. E. Maurath F. Fisher Tank Division	A. 1-1/2" B. Cast Not known C. - - D. - - E. - - F. - -	A. A II .15C 6.98Mn .035S .005S .047P 10.22Cr 7.07Ni .035Mo B. C. Lime D. AC DC-REV	A. 45° DV B. 5/16" C. Flame cutting. Grinding.	A. Copper B. 1. I 3/16" 1a 195 22 2. III 3/16" 3a 195 40 1/4" 8b 285 40 3. II 1/4" 4b 285 40 C. 2 hours 54 minutes. 300°-420°F D. Grinding time 35 minutes.	A. 150°F B. None	1 2 3	792 909 1058 Temp. at time of testing -20°F 75mm T21 projectile	6½" L X	 ½" L	7¼ D 4½ U 1½" D	 - IMP IMP IMP IMP	 - I V I IV	 - 4½" 4¼ 17½ 16¼ 42½"	P
A. AD 2130 B. 1/24,25/43 2/3/43 C. CTF 28 D. Gen'l Steel Castings E. Alloy Rods Company F. Fisher Tank Division	A. 1-1/2" B. Cast Not known C. — D. — E. — F. —	A. A II .42C 2.85Mn .035Si .004S .048P 17.02Cr 9.15Ni .060Mo B. Armorarc C. Titania D. AC DC-REV	A. 45° DV B. 5/16" C. Flame cutting. Grinding.	A. Copper B. 1. I 3/16" 1a 165 22 2. I 1/4" 2a 250 40 5/16" 4a 250 40 3. I 5/16" 2a 250 40 C. 2 hours 3 minutes. 280°-520°F D. Grinding time, none.	A. 150°F B. None	1 2 3	805 903 1001 Temp. at time of testing -29°F. 75mm T21 projectile.	 X	2" L ¾" L	7¼" D 1½" U 4" U	 O IMP IMP IMP	 I I V I	 12" 9¼ 1-3/8" 30¼ 51½"	P

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.	R.L.	C.B.	CRACKING LOC.	TYPE	AMT	REMARKS OR CRACKING RADIOGRAPHIC RESULTS, ETC
A. AD 2132 B. 1/23/43 2/3/43 C. W 51 D. Ford Motor Co. E. McKay Company F. Ford Motor Co.	A. 1-1/2" B. Cast II 1.10Mn .49Si .020S .016P .50Cr .29Mo C. .28C D. Face 241 Back 241 E. Basic Elec. F. 1800°F 5 hrs air 1700°F 3 hrs water 1100°F 8 hrs water	A. A II .09C 4.1Mn .65Si 19.1Cr 8.8Ni B. Armorloy C. Lime D. DC-REV	A. 45° DV B. 3/16" C. Flame cutting.	A. Copper B. 1. II 5/32" 2a 175 25 2. I 5/32" 2a 175 25 1/4" 5a 225 27 3. II 1/4" 6b 225 27 C. 8 hours. D. Grinding time 1 hour.	A. None B. None	Before test 1 2	- 812 900	- ½" L	- 2¼" R	- 3½" D 4-3/8" U	- O IMP	- I I	7-3/8" 4-1/8 16½ 28"	cross weld crack P
						Temp. at time of testing: -20°F. 75mm T31 projectile								
A. AD 2137 B. 1/24, 28 /43 C. # 39 D. Ordnance Steel Foundry E. McKay Company F. International Harvester.	A. 1-1/2" B. Cast III 1.47Mn .48Si .022S .024P .39Mo C. .28C D. Face 277 Back 262 E. B.O.H. F. 1750°F 2½ hr air 1575°F 1½hr water 1125°F 4 hr air	A. A II .12C 4.0Mn .70Si 20.0Cr 9.7Ni B. Armorloy C. Lime D. DC-REV	A. 45° DV B. 5/16" C. Flame cutting. Grinding.	A. Copper B. 1. II 5/32" 1a 135 - 3/16" 1a 250 - 2. III 1/4" 2a 250 - 1/4" 6b 250 — 1/4" 1b 260 - 5/32" 1b 140 - 3. III 5/32" 3b 140 - 1/4" 2b 250 - 1/4" 1b 280 - C. 3.45 hours. 110°-300°F D. Grinding time 3.56 hours.	A. 100° F B. None	1 2	779 899	 X	4" L	8½" D 2" U	- IMP IMP	- I V	- 7½" 11½ 19"	P Piping in plate adjacent to welds.
						Temp. at time of testing: -22°F. 75mm T31 projectile								

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	N	BALLISTIC RESULTS VEL. F/S	LOCATION OF N L.L.	R.L.	C.B.	CRACKING LOC.	TYPE	AMT	REMARKS ON CRACKING RADIOGRAPHIC RESULTS, ETC
A. AD 2127 B. 1/21/43 2/23/43 C. UM 30 D. Carnegie Steel Corp. E. Crucible Steel Corp. Linde Air Products F. Briggs Mfg. Co.	A. 1-1/2" B. R I 1.04Mn .21Si .23S .018P .57Cr 1.00Ni .38Mo C. .27C D. Face 293 Back 293 E. B.O.H. F. 1562°F 1¼ hrs water 1040°F 2¼ hrs water	Crucible A. A I .09C 1.78Mn .30Si 19.17Cr 10.81Ni 2.09Mo B. Armorize C. Ti+Mo D. DC-REV Linde Air A. A II .21C 3.61Mn .47Si .025S .035P 9.14Cr 10.73Ni B. Unionmelt C. Bare D. AC	A. 45° DV B. 1/4" C. Flame cutting.	A. Copper B. 1. II 3/16" 2a 180 25 2. I 1/4" 2a 220 27 3. I 1/4" 2UM 900 30 C. 3-1/2 hours. 130°-265°F D. Grinding time 15 minutes.	A. None B. None	1 2	1110 1083 Temp. at time of testing +20°F. 75mm T21 projectile.	 X	3½" R	4½" " 4½" D	- IMP	- I	- 38½"	F Crossbar is entirely cracked.
A. AD 2128 B. 1/21,22,23/43 2/23,24/43 C. UCTF-1A D. Republic Steel Corp. E. Alloy Rods Co. Linde Air Products F. Fisher Tank Division.	A. 1-1/2" B. R - - C. - - D. - - E. F. 1650°F water spray quench 1200°F draw	Alloy Rods A. Not given B. Armorarc C. Titania D. — Linde Air A. Not given B. Oxweld #42 C. — D. A.C.	A. 45° DV B. 5/16" C. Flame cutting. Grinding.	A. Copper B. 1. I 3/16" 1a 185 22 2. I 1/4" 2a 250 40 3. I 1/4" 2UM 900-1060 35-38 C. 1 hour 29 minutes. 260°-380°F D. Grinding time, none.	A. 150°F B. None	1	823 Temp. at time of testing -15°F. 75mm T21 projectile.	1" L		4" D	IMP	I	36"	F 2" crossbar crack.
A. AD 2135 B. 1/21,22/43 2/23,24/43 C. UCTF 5 D. Jones & Laughlin E. McKay Rods Co. Linde Air Products F. Fisher Tank Division.	A. 1-1/2" B. R III 1.59Mn .25Si .016S .021P .41Mo C. .27C D. - - E. Basic F. Not known	McKay A. not available. B. Armorloy C. Lime D. DC REV. Linde Air A. not available B. Oxweld #42 C. — D. A.C.	A. 45° DV B. 5/16" C. Flame cutting. Grinding.	A. Copper B. 1. I 5/32" 1a 165 22 2. I 3/16" 2a 185 22 3. I 1/4" 2UM 840-1000 35 C. 1 hour 54 minutes. 320°-340°F D. Grinding time, none.	A. 180°F B. None	1	651 Temp. at time of testing -13°F. 75mm T21 projectile.	3½" R		8" D	IMP	I	35"	F 1-1/4" and 1-1/2" cracks at right weld junctions.

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 H. L.L.	R.L.	C.B.	CRACKING LOC.	TYPE	AMT	REMARKS OR CRACKING RADIOGRAPHIC RESULTS, ETC.
A. AD 2128 B. 1/21,22,23/43 2/23/43 C. UCTF 8 D. Great Lakes Steel E. McKay Rods Co. Linde Air Products F. Fisher Tank Division	A. 1-1/2" B. R IV .96Mn .72Si .025S .023P .84Cr .16Mo .10Zr C. .29C D. — E. — F. not known	McKay A. Not available B. Armorloy C. Lime D. Linde Air A. Not available B. Oxweld #42 C. — D. A.C.	A. 45° DV B. 5/16" C. Flame cutting. Grinding.	A. Copper B. 1. I 5/32" 1a 165 22 2. I 3/16" 2a 185 22 3. I 1/4" 2UM 840-1000 35 C. 2 hours 3 minutes. 260°-320°F D. Grinding time, none.	A. 150° F B. None	1	772 Temp. at time of testing -13°F 75mm T21 projectile	X		3" D	IMP	I	36"	F
A. AD 2133 B. 1/23,23/43 2/3/43 C. CO 3 D. Continental Steel E. Crucible Steel Corp. Linde Air Products F. Midland Steel Products	A. 1-1/2" B. Cast I .77Mn .35Si .04S .040P .52Cr .59Ni .40Mo C. .27C D. — E. — F. - -	Linde A. A II .24C 3.83Mn .52Si .019S .033P 7.72Cr 13.03Ni .08Mo B. Oxweld 42 C. Flux #80 D. AC Crucible A. Not given B. Armorize C. — D. —	A. 45° DV B. 1/4" C. Flame cutting.	A. Copper B. 1. I 3/16" 1a 200 23 2. I 3/16" 1a 200 23 1/4 2a 250 25 3. I 1/4 2UM 800 30 C. 7 hours. 110°-450°F D. —	A. None B. None	1	865 Temp. at time of testing -20°F 75 mm T21 projectile.		1/2" I.	2 1/2" U	IMP IMP	I V	36" 10 1/2 46 1/2"	P

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.	R.L.	C.B.	CRACKING LOC.	TYPE	AMT	REMARKS OR CRACKING RADIOGRAPHIC RESULTS, ETC
A. AD 2142 B. 3/6,10/43 C. 94 D. Republic Steel E. McKay Company F. Cadillac Motor Car Division	A. 1" B. R I .90Mn .25Si .022S .025P .72Cr .83Ni .38Mo C. .28C D. Core 311 Surface 302 E. F. 1650°F water 1200°F air	A. A II .09-.12C 4.65-4.85Mn .55-.65Si .009-.027S .020-.025P 18.00-20.10Cr 9.62-10.20Ni .07-.15Mo B. Armorloy C. D. DC-REV	A. 60° DV B. 3/16" C. Flame cutting.	A. B. 1. II 5/32" 2a 180 25 2. I 1/4" 2a 220-240 25 3. II 5/32" 6b 140-170 25 C. 2 hours 41 minutes. 75°-135°F D. Grinding time .68 hours. Entire cross bar and right leg and 16" of left leg removed and rewelded.	A. None B. None	1	804		X	4½" D	IMP	I	24"	Passed after repair welded. Some incomplete fusion.
							Temp. at time of testing -19°F. 75mm T21 projectile							
A. AD 2142 B. 3/6,10/43 C. 96 D. Great Lakes Steel Corp. E. McKay Company F. Cadillac Motor Car Division	A. 1" B. R IV .82Mn .81Si .019S .025P .63Cr .17Ni .18Mo C. .28C D. Core 302 Surface 302 E. F. 1600°F water 975°F water	A. A II .10-.12C 4.65-4.80Mn .65-.66Si .023-.027S .025P 17.90-18.00 Cr 9.62-9.75Ni .07-.08Mo B. Armorloy C. D. DC-REV	A. 60° DV B. 3/16" C. Flame cutting.	A. B. 1. II 5/32" 2a 140 25 2. I 1/4" 2a 220-230 25 3. II 5/32" 6b 120 25 C. 2.32 hours. 70°-160°F D. Grinding time .55 hours. Repair weld. Entire crossbar and 6" on both legs removed and rewelded.	A. None B. None	1	784	1" L		6" D	IMP	I	32"	Passed after repair welded. Some incomplete fusion, two small crater cracks.
							Temp. at time of testing -17°F. 75mm T21 projectile							

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.	R.L.	C.B.	CRACKING LOC.	TYPE	AMT	REMARKS ON CRACKING RADIOGRAPHIC RESULTS, ETC.
A. AD 2142 B. 2/8, 10/43 C. 97 D. Great Lakes Steel Corp. E. Page Steel F. Cadillac Motor Car Division	A. 1" B. I* .90Mn .25Si .022S .025P .72Cr .83Ni .38Mo C. .28C D. Core 302 Surface 302 E. F. 1600°F water 975°F water	A. A II .06-.08C 1.78- 1.80Mn .40-.41Si .020- .024S 21.35- 21.90Cr 11.55- 11.90Ni .10-.12Mo B. C. D. DC-REV	A. 60° DV B. 3/16" C. Flame cutting. Grinding.	A. B. 1. II 5/32" 2a 180 25 2. I 1/4" 2a 240 25 3. II 5/32" 6b 140 25 C. 2.81 hours 70°-190°F D. Grinding time .71 hours. Entire weld on both legs and crossbar removed and rewelded.	A. None B. None	1	774	2¼" R		6" D	-	-	-	P Excessive incomplete fusion. Scattered slag.
						2	775		2" L	3½" U	IMP IMP	I V	8½ 8½	
						3	782		1¼" R	4" D	IMP IMP	I V	9½ 15½ 42½"	
							75mm T21 projectile Temp. at time of testing -17°F.							
A. AD 2143 B. 2/3/43 C. TP 68 D. Jones & Laughlin E. Alloy Rods Co. F. Ternstedt Mfg. Division	A. 1" B. R III 1.53Mn .20Si .023S .010P .38Mo C. .27C D. Face 335 Back 341 E. B.O.H. F. 1600°F ½ hr water 875°F 1½ hr air *Not Great Lakes type composition.	A. A II .08-.10C 3.6-3.9Mn .035- .038P .01S 19.2- 19.5Cr 10.9- 11.5Ni .36-.41Si B. Armorarc B C. Ti + Mn D. DC-REV	A. 60° DV B. 3/16" C. Flame cutting. Grinding	A. Copper B. 1. II 3/16" 2a 190-200 25 2. I 1/4" 2a 300 28 3. I 1/4" 2a 300 28 C. 5 hours. 100°-240°F D. Grinding time 1 hour. Cross bar cooled to 190°F before welding.	A. 100°F B. None	1	782		1¼" R	9" D	IMP	I	22½"	P Large crater crack and a slag pocket, weld appears small but sound.
							75mm T21 projectile Temp. at time of testing -15°F.							

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.	R.L.	C.B.	CRACKING LOC.	TYPE	AMT	REMARKS OR CRACKING RADIOGRAPHIC RESULTS, ETC.
A. AD 2145 B. 2/10,11/43 3/1/43 C. C 11 D. Jones & Laughlin E. Harnischfeger F. General Motors Truck & Coach Co.	A. 1/2" B. R III 1.27Mn .22Si .016S .019P .43Mo C. .22C D. Face 361 Back 363 E. B.O.H. F. 1600°F ½ hr water 875°F 1½ hr draw	A. A I .10C 1.58Mn .58Si 19.36Cr 11.40Ni 2.2Mo B. AW-3 C. Lime D. DC	A. 45° SV B. 3/16" C. Flame cutting	A. Copper B. 1. I 5/32" 1a 125 24 2. I 3/16" 1a 115 24 3. III 5/32" 2b 115 24 3/16" 1b 155 24 One seal bead - 5/32" 1a 150 24 C. 8.2 hours 150°-250°F D. Grinding time 2 hours.	A. None B. None	1	2800	6" R		13½" U	-	-	-	P Frequent slag stringers.
						2	2800	6½" R		6" U	-	-	-	
						3	2800	6½" L		3½" U	-	-	-	
						4	2800	1¾" R		6" U	IMP IMP	I V	9½" 1½	
						5	2800		6½" R	8" D	-	-	-	
						6	2800		3½" L	4½" D	-	-	-	
													11"	
						Temp. at time of testing -17°F. 37mm HE M-54 projectile.								
A. AD 2145 B. 2/10,11/43 3/1/43 C. C 14 D. Jones & Laughlin E. McKay Company F. General Motor Truck & Coach Co.	A. 1/2" B. R III 1.27Mn .22Si .016S .019P .43Mo C. .22C D. Face 361 Back 361 E. B.O.H. F. 1600°F ½ hr water 875°F 1½ hr draw	A. A I .10C 3.66Mn 1.13Si 18.10Cr 10.20Ni .47Mo B. Armorloy A-5 C. Lime D. DC	A. 45° SV B. 3/16" C. Flame cutting.	A. Copper B. 1. I 5/32" 1a 125 24 2. I 3/16" 1a 155 24 3. III 3/16" 1b 155 24 5/32" 2b 115 24 Seal bead - 5/32" 1a 150 24 C. 8.2 hours 150°-250°F D. Grinding time 2 hours.	A. None B. None	1	2800		4" L	8" U	-	-	-	P
						2	2800	1½" R		9½" D	IMP	I	13"	
						3	2800		1¾" R	4½" D	IMP	I	2½	
						4	2800	2¾" L		5" U	IMP	I	4	
													19½"	
						Temp. at time of testing -15°F 37mm HE M-54 projectile								

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. 1. Root Type 2. Body Type 3. Crown Type C. Total Welding Time & Inter Pass Temperature D. Remarks	HEAT TRT	BALLISTIC RESULTS No. Vel. F.S. Location of Hit L.L. R.L. C.R. Cracking Loc. Type Amt.	REMARKS ON CRACKING RADIOGRAPHIC RESULTS, ETC.
A. AD 2146 B. 2/10,11/43 3/1/43 C. C 17 D. Great Lakes Steel Corp. E. Harnischfeger F. General Motor Truck & Coach Co.	A. 1/2" B. R IV .78Mn .72Si .025S .019P .81Cr .17Mo C. .28C D. Face 343 Back 351 E. B. O. H. F. 1600°F ½ hr water 900°F draw	A. A I .10C 1.58Mn .58Si 19.38Cr 11.40Ni 2.2Mo B. AW-3 C. Lime D. DC-REV	A. 45° SV B. 3/16" C. Flame cutting.	A. Copper B. 1. I 5/32" 1a 125 24 2. I 3/16" 1a 155 24 3. III 5/32" 2b 115 24 3/16" 1b 155 24 Seal bead- 5/32" 1a 150 24 C. 8.2 hours. 150°-250°F D. Grinding time 2.0 hours.	A. None B. None	1 2800 3" R 10" U - - - 2 2800 2¼" L 1½" U O I 4" 3 2800 1" L 4½" D IMP I 25, IMP V 12 41" Temp. at time of testing -21°F. 37mm HE M-54 projectile.	P
A. AD 2146 B. 2/10,11/43 3/1/43 C. C 21 D. Great Lakes Steel Corp. E. McKay Company F. General Motor Truck & Coach Co.	A. 1/2" B. R IV .78Mn .72Si .025S .019P .81Cr .17Mo C. .28C D. Face 354 Back 356 E. B.O.H. F. 1600°F ½ hr water 900°F 1½ hr draw	A. A I .10C 3.66Mn 1.13Si 18.10Cr 10.20Ni .47Mo B. Armcrloy A-5 C. Lime D. DC-REV	A. 45° SV B. 3/16" C. Flame cutting.	A. Copper B. 1. I 5/32" 1a 125 24 2. I 3/16" 1a 158 24 3. III 5/32" 2b 115 24 3/16" 1b 155 24 Seal bead - 5/32" 1a 150 24 C. 8.2 hours. 150°-250°F D. Grinding time 2 hours.	A. None B. None	1 2800 X 3" D IMP I 12½ 2 2800 3¼" L 4" D O I 40½ 53" Temp. at time of testing -20°F. 37mm HE M-54 projectile	P Small scattered slag inclusions

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. JT 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.	R.L.	C.B.	CRACKING LOC.	TYPE	AMT.	REMARKS OR CRACKING RADIOGRAPHIC RESULTS, ETC.
A. AD 2145 B. 2/10,11/43 3/1/43 C. C 7 D. Jones & Laughlin E. Linde Air Products Co. F. General Motor Truck & Coach Co.	A. 1/2" B. R III 1.27Mn .22Si .016S .019P .43Mo C. .22C D. Face 356 Back 359 E. B.O.H. F. 1600°F ½ hr water 875°F 1½ hr draw	A. A -- B. Oxweld #42 C. Flux #80 D. AC	A. 45° SV B. 1/16" C. Flame cutting.	A. Copper B. Unionmelt - 3/16" 2UM 640 30-40 C. 5 hours. 200°F D. Travel speed: pass #1-7.5"/min. pass #2-19"/min. 2" tacks placed 8" apart with 5/32" hand austenitic rod, before Unionmelt welding. Grinding time 1 hour.	A. None B. None	1 2 3	2600 2600 2600	7" L 3½" L	 2½" L	2½" U 8" D 12" U	- IMP IMP O O	- I V I V	- 14½ 1½ 6½ 2 24½"	F Excessive incomplete penetration.
							Temp. at time of testing -17°F 37mm HE M-54 projectile							
A. AD 507 B. 2/10,11/43 3/1/43 C. C 10 D. Great Lakes Steel Corp. E. Linde Air Products. F. General Motor Truck & Coach Co.	A. 1/2" B. R IV .78Mn .72Si .025S .019P .61Cr .17Mo .08Zr C. .28C D. Face 347 Back 350 E. F. 1600°F ½ hr water 900°F 1½ hr draw	A. A B. Oxweld #42 C. Flux #80 D. AC	A. 45° SV B. 1/16" C. Flame cutting.	A. Copper B. Unionmelt- 3/16" 2UM 640 30-40 C. 5 hours. 200°F D. Travel speed: pass #1-7.5"/min. pass #2-19"/min. Grinding time 1 hour. 2" tacks were placed 8" apart with 5/32" hand austenitic rod, before Unionmelt welding.	A. None B. None	1 2 3	2600 2600 2600	 1¼" R ¾" L	1¼" R	2½" U 12¼" D 2" U	IMP IMP IMP IMP	I I V I	8" 9 ½ 28½ 44"	F Excessive amount of incomplete penetration, and porosity.
							Temp. at test. +70°F 37mm HE M-54 projectile.							

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	REMARKS OR CRACKING RADIOGRAPHIC RESULTS, ETC
A. AD 2145 B. 2/10, 11/43 3/1/43 C. C3 D. Jones & Laughlin E. Linde Air Products F. General Motor Truck & Coach Co.	A. 1/2" B. R III 1.27Mn .22Si .016S .019P .43Mo C. .22C D. Face 350 Back 359 E. B.O.H. F. 1600°F ½hr water 875°F 1½ hr draw	A. Ferritic - B. Oxweld #36 C. #20 Flux D. AC	A. 45° SV B. 1/16" C. Flame cutting.	A. Copper B. Unionmelt 3/16" 2UM 640 36-40 C. 5 hours. 200°F D. Travel speed: pass #1-9"/min; pass #2-19"/min. Grinding time 1 hour. 2" tacks were placed 8" apart with 5/32" Fleetweld #7 before Unionmelt welding.	A. None B. None	P A few scattered gas pores.
A. AD 395 B. 4/23/43 C. D5-45-22 D. Dominion Foundry & Steel E. Union Carbide Company F. International Harvester Company.	A. 1/2" (12mm) B. R I .80Mn .31Si .023S .022P .93Cr .65Ni .25Mo C. .25C D. — E. Elec. Basic F. 1650°F 4 hrs. air 1680°F 1 hr water 1000°F 1 hr water	A. F .11C 1.75Mn .05Si max .05S max .04P max .45Mo. max B. #40 rod C. D. DC-REV	A. 34° SV B. C. Machining. Grinding.	A. Copper B. Unionmelt- 3/16" 1b 950 33	A. None B. None	P

BALLISTIC RESULTS — AD 2145

R	Vel. F/S	Location of E.		Cracking Loc.	Type	Amt.
1	2800	2½" L	3" D	IMP	I	17"
2	2800	5" L	11½" U	-	-	-
3	2800	1" R	4" D	IMP IMP	I V	23 8½
						48½"

Temp. at time of testing: -17°F.

37mm HE M-54 projectile

BALLISTIC RESULTS — AD 395

R	Vel. F/S	Location of E.		Cracking Loc.	Type	Amt.
1	2800	1-3/8" R	5" D	-	-	-
2	2800	2-1/8" L	3½" U	-	-	-
3	2800	7½" R	4½" U	-	-	-
4	2800	1" L	5" D	-	-	-
5	2800	3½" L	1-5/8" U	IMP	I	½"
6	2800	7½" R	X	-	-	-
						½"

Temp. at time of testing +50°F.

37mm HE M-54 projectile

APPENDIX B

1. Tables I through VIII -
   Summary of Ballistic Tests of "H" Plates
   for the Canadian Cold Test Program
   (WAL Report No. 642/117).

2. Table IX - Average Distribution of Structure
   Zones on Ballistic Fracture Surface (courtesy
   U. S. Steel Research Laboratory).

TABLE I

COLD TESTS OF WELDED ARMOR - CAMP SHILO - 1942/1943

1/2" ROLLED HOMOGENEOUS PLATE

Moly. Mod. Austenitic 18/8 Electrode

Fabricator	Armor Mfr.	C	Electrode	Joint Bevel	Joint Gap	Weld Deposit Body	Weld Deposit Surface	RD.	Shock Test Vel. f/s	Wld. Ck.	Test Plate Temp.	X-ray	Bal.	Firing Record	Plate No.	Remarks
Yellow Truck	J & L	0.22	Harn. AW-3	45° SV	3/16"	L	B 1SB	1*	2600	—	-19°	F		AD2145	C12	
								2*	2600	—						
								4 rds. at 2600					P			None fair, no cracks
"	"	"	"	"	"	"	"	1*	2600	—	-17°	P		"	C11	
								2 rds. at 2600								None fair, no cracks
								4	2600	9-1/2			P			
								2 rds. at 2600								Not fair, no further cracks
	One plate held for A. P. G. test															
Yellow Truck	Great Lakes	0.28	Harn. AW-3	45° SV	3/16"	L	B 1SB	2 rds. at 2600			-21°	P		AD2146	C17	Not fair. 4" weld crack
								3	2600	25			F			Plate cracked 12"
"	"	"	"	"	"	"	"	1*	2600	20	-20°	P	F	"	C18	
								2 rds. at 2600								Not fair, no further cracking
"	"	"	"	"	"	"	"	1*	2600	—		P		"	C19	
								2	2600	25-1/2	-15°		F			Plate cracked 18"
Hamilton Bridge	Dom. Fdry.	0.25	Harn. AW-3	60° SV	1/16"	L	L 1SB	1	2600	18	-8°	F	F	AD2138	2	Plate cracked 12"
								2*	2600	—						Plate cracked 13-3/4" more
"	"	"	"	"	"	"	"	1*	2600	—	-13°	P		"	3	
								2	2600	46			F			Broke in 2 pieces
"	"	"	"	"	"	"	"	1*	2600	12	-16°	P	F	"	4	Plate cracked 16"

Manganese Mod. Austenitic 18/8 Electrode

Fabricator	Armor Mfr.	C	Electrode	Joint Bevel	Joint Gap	Weld Deposit Body	Weld Deposit Surface	RD.	Shock Test Vel. f/s	Wld. Ck.	Test Plate Temp.	X-ray	Bal.	Firing Record	Plate No.	Remarks
Yellow Truck	J & L	0.22	McKay	45° SV	3/16"	L	B 1SB	1*	2600	—	-15°	P		AD2145	C14	
								2	2600	13			P			
								3	2600	2-1/2						
								4*	2600	4						
"	"	"	"	"	"	"	"	1	2600	4-1/2	-19°	P	P	"	C15	
								2*	2600	—						
								3	2600	—						
								4	2600	19-1/2						
"	"	"	"	"	"	"	"		2600	—	-18°	P		"	C16	4 rds., none fair, no cracks
								5	2600	26-3/4			P			
Yellow Truck	Great Lakes	0.28	McKay	45° SV	3/16"	L	B 1SB	1*	2600	17	-17°	P	F	AD2146	C20	
								2*	2600	13						Plate cracked 3"
								2 rds. at 2600								Not fair. Plate cracked 3" more
"	"	"	"	"	"	"	"	1	2600	12-1/2	-20°	P	F	"	C21	
								2*	2600	40-1/2						Broke in 2 pieces
"	"	"	"	"	"	"	"	1	2600	13-1/2	-14°	P	(F)	"	C22	
								2 rds. at 2600		11						Not fair. Plate cracked 2"
Int. Harv. Canada	Dom. Fdry.	0.25	Lincoln	34° SV	1/16"	L	L	1	2600	50-3/4	-14°	F	F	AD2140	7	Broke in 2 pieces
"	"	"	"	"	"	"	"	1	2600	22	-13°	F	F	"	8	
								2	2600	30-1/2						

I

* - NOT FAIR HIT - OUTSIDE 2" LIMIT

TABLE II

COLD TESTS OF WELDED ARMOR - CAMP SHILO - 1942/1943

1" ROLLED HOMOGENEOUS PLATE

Molybdenum Mod. Austenitic 18/8 Electrode

Fabricator	Armor Mfr.	C	Electrode	Joint Bevel	Joint Gap	Weld Deposit Body	Weld Deposit Surface	RD.	Shock Test Vel. f/s	Shock Test Wld. Ck.	Test Plate Temp.	X-ray	Bal.	Firing Record	Plate No.	Remarks
Ternstedt	J & L	0.27	Alloy Rods	60° DV	3/16"	L	L	1	778	29-1/2	-15°	P	F	AD2143	TH-67	Plate cracked 1-1/4"
"	"	"	"	"	"	"	"			6-1/2	-16°	P		"	TH-69	Passed X-ray after CB was rewelded
								1*	697	17-1/4			F			Crk. in CB before test. Plate cracked 5"
	Two plates held for A. P. G. test															
Cadillac	Great Lakes	0.28	Page	60° DV	3/16"	L	B	1*	774		-17°	F		AD2142	97	Failed X-ray after repairs
								2*	775	8-1/2						Plate cracked 8-1/2"
								3	782	9-3/4			NWT			Broke in 2 pieces
"	"	"	"	"	"	"	"	1*	775		-16	P		"	99	Passed X-ray after repairs
								2*	775	11-1/2						Plate cracked 14"
								3*	775				NWT			
	One plate held for A. P. G. test															
Cadillac	Republic	0.28	Page	60° DV	3/16"	L	B	1	809	30-1/2	-17°	F	F	AD2142	91	Failed X-ray after repairs
"	"	"	"	"	"	"	"	1	775	36	-11°	F	F	"	95	Failed X-ray after repairs Broke in 2 pieces
	One plate held for A. P. G. test															

Manganese Mod. Austenitic 18/8 Electrode

Fabricator	Armor Mfr.	C	Electrode	Joint Bevel	Joint Gap	Weld Deposit Body	Weld Deposit Surface	RD.	Shock Test Vel. f/s	Shock Test Wld. Ck.	Test Plate Temp.	X-ray	Bal.	Firing Record	Plate No.	Remarks
Ternstedt	J & L	0.27	Alloy Rods	60° DV	3/16"	L	L	1	782	22-1/2	-15°	P	F	AD2143	TH-68	
"	"	"	"	"	"	"	"	1	797	43	-15°	P	F	"	TH-72	Broke in 2 pieces
	Two plates held for A. P. G. test															
Cadillac	Great Lakes	0.28	McKay	60° DV	3/16"	L	B	1	784	32	-17°	P	F	AD2142	96	Passed X-ray after repairs Broke in 2 pieces
"	"	"	"	"	"	"	"	1	764	11	-18°	F		"	98	Failed X-ray after repairs Plate cracked 15"
								2	760	13-1/2			NWT			Plate cracked 8-3/4" more
"	"	"	"	"	"	"	"	1	775	14	-18°	P		"	100	Passed X-ray after repairs Back spall in plate
								2	775	20-1/4			NWT			Piece punched out
Cadillac	Republic	0.28	McKay	60° DV	3/16"	L	B	1	773	26	-19°	P	F	AD2142	92	Passed X-ray after repairs
"	"	"	"	"	"	"	"	1	804	24	-19°	P	F	"	94	Passed X-ray after repairs
	One plate held for A. P. G. test															

II

* - NOT FAIR HIT - OUTSIDE 2" LIMIT

TABLE III

COLD TESTS OF WELDED ARMOR - CAMP SHILO - 1942/1943

1-1/2" ROLLED HOMOGENEOUS PLATE

Molybdenum Mod. Austenitic 18/8 Electrode

Fabricator	Armor Mfr.	Armor C	Electrode	Joint Bevel	Joint Gap	Weld Body	Deposit Surface	RD.	Shock Test Vel. f/s	Shock Test Wld. Ck.	Test Plate Temp.	X-ray	Bal.	Firing Record	Plate No.	Remarks
Fisher	J & L	0.27	Raco	45° DV	5/16"	L	L	1	1100	---	-27°	P	P	AD2135	CTF-13	
								2	1101	17						
"	"	"	"	"	"	"	"	1	1094	---	-19°	P	P	"	CTF-15	Passed X-ray after repair
								2	1121	30-1/2						Plate cracked 7"
"	"	"	"	"	"	"	"	1	1110	36	-15°	P	F	"	CTF-14	Broke in 2 pieces
Fisher	Re-public	0.27	Raco	45° DV	5/16"	L	L	1	1100	23	-30°	P	F	AD2128	CTF-6	Plate cracked 4"
								2	1098	10						Plate cracked 2-1/4" more
"	"	"	"	"	"	"	"	1	1108	20	-19°	P	F	"	CTF-4	Plate cracked 2"
								2*	1107	---						Plate cracked 2" more
								3	1095	9						
"	"	"	"	"	"	"	"	1	1094	14	-21°	P	P	"	CTF-5	Plate cracked 5-1/2"
								2*	1102	16-1/2						
										6						Crack in CB before test
Fisher	Great Lakes	0.29	Raco	45° DV	5/16"	L	L	1	1085	37-1/2	+24°	P	F	AD2126	CTF-19	
"	"	"	"	"	"	"	"	1	1098	36	-15°	P	F	"	CTF-21	Broke in 2 pieces
"	"	"	"	"	"	"	"	1	806	14	-15°	P	F	"	CTF-20	
								2	910	23						
Ford	Ford	0.26	Crucible	45° DV	3/16"	L	B	1	1085	12	-20°	P	P	AD2123	W-65	Plate cracked 1/2"
								2	1105	21						Plate cracked 5" more
"	"	"	"	"	"	"	"	1	1104	13-1/4	-17°	P	P	"	W-64	
								2	1093	3-3/4						Plate cracked 7-1/2"
Ford (Cont.)	Ford	0.26	Crucible	45° DV	3/16"	L	B	1	725	---	-16°	P		AD2123	W-63	
								2*	868	---						
								3	994	---						
								4	1113	11-1/2			P			
								5*	1149	---						
								6	1154	29						
Midland	Carnegie	0.27	Crucible	45° DV	5/16"	L & B	B	1	1099	11-1/4	-24°	P	P	AD2124	CR-38	Plate cracked 2-3/4"
								2	1099	10						Plate cracked 3-1/4" more
"	"	"	"	"	"	"	"	1*	1109	---	-19°	P		"	CR-39	Hit 2-1/2" from left leg weld No cracks
								2	1093	16-1/2			(F)			Hit on right leg weld Crack in right leg weld
								3	1093	1						
								4	1123	18-1/2						Plate in 2 pieces
"	"	"	"	"	"	"	"	1	1100	---	-25°	P	P	"	CR-41	
								2	1084	---						
G.M.C. Canada	Dominion Foundry		Harn. AW3A	DV	1/4"	L & B	B	1	1090	11	-19°	P	NWT	AD2125	GMC-6	Broke in 2 pieces
"	"		"	"	"	"	"	1	799	5-1/4	-19°	P	NWT	"	GMC-5	11-3/4" plate crack
								2	814	1-3/8						
								3	902	8-1/2						Broke in 2 pieces
"	"		"	"	"	"	"					F				Crack in CB before test
								1	1089	16-1/2	-22°		NWT	"	GMC-7	24" plate crack

* - NOT FAIR HIT - OUTSIDE 2" LIMIT

TABLE IV

COLD TESTS OF WELDED ARMOR - CAMP SHILO - 1942/1943

1-1/2" ROLLED HOMOGENEOUS PLATE

Manganese Mod. Austenitic 18/8 Electrode

Fabricator	Armor Mfr.	C	Electrode	Joint Bevel	Joint Gap	Weld Body	Deposit Surface	RD.	Shock Test Vel.f/s	Shock Test Weld.Ck.	Test Plate Temp.	X-ray	Bal.	Firing Record	Plate No.	Remarks
Fisher	J & L	0.27	Alloy Rods	45°DV	5/16"	L	L	1	1097	27-1/2	-19°	P	F	AD2135	CTF-11	Passed X-ray after repairs
"	"	"	"	"	"	"	"	1	793	24	-15°	F	F	"	CTF-12	
	One plate held for A.P.G. test															
Fisher	Re-public	0.25	Alloy Rods	45°DV	5/16"	L	B	1	1097	9-1/2	-18°	F	P	AD2128	CTF-1A	
								2*	1097	21						Back spall
"	"	"	"	"	"	"	"	1	1110	23	-25°	P	F	"	CTF-2A	Passed X-ray after repairs
								2	1088	1-1/2						Plate cracked 3-1/4"
"	"	"	"	"	"	"	"	1	1091	10	-19°	P	P	"	CTF-3A	Passed X-ray after repairs
								2*	1089	29						
Fisher	Great Lakes	0.29	Alloy Rods	45°DV	5/16"	L	L	1	1102	22-1/4	+24°	P	F	AD2126	CTF-18	
"	"	"	"	"	"	"	"	1	1094	37	-18°	P	F	"	CTF-16	
								2*	1095	31						
"	"	"	"	"	"	"	"	1	817	48	-15°	F	F	"	CTF-17	Broke in 2 pieces
Ford	Ford	).26	McKay	45°DV	3/16"	L	B	1	1091	32-3/4	-17°	P	F	AD2123	W-53	
								2	1094	16						Broke in 2 pieces
"	"	"	"	"	"	"	"			12		P		"	W-66	Crack in CB before test
								1	1099	29	-16°		F			
"	"	"	"	"	"	"	"	1	891	10-1/2		P		"	W-61	
								2	928	20	-16°		F			
Midland	Car-negie	0.27	McKay	45°DV	5/16"	L & B	B	1	1098		-24°	P	P	AD2124	CR-40	
								2	1093	17-1/2						
								3	1095	1/2						
								4	1097	36-1/4						Broke in 2 pieces
"	"	"	"	"	"	"	"	1	1111		-18°	P	P	"	CR-42	
								2	1113	5-3/4						Plate cracked 2-3/4"
								3*	1099							Plate cracked 1-7/8" more
								4	1095	9-1/4						Plate cracked 9" more
								5	1105	29						
"	"	"	"	"	"	"	"	1*	1092		-18°	P		"	CR-43	
								2	1121	7			P			Plate cracked 1-1/2"
								3	1156	27-1/4						Plate cracked 4-1/4" more

FERRITIC WELDS

1-1/2" ROLLED HOMOGENEOUS PLATE

Fabricator	Armor Mfr.	C	Electrode	Joint Bevel	Joint Gap	Weld Body	Deposit Surface	RD.	Shock Test Vel.f/s	Shock Test Weld.Ck.	Test Plate Temp.	X-ray	Bal.	Firing Record	Plate No.	Remarks
A. O. Smith	Car-negie	0.24	SW101	13/16"DV	3/8"	L	B	1	1097	13-1/4	-20°	P	P	AD2139	29391	No postheat treatment
								2	1094	9-1/4						Two gaps in crossbar welded with austenitic electrode
"	"	"	"	"	"	"	"	1	1100		-19°	P	P	"	29393	No postheat treatment
								2	1100							Two gaps in crossbar welded with austenitic electrode
								3*	1149							
								4	1199	1-3/4						
								5	1251	49						Broke in 2 pieces
	Two plates held for A. P. G. test															

* - NOT FAIR HIT - OUTSIDE 2" LIMIT

TABLE V

COLD TESTS OF WELDED ARMOR - CAMP SHILO - 1942/1943

1-1/2" CAST HOMOGENEOUS PLATE

Molybdenum Mod. Austenitic 18/8 Electrode

Fabricator	Armor Mfr.	C	Electrode	Joint Bevel	Joint Gap	Weld Deposit Body	Weld Deposit Surface	RD.	Shock Test Vel. f/s	Shock Test Weld. Ck.	Test Plate Temp.	X-ray	Bal.	Firing Record	Plate No.	Remarks
Baldwin	Sym. Gould	0.25	Alloy Rods	DV	3/16"	L	B	1*	897	---	-19°	None	NWT	AD2134	35	Plate cracked 34"
"		"	"	"	"	"	"	1	906	---	-21°	None	NWT	"	36	Plate cracked 20-1/2"
								2	914	---						Two more hits at 955 and 1002 broke up the plate
One plate held for A. P. G. test																
Briggs	American	0.28	Crucible	45°DV	5/16"	L	L	1	800	36	-24°	P	F	AD2131	M-33	Broke in 2 pieces
"	"	"	"	"	"	"	"	1	808	7-1/2	-20°	P	F	"	M-38	Plate cracked 6"
								2	904	9-1/2						Plate cracked 6-1/4" more
"	"	"	"	"	"	"	"	1	904	25-1/2	-26°	P	F	"	M-37	Plate cracked 15-3/4"
Chrysler	Continental	0.27	Crucible	45°DV	3/16"	L & B	B	1	805	—	-25°	P		AD2136	CP-49	
								2	900	5-3/4			NWT			Plate cracked 5-1/4"
								3	1004	2						Plate cracked 32-3/4" more
"	"	"	"	"	"	"	"	1*	802	11	-20°	P	NWT	"	CP-51	Passed X-ray after repairs. Plate cracked 38-3/4"
								2	907	2-3/4						Plate broke up
"	"	"	"	"	"	"	"	1	800		-27°	P	NWT	"	CP-50	Broke in 2 pieces
Int. Harv.	Ord. St. Fdry.	0.28	Alloy Rods	45°DV	5/16"	L & B	B			5						Crack in CB before test
								1	806	6	-20°	P	F	AD2137	42	
								2	901	3						Piece broke out
"	"	"	"	"	"	"	"	1*	88[illegible]	11	-19°	P	F	"	43	Crossbar cracked
								2*	938	—						
								3	938	—						
								4	938	1-3/4						
								5	1050	12-1/4						Plate cracked 19"
Int. Harv. (Cont.)	Ord. St. Fdry.	0.28	Alloy Rods	45°DV	5/16"	L & B	B	1	924	8-1/2	-19°	P	NWT	AD2137	44	Broke in 3 pieces
Ford	Ford	0.26	Crucible	45°DV	3/16"*	L	B	1	1017	26-1/2	+24°	P	F	AD2132	W-54	Plate cracked 5-3/4"
										4						Crack in CB before test
"	"	"	"	"	"	"	"	1*	773	10	-22°	P	F	"	W-62	Plate cracked 25"
								2	800	5						Plate cracked 3" more
										7						Crack in CB before test
"	"	"	"	"	"	"	"	1	849	16-1/2	-22°	P		"	W-52	Plate cracked 2"
								2	906	19			F			Plate cracked 10-1/4" more

* - NOT FAIR HIT - OUTSIDE 2" LIMIT

TABLE VI

COLD TESTS OF WELDED ARMOR - CAMP SHILO - 1942/1943

1-1/2" CAST HOMOGENEOUS PLATE

Manganese Mod. Austenitic 18/8 Electrode

Fabricator	Armor Mfr.	C	Electrode	Joint Bevel	Joint Gap	Weld Body	Deposit Surface	HD.	Shock Test Vel. f/s	Shock Test Weld. Ck.	Test Plate Temp.	X-ray	Bal.	Firing Record	Plate No.	Remarks
Baldwin	Sym. Gould	0.25	Alloy Rods	DV	3/16"	L	B	1	900	4	-21°	None	P	AD2134	39	
								2	950	4-1/2						Plate cracked 7"
								3	1000	6						Plate cracked 10" more
								4	1050	5-1/2						Plate cracked 13" more
"	"	"	"	"	"	"	"	1	818	---	-19°	P	P	"	40	
								2	896	---						
								3*	1002	---						
								4	1048	9						Plate cracked 16"
"	"	"	"	"	"	"	"	1	809	---	-20°	P	NWT	"	38	Plate cracked 12"
								2	815	1-1/2						
								3	811							Piece broke out
Briggs	American	0.28	McKay	45° DV	5/16"	L	L	1	912	—	-28°	P	P	AD2131	M-36	
								2*	908	—						Plate cracked 28-3/4"
								3	902	—						Plate cracked 11-3/4" more
"	"	"	"	"	"	"	"	1	907	5-1/2	-29°	P		"	M-35	Plate cracked 6"
								2	1000	4-1/2			NWT			Plate cracked 34-1/2" more
								1*	822	—	-20°	P		"	M-34	
								2*	823	—						
								3	920	—			P			
								4	1001	18-1/4						Plate cracked 25-1/2"
Fisher	Gen. Steel		Alloy Rods	45° DV	5/16"	L	L	1	1094	17-1/4	+24°	P	F	AD2130	CTF26	
								2	1117	16-3/4						
"	"		"	"	"	"	"	1*	805	12	-29°	P	F	"	CTF28	
								2	903	8						Plate cracked 1-3/8"
								3	1001	30						
Fisher (Cont.)	Gen. Steel		Alloy Rods	45° DV	5/16"	L	L	1*	819	11	-20°	P	F	AD2130	CTF27	
								2	909	21						Plate cracked 2"
										6						Left leg crack before test
Chrysler	Continental	0.27	McKay	45° DV	3/16"	L & B	B	1	809	14	-20°	P	F	AD2136	CP-47	Passed X-ray after repairs
								2	911	2						Plate cracked 44-3/4"
"	"	"	"	"	"	"	"	1	810	23	-25°	P	F	"	CP-48	Passed X-ray after repairs
								2	905	13						Plate cracked 8-1/4". Broke in 3 pieces
"	"	"	"	"	"	"	"	1	1101	20-1/2	+24°	P	F	"	CP-46	Passed X-ray after repairs
								2	1059	—						Plate cracked 26-1/4"
Int. Harv.	Ord. St. Fdry.	0.28	McKay	45° DV	5/16"	L&B	B	1	1025	4-1/4	-20°	P	NWT	AD2137	40	Plate cracked badly
								2	1050	—						Plate broke 5 pieces
"	"	"	"	"	"	"	"	1*	909	—	-20°	P		"	41	
								2	1017	1-3/4						
								3	1040	—			P			Plate cracked 7"
								4	1045	12-1/4						Plate cracked 15-1/2" more
"	"	"	"	"	"	"	"	1*	779	—	-22°	P		"	39	
								2	899	7-1/2			P			Plate cracked 11-1/2"
										3		P				Crack in CB before test
Ford	Ford	0.26	McKay	45° DV	3/16"	L	B	1	1049	12-1/2	+24°			AD2132	W-49	
								2*	1053	1-1/2			F			Plate cracked 19-1/2"
										9-1/2						Crack in CB before test
"	"	"	"	"	"	"	"	1	786	3	-20°			"	W-67	Plate cracked 2-5/8"
								2	898	11-3/4			F			Plate cracked 30-3/4" more
										7-3/8		P				Crack in CB before test
"	"	"	"	"	"	"	"	1*	812	4	-20°			"	W-51	
								2	900	16-1/2			F			

* - NOT FAIR HIT - OUTSIDE 2" LIMIT

VI

TABLE VII

COLD TESTS OF WELDED ARMOR - CAMP SHILO - 1942/1943

1/2" ROLLED HOMOGENEOUS PLATE

Unionmelt

Fabricator	Armor Mfr.	C	Electrode Rod	Electrode Melt	Joint Bevel	Joint Gap	Weld Body	Deposit Surface	RD.	Shock Test Vel. f/s	Shock Test Weld. Ck.	Test Plate Temp.	X-ray	Bal.	Firing Record	Plate No.	Remarks
Yellow Truck	J & L	0.22	36 Ferritic	20	45° SV	1/16"	1L	1SB	1*	2600	—	-17°	P		AD2145	0-2	
									2	2600	10			(F)			Plate cracked 10"
									3*	2600	—						
									4*	2600	22-1/2						
"	"	"	"	"	"	"	"	"	1*	2600	17	-17°	P	F	"	0-3	
									2*	2600	—						
									3	2600	23						Plate cracked 8-1/2"
	Two plates held for A. P. G. test																
Yellow Truck	J & L	0.22	42	80	45° SV	1/16"	1L	1SB	1	2600	16	-20°	F	F	AD2145	0-5	Plate cracked 13"
									2*	2600	—						Plate cracked 6" more
									3*	2600							Plate cracked 12" more
"	"	"	"	"	"	"	"	"	1*	2600	—	-17°	F		"	0-7	
									2*	2600	14-1/2			F			Plate cracked 1-3/4"
									3*	2600	6-1/2						Plate cracked 2" more
	One plate held for A. P. G. test																
Yellow Truck	Great Lakes	0.28	42	80	45° SV	1/16"	1L	1SB	1	2600	52-1/2	-20°	F	F	AD2146	0-8	
									1*	2600							No cracks
									2*	2600							No cracks
"	"	"	"	"	"	"	"	"	3*	2600	13-1/2	-20°	F	F	"	0-9	
	One plate held for A. P. G. test								4	2600	46-1/2						Broke in 2 pieces
Int. Harv. Canada	Dom. Fdry.		Ferritic		34° SV	0	1L	1SB	1	2600	21	-18°	F	F	AD2140	13	
			"		"	"	"	"	1	2600	27-1/2	-15°	F	F	"	15	Plate cracked badly
"	"		"		"	"	"	"	1	2636	31	-11°	F	F	"	16	" " "
"	"		"		"	"	"	"	1	2632	34-1/2	-13°	F	F	"	18	Broke in 2 pieces

1-1/2" ROLLED HOMOGENEOUS PLATE

Unionmelt

Fabricator	Armor Mfr.	C	Electrode Rod	Electrode Melt	Joint Bevel	Joint Gap	Hand Layers	RD.	Shock Test Vel. f/s	Shock Test Weld. Ck.	Test Plate Temp.	X-ray	Bal.	Firing Record	Plate No.	Remarks
Fisher	J & L	0.27	#42	8020XD	45° DV	5/16"	3	1	1087	36	-17°	F	F	AD2135	UCTF-4	Broke in 2 pieces
"	"	"	"	"	"	"	3	1*	651	35	-13°	F	F	"	UCTF-5	
"	"	"	"	"	"	"	3	1	1066	36	+20°	F	F	"	UCTF-6	Broke in 2 pieces
Fisher	Republic	0.25	#42	8020XD	45° DV	5/16"	3	1	823	36	-15°	F	F	AD2128	UCTF-1A	Broke in 2 pieces
"	"	"	"	"	"	"	4	1	1089	45	-19°	F	F	"	UCTF-2A	Failed X-ray after repairs Broke in 2 pieces
"	"	"	"	"	"	"	4	1	1082	36	+24°	P	F	"	UCTF-3A	Passed X-ray after repairs Broke in 2 pieces
Fisher	Gr. Lakes	0.29	#42	8020XD	45° DV	5/16"	3	1	704	36	-13°	P	F	AD2126	UCTF-7	Passed X-ray after repairs Broke in 2 pieces
"	"	"	"	"	"	"	3	1	772	36	-13°	F	F	"	UCTF-8	Broke in 2 pieces
"	"	"	"	"	"	"	3	1*	1098	36	-17°	P	F	"	UCTF-9	Broke in 2 pieces
Briggs	Carnegie	0.27	#42	—	45° DV	1/4"	4	1	1098	36	-21°	P	F	AD2127	UM-32	Broke in 2 pieces
"	"	"	"		"	"	4	1	1096	12	-18°	P	(F)	"	UM-31	Plate cracked 5/8"
							4	2	1128	30						Broke in 2 pieces
"	"	"	"		"	"	4	1*	1110	—	+20°	F		"	UM-30	
							4	2	1083	36			F			Broke in 2 pieces

1-1/2" CAST HOMOGENEOUS PLATE

Fabricator	Armor Mfr.	C	Electrode Rod	Electrode Melt	Joint Bevel	Joint Gap	Hand Layers	RD.	Shock Test Vel. f/s	Shock Test Weld. Ck.	Test Plate Temp.	X-ray	Bal.	Firing Record	Plate No.	Remarks
Midland	Continental	0.27	#42	#60	45° DV	1/4"	4	1	865	36	-22°	P	F	AD2133	CO-1	Broke in 2 pieces
"	"	"	"	"	"	"	4	1	1057	9-1/2	+24°	P	NWT	"	CO-2	Broke in 4 pieces
"	"	"	"	"	"	"	4	1	800	36	-20°	P	F	"	CO-3	Broke in 2 pieces

* - NOT FAIR HIT - OUTSIDE 2" LIMIT

VII

TABLE VIII

TESTS AT NORMAL TEMPERATURE - ABERDEEN PROVING GROUND - 1943

WELDED ARMOR H PLATES FROM CAMP SHILO (See Tables 1 - 11)

Fabricator	Armor	Rd.	Shock Test Vel. f/s	Weld Ck.	Test Plate Temp.	X-ray	Bal.	Firing Record	Plate No.	Electrode	Remarks
					1/2" Rolled Homogeneous Plate						
Yellow Truck	J & L	1* 2* 3 4 5	2600 " " " "	--- --- --- 10 2	+70°	P	 P	AD-507	C-13	Mo Mod.	Originally acceptable.
Yellow Truck	J & L	1* 2* 3 4	2600 " " "	--- --- 8 7-3/4	+70°	F	 P	AD-507	C-1	Unionmelt Ferritic	Excessive cracks in crossbar. Originally acceptable.
Yellow Truck	J & L	1* 2 3	2600 " "	12 --- 11-1/2	+70°	F	F	AD-507	C-4	Unionmelt Ferritic	Excessive cracks and porosity in crossbar. Originally unacceptable.
Yellow Truck	J & L	1 2 3* 4* 5	2600 " " " "	4 --- --- --- 4	+70°	F	P	AD-507	C-6	Unionmelt Austenitic	Excessive amount of incomplete penetration. Originally unacceptable.
Yellow Truck	Great Lakes	1 2 3	2600 " "	8 9-1/2 26-1/2	+70°	F	P	AD-507	C-10	Unionmelt Austenitic	Excessive amount of incomplete penetration. Originally unacceptable due to lack of penetration.
					1" Rolled Homogeneous Plate						
Ternstedt	J & L	1 2	775 774	16 19-1/4	+70°	F	P	AD-507	TH-71	Mo Mod.	Excessive cracks in crossbar. Originally acceptable with small cracks in crossbar.
Ternstedt	J & L	 1	 768	6-1/4 20-3/4	+70°	F	 F	AD-507	TH-73	Mo Mod.	Excessive cracks in crossbar. Originally acceptable. Repairs are evident.
Ternstedt	J & L	1 2 3	769 772 775	13-3/4 15-1/2 30-3/4	+70°	F	P	AL-507	TH-66	Mn Mod.	Excessive cracks in crossbar. Originally rejectable. 3" plate crack.
Ternstedt	J & L	1	789	20-1/2	+70°	F	F	AD-507	TH-70	Mn Mod.	Excessive cracks in crossbar. Originally rejectable.
Cadillac	Great Lakes	1	785	21	+70°	F	F	AD-507	101	Mo Mod.	Excessive cracks in crossbar. Originally rejectable because of cracks. 2" plate crack.
Cadillac	Republic	1* 2	772 774	--- 23	+70°	F	 F	AD-507	93	Mo Mod.	Excessive cracks in crossbar. Originally rejectable.
Cadillac	Republic	1 2	772 773	11-1/2 8-1/4	+70°	F	P	AD-507	90	Mn Mod.	Unsoundness. Scattered cracks. Originally acceptable. 3-1/2" plate crack. 3" plate crack.
					1-1/2" Rolled Homogeneous Plate						
Fisher	J & L	1 2 3	953 1095 1101	7-1/2 4 21-1/2	+65°	F	 P	AD-507	CTF-10	Mn Mod.	Excessive cracks in crossbar. Originally acceptable.
A. O. Smith	Carnegie	1 2 3 4	1105 1094 1131 1201	--- 3/4 [illegible] 18	+65°	P	P	AD-507	29390	SW-101 Ferritic	Originally acceptable after repairs of cracks.
A. O. Smith	Carnegie	1 2 3 4	1109 1135 1162 1179	4-1/2 16 1-1/2 33	+65°	F	P	AD-507	29392	SW-101 Ferritic	Excessive cracks in crossbar. Originally acceptable. The firing record refers to the shock performance as unsatisfactory.
					1-1/2" Cast Homogeneous Plate						
Baldwin	Sym.-Gould	1 2 3	1077 1079 1096	12-1/2 4 19	+70°	P	P	AD-507	37	Mo Mod.	Originally acceptable.

* - NOT FAIR HIT - OUTSIDE 2" LIMIT

TABLE IX

Average Distribution of Structure Zones on Ballistic Fracture Surface*

Armor	No. of Plates Examined	Visual Estimate of Structure Zones: Weld Metal %	Fusion Zone %	Base Metal: HAZ %	UBM %	Predominant Path of Fracture under or near Impact Causing Failure
Manual, Mn-Modified, Austenitic						
1/2" R	3	15	10	73	2	HAZ
1" R	4	48	36	16	0	WM
1-1/2" R	7	20	73	6	1	FZ
1-1/2" C	7	13	45	13	29	FZ
Manual, Mo-Modified, Austenitic						
1" R	3	38	42	20		WM, FZ
1-1/2" R	3	28	72	--		FZ
1-1/2" C	2	28	52	20		FZ, WM
Unionmelt, Ferritic						
1/2" R	4	22	0	66	12	HAZ
Unionmelt, Austenitic						
1/2" R	3	15	0	78	7	HAZ
1-1/2" R	8	6	5	86	3	HAZ
1-1/2" C	1	5	0	85	10	HAZ

* Data obtained from U. S. Steel Corporation, Research Laboratory, Kearny, New Jersey.

R = Rolled
C = Cast
HAZ = Heat-affected zone
UBM = Unaffected base metal
FZ = Fusion zone
WM = Weld metal