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OTTAWA October 9th, 1943.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1513.

Examination of Welded Splash Strips.

(Copy No. 5.)

Bureau of Mines
Division of Metallic
Minerals
-
Ore Dressing
and Metallurgical
Laboratories

CANADA
DEPARTMENT
OF
MINES AND RESOURCES
Mines and Geology Branch

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Origin of Material:

On September 21st, 1943, Mr. V. G. Morris, for the Director of Metallurgy, Army Engineering Design Branch, Department of Munitions and Supply, Ottawa, Ontario, submitted samples of welded splash strips for examination.

These samples consisted of six ¼-inch splash strips (thought to be of SAE 4130 steel) welded to a 6-mm. plate, said to be Dominion Foundries and Steel Limited standard bullet proof armour plate. Four of the strips were fillet-welded to the armour plate, one was fillet-and-plug welded, and one was

(Origin of Material, cont'd) -

plug-welded only. The welding was identified as follows:

Strip Number	Type of Weld	Electrode Size and Type
S	Fillet	¼", austenitic.
1	Fillet	5/32", austenitic.
2	Plug	Austenitic.
	Fillet	5/32", ferritic - 50,000 p.s.i.
3	Fillet	¼", ferritic - 50,000 p.s.i.
4	Plug	Austenitic.
5	Fillet	¼", austenitic.

There is reason to believe that the ferritic electrode used was Fleetweld No. 7 operated on reverse polarity. On ballistic testing, the armour plate cracked badly under the two ferritic welds.

Object of Investigation:

To determine the cause of failure of the plate under the ferritic welds at ballistic proof tests.

PROCEDURE:

1. The plate and welds were given a thorough visual examination.

2. Figure 1 is a photograph of the assembly as received, showing the location of the cracks. Figure 2 is a photograph of the back of the plate, showing the location and extent of cracking.

3. Sections of the welds were removed, polished, and etched. Figure 3 shows sections from Welds 1 and 5 (austenitic). Figure 4 shows sections of two austenitic plug welds (Welds 2 and 4). Figure 5 shows sections of Welds 2 and 3 (ferritic).

4. Samples were machined from the splash strips and the armour plate for chemical analysis. The following table

(Procedure, cont'd) -

gives the results obtained and specifications for comparison:

TABLE I.

	PLATE			SPLASH STRIPS	
	Bullet Proof "Specification"	Obtained	Armour Plate "Specification"	SAE 4130	Obtained
	- Per cent -				
Carbon -	0.20-0.30	0.30	0.25-0.30	0.28-0.33	0.26
Phosphorus -	0.04 max.	0.018	0.04 max.	0.04 max.	0.058
Sulphur -	0.04 max.	0.012	0.04 max.	0.04 max.	0.033
Manganese -	0.70-0.90	0.57	0.50-0.70	0.40-0.60	0.83
Silicon -	0.40-0.60	0.29	0.35-0.55	0.20-0.35	0.46
Chromium -	0.80-1.10	2.43	2.00-2.50	0.80-1.10	0.80
Nickel -	0.70-0.90	0.18	0.65-0.85	None.	0.85
Molybdenum -	0.20-0.30	0.45	0.30-0.50	0.15-0.25	0.25
Vanadium -	None.	0.03	None.	None.	0.02

5. Transverse sections of all welds were examined under the microscope. Figure 6 (obtained from Weld 2) shows the typical structure of the heat-affected zones close to the fusion line. A crack running through the heat-affected zone of Weld 2 may also be seen. Figure 7 shows the typical transformation zone structure of all welds. Figure 8 shows the normal plate structure.

Figure 9 is a low-magnification photograph of the cracks under Weld 3. Note the smaller crack in the heat-affected zone and its sharp change of direction towards the end. Figure 10 is a similar photograph of small "hard" cracks in the heat-affected zone of Weld 2. Note that the cracks are parallel and very close to the fusion line.

6. A longitudinal section of the armour plate was examined under the microscope. Figure 11 shows a typical group of inclusions. In Figure 12, at higher magnification, it may seem that the inclusions are mainly sulphides with a few oxides.

The same sample was heated to 1600° F. for 30 minutes, cooled to 1000° F. at the rate of 200° F. per hour, and

(Procedure, cont'd) -

then cooled in still air to room temperature. This heat treatment is designed to produce a structure which will reveal banding or laminations more readily than a quenched and tempered structure. On examination, no evidence of banding was detected.

7. A longitudinal section of Weld 2 was polished and then examined under a microscope. A "hard" crack (See Figure 10) in the heat-affected zone is shown in Figure 13. Note that the crack apparently originates at a sulphide inclusion.

8. Hardness readings, using a Vickers machine and a 10-kilogram load, were taken on all welds and heat-affected zones. The averages of four readings in each case, in Vickers hardness numbers, are given below:

FERRITIC WELDS 2 AND 3		AUSTENITIC WELDS 1 AND 5		NORMAL ARMOUR PLATE
Weld Metal	Heat-Affected Zone	Weld Metal	Heat-Affected Zone	
253	519-572	187	519-542	421

DISCUSSION:

A visual examination of the bead contours of the welded splash strips indicates that the electrode sizes given were those actually used. However, it will be noted that there are great differences in penetration and width and depth of the heat-affected zones of Welds 1 and 5 and also Welds 2 and 3. It would seem that in the case of Welds 1 and 5 these differences are too great to be wholly attributable to differences in electrode sizes. Large variations in welding speeds might be responsible but large variations would be reflected by the bead contours. In both cases the bead contours indicate a fairly uniform welding speed. In the case of Welds 2 and 3, it is stated that Weld 2 was made with 5/32"-diam. electrode and Weld 3 with a ¼"-diam electrode. Here again the differences

(Discussion, cont'd) -

in penetration and heat-affected zones are so pronounced that apparently they can be accounted for only if Weld 2 was made using straight polarity and Weld 3 using reverse polarity.

Unfortunately, it was impossible to obtain information as to the speed of welding, welding currents, and polarity used. Fleetweld No. 7 (Lincoln Electric Co. of Canada, Ltd.) conforms to the American Welding Society's Specification E6012. The maker recommends that this electrode be used on straight polarity and states that the weld metal as deposited will develop a tensile strength of from 71,000 to 82,000 p.s.i. However, the ductility of the weld metal is lower than that deposited by electrodes conforming to E6010, 6020 and 6030 specifications. It will be evident that the tensile strength developed by this electrode in deposit is considerably higher than the 50,000 p.s.i. specified for this weld.

The ferritic welds exhibit two types of cracks. The major cracks in both cases originate in areas of high stress concentration. In Weld 3 this stress concentration arises from a slag inclusion at the root of the weld. Further up from the area in which this section was taken, this crack runs completely through the plate. In Weld 2 the major crack began at the fusion line between the plate and weld metals. The differences in hardness and ductilities of the two metals permit stress concentration at this point. It is also possible that a small "hard" crack in this area created a stress raiser.

The second type of crack shown in the ferritic welds are known as "hard" cracks since they are confined to the very hard, heat-affected zones of the armour plate. There is no single cause of these cracks but they are nearly inevitable when welding armour plate with <u>commercial</u> mild steel

(Discussion, cont'd) -

electrodes. Contributing causes are shrinkage, tensile stresses, and inclusions, the latter acting as stress raisers. The shrinkage stresses can be absorbed by low-yield-point weld metal and by better stress distribution. It has been stated[1] that the use of an electrode which will deposit metal of the approximate analysis C 0.08-0.10, Mn 0.30 min., and Si 0.05 min., not including pick up from the base metal, will prevent hard cracks due to high ductility of the weld metal. In addition, stresses may be reduced by keeping the heat-affected zone to minimum thicknesses. In confirmation of this it will be noted that the narrow heat-affected zone of Weld 3 does not contain the large number of hard cracks shown in Weld 2. Better distribution of shrinkage stresses may be secured by welding away from the plate edges and by the liberal use of tack welds.

The subject of ferritic welding of armour plate has recently occupied the attention of the National Research Council in the United States. A recent report[2] reveals that a mild steel electrode, with a coating (lime) usually used only on austenitic electrodes, shows remarkable possibilities for the welding of armour plate. It is probable that electrodes of this type, if available, would prove satisfactory for this type of welding.

The structures of the heat-affected zones, transition zones, and the unaffected armour plate are normal. The hardnesses in the same areas are not abnormal, beyond the possibility that the armour plate is harder than is usually encountered. The upper hardness limit for homogeneous armour plate is 388

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(1) The Welding Journal - May, 1941, "Weldability - Base Metal Cracks."

(2) "The Development of Ferritic Electrodes for Welding Armour Plate." O.S.R.D. 1744, M-97.

(Discussion, cont'd) -

Brinell. The higher hardness of this plate would tend to propagate readily any cracks formed in welding.

The presence of heavy stringers of inclusions is definitely detrimental to the ballistic performance of the plate. In addition, the welding is parallel to the direction of rolling and therefore parallel to the direction of progression of the inclusions. In the main these inclusions are sulphides and as shown in Figure 13 they provide stress raisers, thus acting as a fertile starting point for cracks. The examination indicates that armour plate is homogeneous and shows no evidence of banding.

The chemical analysis results obtained conform to no known specification. In view of the irregular nature of the analyses obtained both were checked carefully, without revealing any change. From Table I it will be noted that the splash strip steel has the bullet proof composition. The plate, however, is much higher in alloy and conforms closely to the specification for heavier plate, with the exception that nickel is a residual and not in the 0.65-0.85 range.

It will be evident that the analysis of the armour plate is such as to confer high hardenability to the steel. This enhanced hardenability is detrimental to weldability, promoting the formation of hard brittle structures in the heat-affected zones.

An examination of Figure 4 reveals slag trapped at the root of the weld and that the overall penetration is poor. The shape of the heat-affected zones and the presence of slag traps indicate the following procedure. The arc was struck in the centre of the hole (note greater depth of penetration at this point) and the metal puddled until the hole was filled. The chilling action of the walls of the hole has prevented the slag

(Discussion, cont'd) -

from rising to the top of the molten pool. The presence of slag so trapped materially reduces the strength of the weld.

In making a plug weld, the following procedure will increase penetration and eliminate the possibility of trapping slag. The arc should be struck at the side of the root and then the root fillet-welded all around. When the fillet is completed the arc should be gradually brought into the centre of the hole in a spiral path. Should one electrode be sufficient to fill the hole it is unnecessary to stop and clean off the slag before filling up the hole, since the slag will be molten, or nearly so, until the weld is completed.

CONCLUSIONS:

1. Penetration, weld contour, and heat-affected zones indicate considerable differences in welding technique.

2. The ferritic electrode used gives a weld of considerably higher tensile strength than is specified and less ductility than is available in other mild steel electrodes.

3. Ballistic failure of the plate may be attributed to one or all of the following causes:

(a) Welding defects, causing stress concentrations at the roots and toes of welds.

(b) The presence of "hard" cracks in the heat-affected zones.

(c) The presence of elongated sulphide inclusions running in the same direction as the welding, and these acting as stress raisers.

(d) The high hardenability of the armour plate.

4. Ferritic welding of armour plate with commercial grades of mild steel electrodes is rarely successful.

5. The armour plate was found to have numerous

(Conclusions, cont'd) -

sulphide inclusions and some oxide inclusions.

6. The analysis of the armour plate is considerably different from that of the standard bullet proof armour plate made by Dominion Foundries and Steel Limited, which was said to have been used. It is comparable to that of the heavier armour plate with the exception of a residual nickel instead of a 0.65-0.85 nickel content.

7. The analysis of the splash strip conforms to the standard bullet proof armour plate composition.

8. The plug welds apparently are made with a welding technique which enhances the possibility of slag being trapped in the root of the weld.

RECOMMENDATIONS:

1. For ferritic welding of armour plate, an electrode especially designed for this application should be used. It has been definitely established that the commercial ferritic electrodes are unsuitable for this type of welding.

2. Every effort should be made to overcome the welding defects shown above and to maintain uniform welding conditions.

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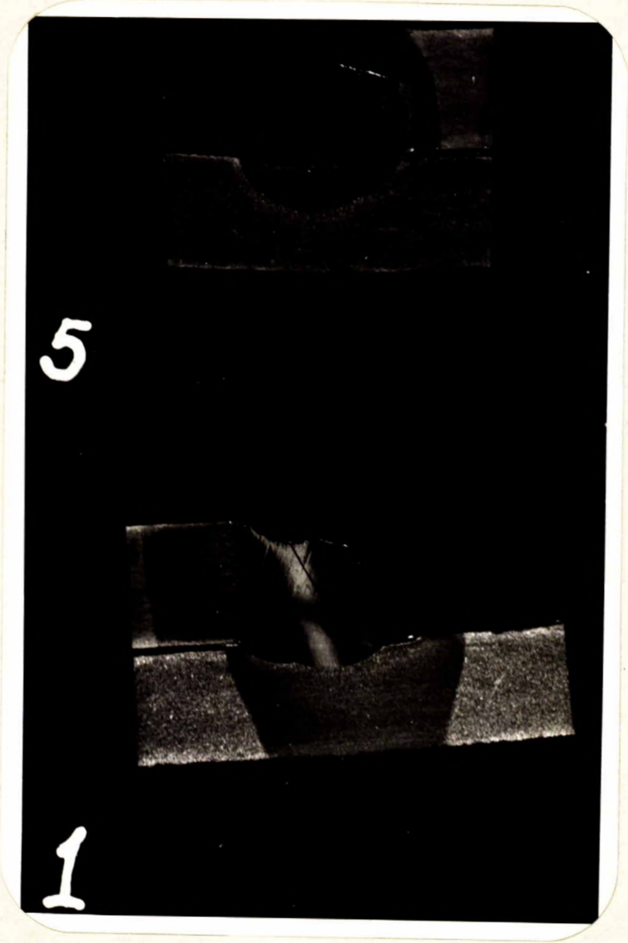
Figure 1.

PHOTOGRAPH OF THE ASSEMBLY AS RECEIVED.

Figure 2.

PHOTOGRAPH OF BACK OF PLATE, SHOWING
THE LOCATION AND EXTENT OF CRACKING.

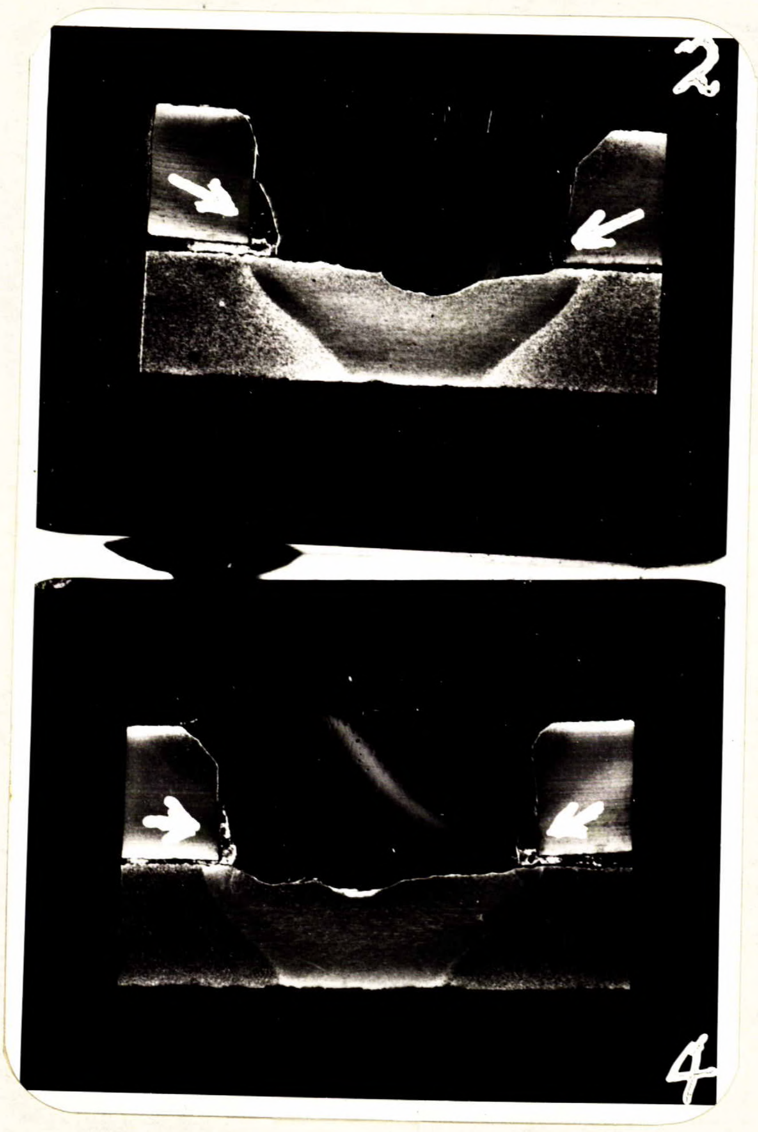
Figure 3.



SECTIONS OF AUSTENITIC WELDS 1 AND 5.

Note light penetration and great differences in depth and width of heat-affected zones.

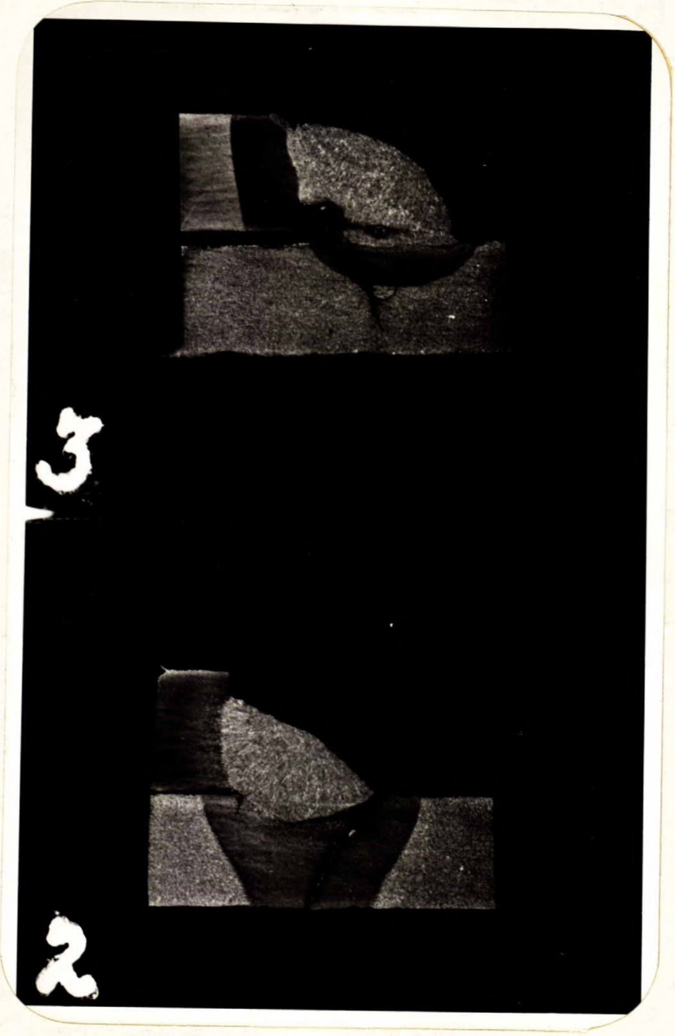
Figure 4.



SECTIONS OF AUSTENITIC PLUG WELDS 2 AND 4.

Note greater-than-average depth of penetration at approximately the centre of the hole. Arrows point to slag trapped at roots of welds.

Figure 5.



SECTIONS OF FERRITIC WELDS 2 AND 3.

Note slag trapped at root of Weld 2 and crack originating in this area.

Note great differences of width and depth of heat-affected zones which are the reverse of what would be expected in view of the rod sizes used.

Figure 6.

X500, etched in 4 per cent picral.

TYPICAL FINE MARTENSITIC STRUCTURE
OF ALL HEAT-AFFECTED ZONES.

Note crack.

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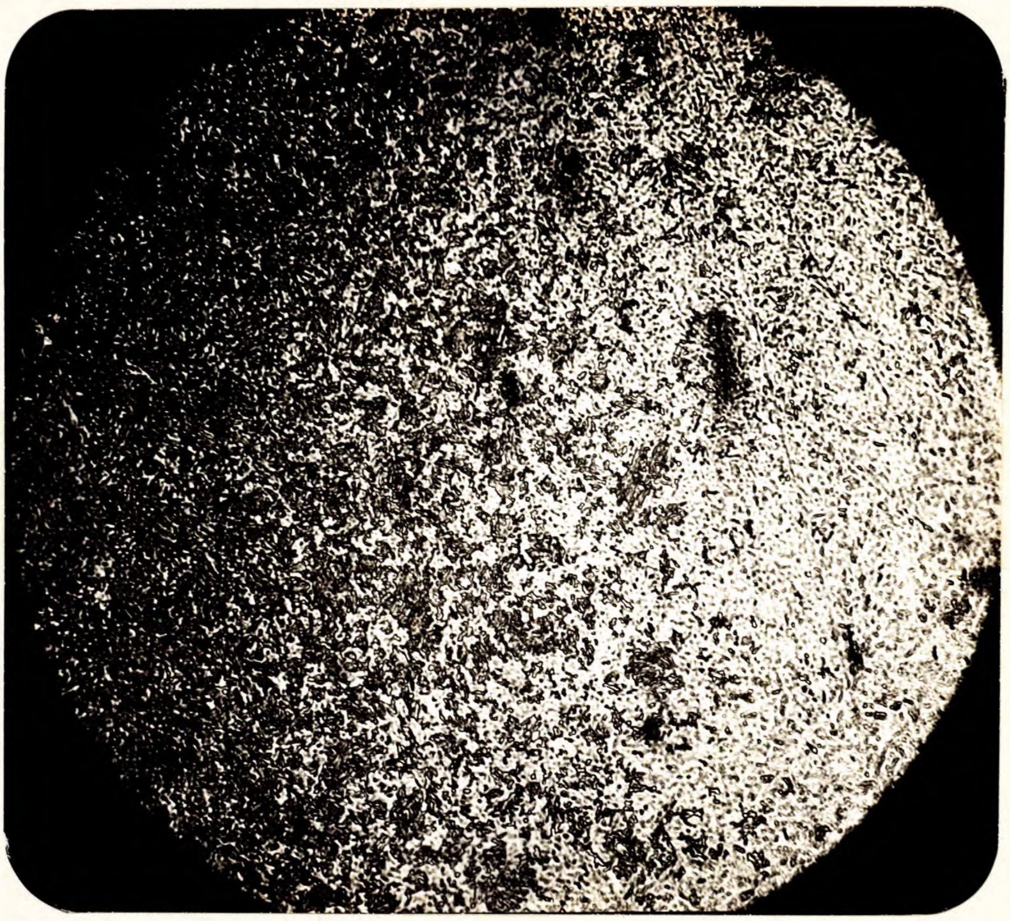
Figure 7.



X500, etched in 4 per cent picral.

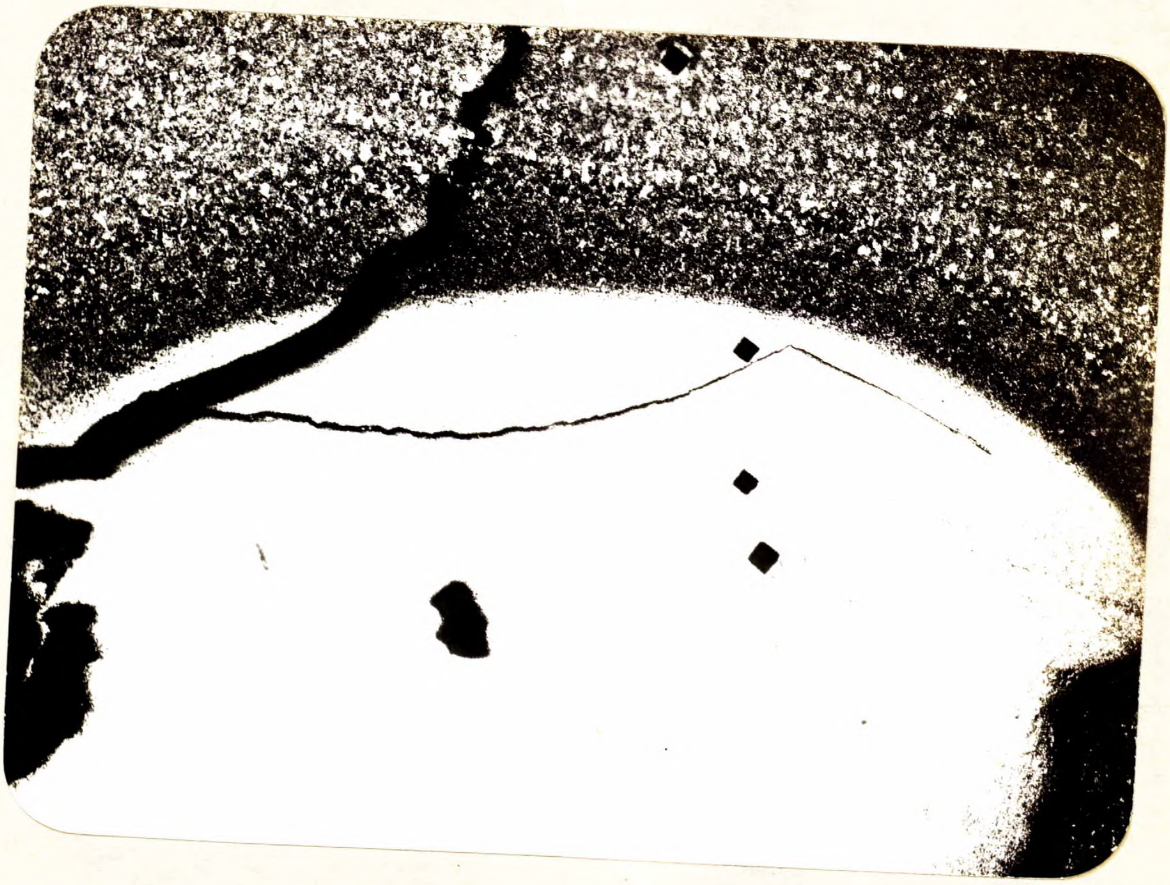
TYPICAL TRANSITION ZONES. FINE MARTENSITE, TROOSTITE, AND NORMAL PLATE STRUCTURE.

Figure 8.

X500, etched in 4 per cent picral.

NORMAL PLATE STRUCTURE OF TEMPERED MARTENSITE.

Figure 9.



X20, etched in 2 per cent nital.

WELD 3.

Note smaller crack in the heat-affected zone and its sharp change of direction towards the end.

Note also small gas inclusion.

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Figure 10.

X30, etched in 2 per cent nital.

WELD 2.

Note small "hard" cracks in the heat-affected zone close to the fusion line.

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Figure 12.

X500, etched in 4 per cent picral.

SULPHIDE INCLUSIONS IN LONGITUDINAL SECTION OF ARMOUR PLATE.

Figure 13.

X1500, etched in 4 per cent picral.

SMALL "HARD" CRACK, APPARENTLY ORIGINATING AT A SULPHIDE INCLUSION. TAKEN IN THE HEAT-AFFECTED ZONE OF A LONGITUDINAL SECTION OF WELD 2.

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