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OTTAWA November 26th, 1943.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1542.

Examination of Studs Flash-Welded to Armour Plate.

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(Copy No. 10.)

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

CANADA
DEPARTMENT
OF
MINES AND RESOURCES
Mines and Geology Branch

O T T A W A November 26th, 1943.

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Origin of Material:

On November 18th, 1943, under Requisition No. 610, AEDB Lot No. 397, Report No. 13, Mr. V. G. Morris, on behalf of the Director of Metallurgy, Army Engineering Design Branch, Department of Munitions and Supply, Ottawa, Ontario, submitted for examination a sample of armour plate to which had been flash-welded two studs. The welding is stated to have been done with an electric stud-welding gun, a recent development in welding.

It is our understanding that it is desired to replace welded tapping blocks and bolts (the present method of securing attachments to the inside of armoured vehicles), by holding studs welded directly to the armour plate surface.

In conversation with Mr. Morris, it was learned that the current used was supplied by connecting three D.C. welding machines in parallel and that the welding was done by a welder inexperienced in the use of this new equipment. It was also stated that this welding equipment and technique is being introduced into Canada by the Hollup Corporation, of Toronto, Ontario.

Object of Investigation:

(1) To determine the resistance of the stud weld to impact.

(2) To determine the depth to which the stud is embedded in armour plate.

(3) To examine the quality of the welds produced.

PROCEDURE:

(1) The sample was given a careful visual examination.

(2) An impact test on one stud was secured by removing a small section of the armour plate to which the stud was welded. Since the stud is of such a diameter (3/8") as to preclude any possibility of a standard impact test, an empirical test had to be devised. The stud was tested in an Amsler impact machine by gripping the stud end of the test piece and striking the armour plate with the anvil. This holds the stud in a vertical position, as in the standard Izod test. The centre of impact was 1.1 inch above the vise and in the same plane as the fusion line of the weld. The method results in energy being absorbed in bending the stud but is roughly equivalent to the effect of a projectile on the armour plate.

On testing it was found that 88 foot-pounds of energy was absorbed in breaking the weld and bending the stud approximately 68 degrees. This test does not give the true impact strength of the weld but could be used as a comparative test.

(3) Micro specimens were machined through the centre of the remaining stud and armour plate and also from the location of the stud used in the above impact test. Figure 1 shows the weld area of the untested stud and Figure 2 the weld area of the tested stud.

(4) Both specimens were examined under the microscope. Figure 3 illustrates the typical structure of the junction of the stud and armour plate. Figure 4 shows the typical structure of heat-affected zone of the untested stud. Note the micro-

(Procedure, cont'd) -

cracks in this area. Figure 5 is the narrow transition zone between the heat-affected zone and the unaffected plate metal. Figure 6 shows the structure of the armour plate.

Figure 7 shows the structure of the heat-affected zone of the armour plate of the tested stud. Note the difference of structures of the heat-affected zones. Figure 8 illustrates the structure of the low-carbon stud material.

(5) Hardness tests were made on the heat-affected zones of both welds and the unaffected armour plate, using a Vickers hardness machine and a 10-kilogram load. The following table gives the results obtained:

	Heat-Affected Zone	Armour Plate
Untested Stud -	317-488; Average, 394	380
Tested Stud -	514-536	380

(6) The depth of penetration was measured and found not to exceed 0.01 inch.

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DISCUSSION:

A visual examination reveals that both studs show a flashing of metal completely surrounding the stud at the fusion line. This metal apparently comes from a metal-containing flux and is ejected when the stud is forcibly plunged into the molten pool. This flashing metal would have no deleterious effect on the quality of the welds.

Although the impact test devised does not give the true impact strength of the weld, it could easily be used for the purpose of comparison. In view of the slight penetration obtained, the 88 foot-pound impact strength seems to be fairly good.

Micro-examination of the fusion zone of the untested stud shows two very small areas of entrapped slag. In our

(Discussion, cont'd) -

opinion they are too small to seriously weaken the weld but they do indicate that care must be taken to avoid greater slag inclusions. To minimize this danger, both the end of the stud and the surface of the armour plate should be ground down to clean metal.

Both micro-examination and hardness tests indicate considerable difference in technique in welding the two studs. By sheer chance the stud selected for impact testing was the one showing a very high hardness and a martensitic structure in the heat-affected zone. The other stud shows the same depth of penetration and the same width of heat-affected zone but a considerably lower hardness and a tempered martensitic structure with some precipitated ferrite. Since in both samples the width of the heat-affected zone is approximately the same, the conditions of current value and time of flow must have been approximately the same. The only explanation of the differences in hardness and structure which readily comes to mind is that the untested stud of the welding has been given a second 'shot' of current, which has had the effect of tempering the fusion and heat-affected zones by reducing the cooling rate through the critical range or, more probably, by reheating to above the lower critical.

It is interesting to note that the relatively soft heat-affected zone of the untested stud has fine hairline cracks which are typical "hard" cracks, frequently found in areas of high hardness under welds. A close examination of the harder heat-affected zone of the tested stud failed to reveal any such cracks. It is probable that the cracks found formed immediately after welding, and the subsequent surge of current cannot be expected to eliminate them.

This process of welding, although on a larger scale, is closely related to spot welding. It has been found that in

(Discussion, cont'd)

spot welding of a hardenable steel, the time of flow of current, the pressure between surfaces to be welded, and the time of flow of the annealing shot are quite critical and must be worked out with precision.

It is thought, then, that before this process is used in production the best operating conditions should be determined by suitable experiments. Since this equipment can regulate the time of current flow over a range of from 1/30 to 1 2/3 seconds, it is probable that welding conditions and post-heating can be determined to give good impact characteristics.

The welds examined indicate the use of a flat-ended stud. This has resulted in a narrow heat-affected zone running parallel to the surface of the armour plate. This is undesirable in that the impact stresses of projectiles would readily tear or crack this harder metal. It would seem that the use of a pointed stud and higher welding currents would tend to produce a heat-affected zone at an angle to the surface of the armour plate and thus give better resistance to projectile shock.

The very small depth of penetration of the stud into the armour plate indicates the use of a relatively low welding current and is, of course, due partly to the use of flat-ended studs. Better welds would result from the use of pointed studs and higher welding currents.

CONCLUSIONS:

1. The impact strength of a welded stud, determined by an empirical test, was fairly good.

2. There is some slight evidence of entrapped slag. While this amount is too small to cause concern in this particular weld, it does indicate the necessity of taking precautions to minimize this type of defect.

(Conclusions, cont'd) -

3. The two welds seem to be made with different techniques. The possibility is that one was welded with a single welding current surge (producing a heat-affected zone of high hardness) and that with the second the welding was followed by a postheat treatment by a second surge of current (producing a heat-affected zone of low hardness).

4. The weld with a low hardness in the heat-affected zone showed typical 'hard' cracks in that zone. These are the result of a brittle structure produced by the welding operation, the hardness being lowered by a subsequent drawing.

5. It is desirable to experimentally determine the conditions of the welding and postheating cycle which will produce welds capable of withstanding projectile shock.

6. The use of pointed-end rather than flat-ended studs would tend to produce a heat-affected zone at an angle to the surface of the armour plate. This would improve the impact properties of the weld.

7. The very small depth of penetration of the stud into the armour plate (not more than 0.01 inch) is due partly to the use of low welding current and partly to the use of flat-ended studs.

8. It is our opinion that the process shows promise and should be investigated further.

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Figure 1.

X10, etched in 5
per cent nital.

FUSION AND HEAT-AFFECTED ZONES OF UNTESTED STUD.

Note small penetration and narrow heat-affected zone.
Note also ejection of molten metal at right edge.
Arrows point to small slag inclusions at fusion line.

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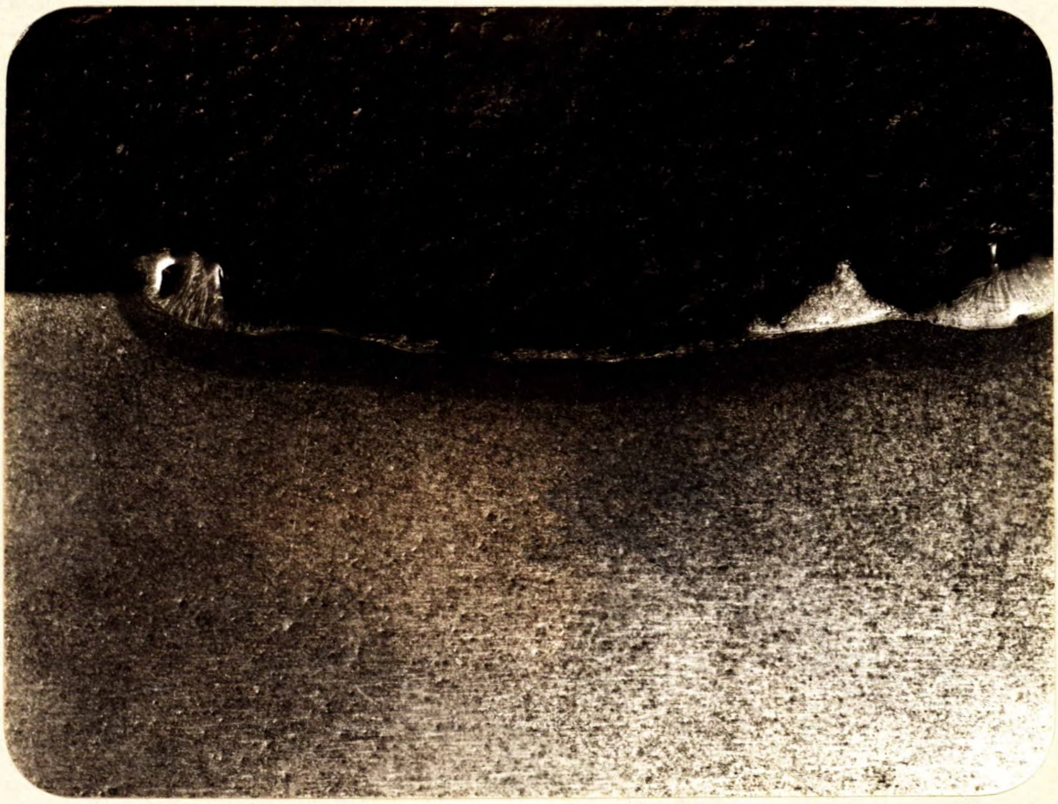
Figure 2.



X10, etched in 5
per cent nital.

FUSION AND HEAT-AFFECTED ZONE OF TESTED STUD.

Note small penetration and narrow heat-affected zone. Note that failure occurred in the stud material just above the fusion line.

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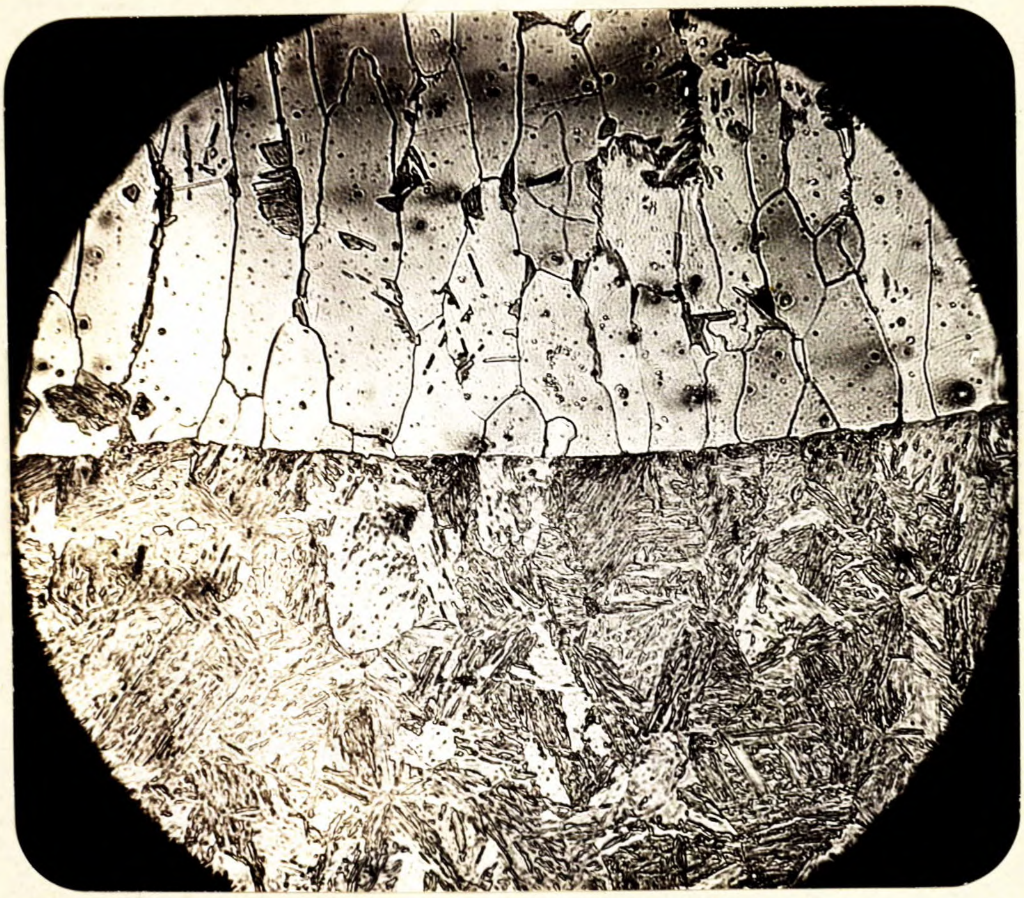
Figure 3.



X500, etched in 2
per cent nital.

FUSION ZONE OF UNETCHED STUD.

Note good bond secured.

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Figure 4.

X500, etched in 2
per cent nital.

HEAT-AFFECTED ZONE OF UNTESTED STUD.

Highly tempered martensite and some ferrite (white constituent). Note transgranular 'hard cracks'.

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Figure 5.

X500, etched in 2
per cent nital.

TRANSITION ZONE OF UNTESTED STUD.

Nodular martensite of heat-affected zone - fine pearlite and ferrite in transition zone - tempered martensite of unaffected armour plate.

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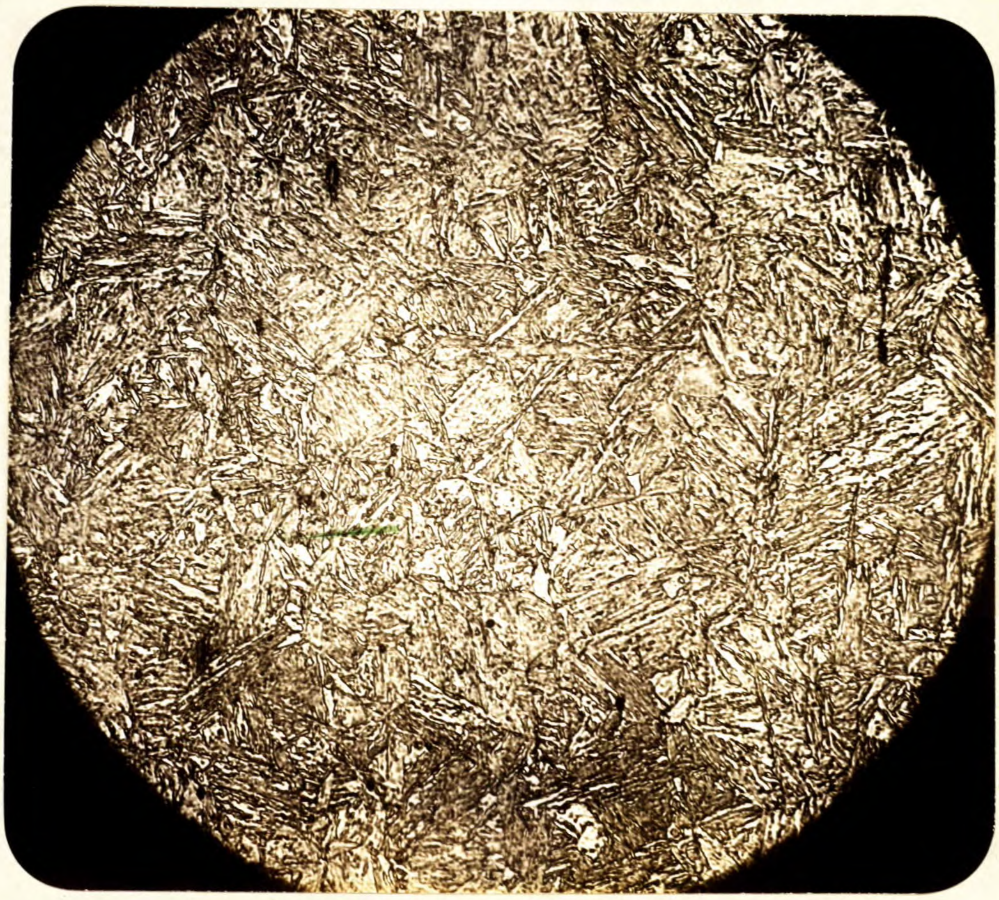
Figure 6.



X500, etched in 2
per cent nital.

TEMPERED MARTENSITIC STRUCTURE OF ARMOUR PLATE.

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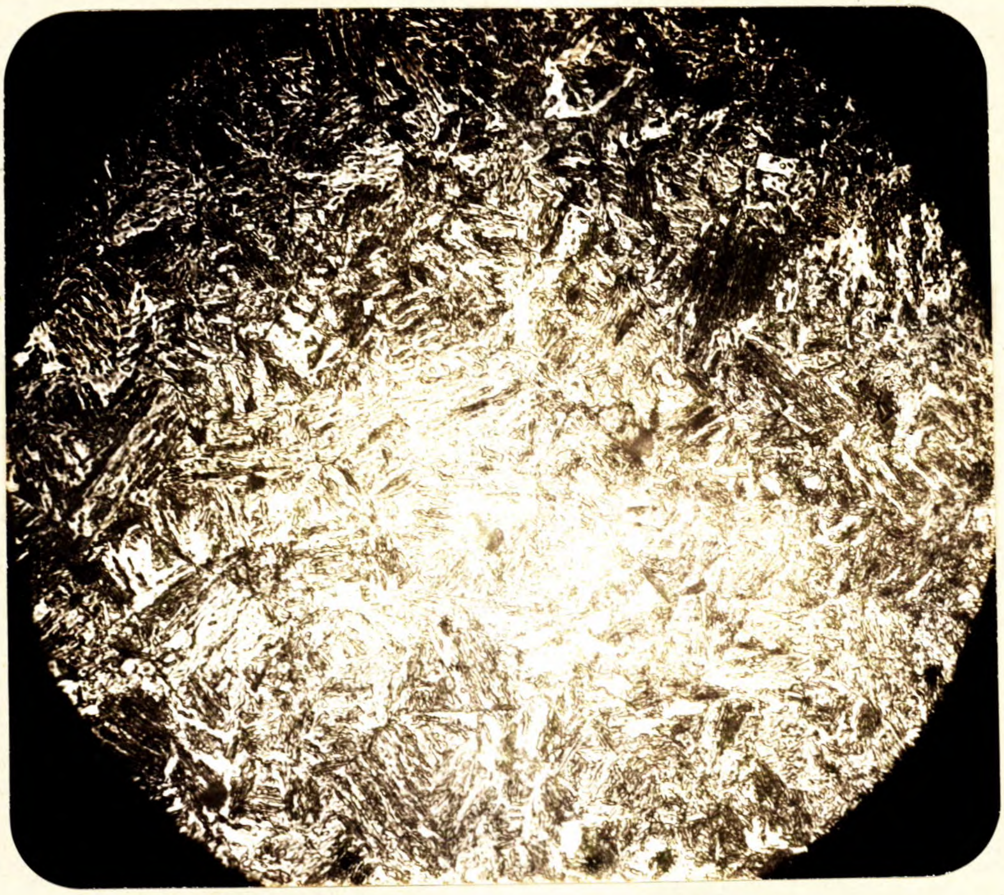
Figure 7.

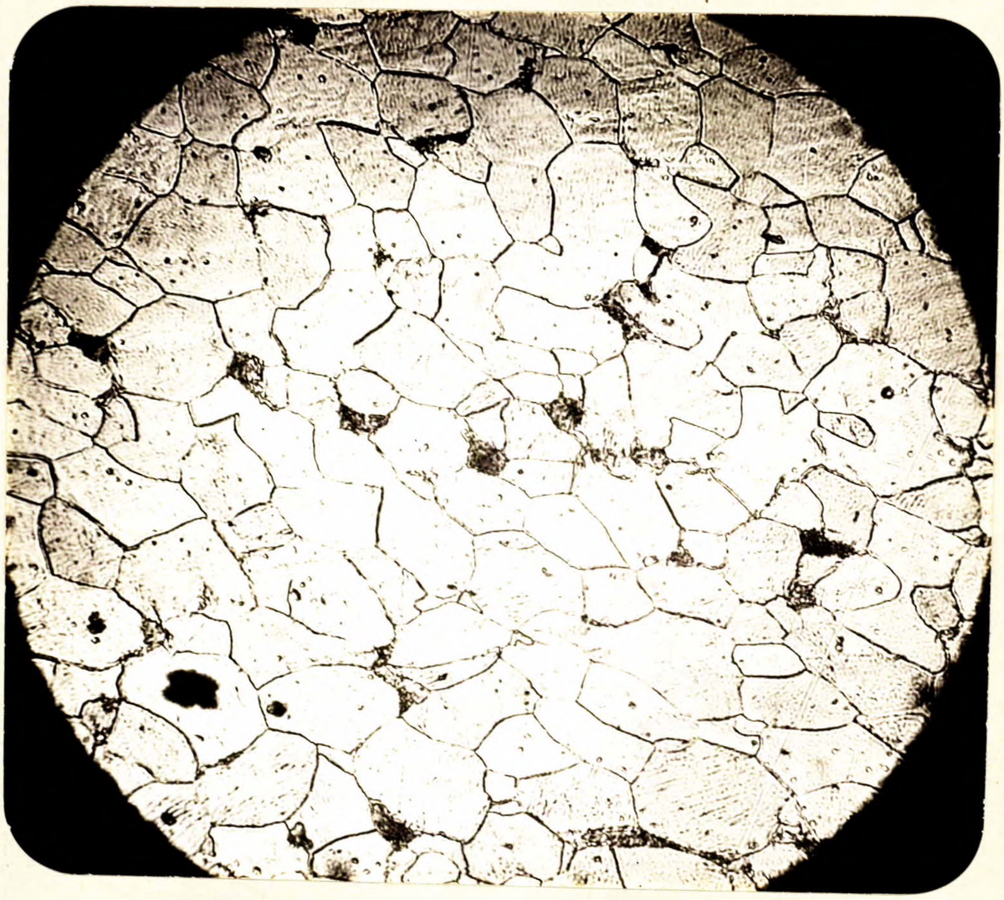


X500, etched in 2
per cent nital.

STRUCTURE OF HEAT-AFFECTED ZONE OF THE TESTED STUD.

White constituent is white etching martensite
and remainder is nodular martensite.

Figure 8.



X500, etched in 2
per cent nital.

LOW-CARBON STRUCTURE OF STUD MATERIAL.

Ferrite and islands of pearlite.

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