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WELDING EMBRITTLEMENT OF THE PARENT PLATE

OUTSIDE THE VISIBLE HEAT AFFECTED ZONE REGION

by

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DEPARTMENT OF MATERIALS

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S U M M A R Y

Embrittlement of steels outside the visible heat affected zone region
due to plastic straining from the weldment and subsequent ageing has been
reported by several authors. The problem is reviewed in this Note and an
attempt made to detect this region in a semi-killed mild steel by means of
a micro-hardness testing survey taken at regular intervals in a direction
away from the weld fusion boundary. Recommendations for future work in
understanding the magnitude of this problem particularly in multi stressed
welded joints are given.

Contents

Introduction

Investigations into service failures of welded structures have shown that many fractures originate in the welded joint, either in the weld metal itself or in the parent plate adjacent to the weld metal. Microcracking in weld metal has been shown to be attributed to a high carbon and/or phosphorous content and to contamination of the metal with hydrogen and/or nitrogen. Heat affected zone cracking has been attributed to the formation of a suscept- ible microstructure in the presence of both hydrogen and residual stress.

Increasing attention, however, has been given over the last few years to structural failures originating at points close to welds but outside the region where visible microstructural changes occur due to the welding[1],[2]. Although beyond this heat affected zone region no further changes in micro- structure on the scale of optical microscopy have been observed, hardness measurements[3], tensile tests[4] and impact tests of notched specimens[5] have indicated that there are variations in mechanical properties at different distances from the centre line of the weld. The hardness tests showed an increase in hardness at some distance from the weld interface as shown in figure 1, and the impact tests similarly gave an increase in transition temperature at an equivalent distance, as shown in figure 2. These regions of embrittlement were removed by a stress relief heat treatment at temperatures above 650°C.

The embrittlement in this region was originally suggested by Wells[6] to be caused by plastic deformation resulting from the complex hot straining produced in the parent plate adjacent to the weld during the welding cycle. This straining is particularly significant in the presence of any kind of defect which can increase significantly the value of the local stress and makes the material behave in a more brittle manner. However Wells' suggestion does not fully explain fracture initiation close to welds at low deformation. It was shown[7] that ageing mild steel at elevated temperatures after plastic tensile deformation caused a return of the upper yield point. For example deformation by 40% in compression followed by ageing for $1\frac{1}{2}$ hours at 150°C prompted facture with low additinal deformation[8]. Since a prestraining and ageing treatment embrittled whole specimens it was proposed[9] that a similar treatment could have the same effect on small regions such as the volume near the tip of a notch.

Zhemchuzhnikov et al[10] investigated the effects of acute ended notches on the brittle strength of mild steel plates after preliminary plastic tensile deformation and following different ageing processes. The authors showed that the degree of embrittlement depended greatly both on the pre- liminary plastic deformation and on its direction. Preliminary deformation and subsequent ageing greatly embrittled the material. Of importance is the result that slight deformation, in the presence of a geometrical stress raiser and with elevated temperature ageing, is capable of producing severe embrittlement. Tests on steel which had undergone a preliminary 10% deformation at 100-550°C showed that at all temperatures the material was embrittled but that deformation at 250°C caused the worst embrittlement.

Work at B.W.R.A.[15] showed that if thermal straining in the parent plate adjacent to the weld was concentrated at a crack-like defect, locally embrittled areas were created that had a lowered resistance to crack initiation when compared with the unaffected parent plate. The most severly embrittled region was associated with a thermal cycle of peak temperature 520°C, and from microhardness - strain calibration experiments several of the embrittled areas examined corresponded to notch root strains greater than 20%. In practice, thermal deformations always accompany welding; when the weld zone is heated it undergoes compression, and while it is cooling it undergoes tension. The magnitude of these deformations is usually small, in the region of 2-4%, but in the presence of a geometrical stress raiser close to the weld they may increase substantially.

Further work[11] showed that the brittle fracture behaviour of a weldment strongly depended on the combined stress field resulting from the service stresses and the stress pattern induced by the welding operation. The latter depended on the thermal cycles undergone and the yield values of the weld and adjacent zones and, to a lesser extent, on the geometry of the structure.

In this respect Nicholls[12] demonstrated that in certain welded joints embrittlement was produced which led to lamellar tearing and failure of the structure. The tearing or cracking occurred in hot rolled steel plates, in sections under a weld which stressed the steel normal to the plane of rolling, i.e. in the thickness direction. The tear surface was composed of fibrous terraces which resulted from the propagation of the tear by lamellar weaknesses in the rolling plane. Thus, in section the crack ran in the rolling plane with approximately right angled changes of direction where shear occurs to join adjacent weaknesses, (figure 3).

The Cranfield test[12] was developed to determine the susceptibility of different steels to lamellar tearing. From this Elliot[13] confirmed Nicholl's work that lamellar tearing in the rolling plane was due to interfacial decohesion between the inclusion particles and the matrix, thus generating internal cavities which eventually linked up to form a major ductile crack. Hence the susceptibility to lamellar tearing is dependent upon the quantity and distribution of inclusions. The reduction in ductility in the through thickness direction however may be due to welding embrittlement due to plastic straining and ageing. Wilson[14] showed that the development of lamellar tear cracks by the Cranfield test was dependent on the number of weld runs. The increase in weld runs produced an increase in the stress concentration at the root on the weld due to the overall contraction of the weld metal. This meant that considerable plastic straining was necessary for the production of lamellar tears. Hence this would greatly contribute to embrittlement by plastic straining and ageing due to the welding process.

The object of the present work was to investigate the susceptibility of a mild steel to strain ageing embrittlement outside the visible heat affected zone region of a bead on plate weld.

Experimental work

A bead on plate weld was produced in a semi-killed hot rolled mild steel plate by submerged arc welding with a heat input of 108kJ/in. The composition of the mild steel is given in Table 1 and the welding conditions used in Table 2.

Element	Composition %
C	0.21
Mn	0.89
S	0.065
S	0.050
P	0.040

TABLE 1

Arc Voltage	30 ± 2 volts
Arc Current	390 ± 10 amps.
Welding Speed	$6\frac{1}{2} \pm \frac{1}{2}$ in/min.

TABLE 2

After welding, the plate and weld were sectioned and a sample prepared for examination by rough grinding on graded emery paper and finally polished on 6 micron, 1 micron and $1/4$ micron diamond pads. Light etching of the surface was carried out using 2% Nital for approximately 5 seconds.

A Zwick Hardness Tester, model 23,2A, using a diamond pyramid indentor was used to determine the hardness variations at intervals of $\frac{1}{2}$ mm. on a line away from the visible heat affected zone boundary. Loads of 10g. and 50g. were originally used, but the extremely wide range of scatter in the measurements using a 10g. load results in all the final tests being carried out with a load of 50g. All diamond indentations were made within surface ferrite grains and numerous impressions were made at each interval of distance away from the fusion boundary.

A hardness survey was made immediately after welding and 10 weeks later. The results are shown in figures 4 and 5.

Discussion

The results of the change in ferrite hardness with distance from the fusion boundary outside the visible heat affected zone show considerable scatter. This is partly due to the fact that in microhardness testing using low loads the deformation is not entirely plastic, and it is the influence of the elastic stresses that produce these anomalies. Moreover, errors in the hardness value of the ferrite are also introduced by cementite particles, grain boundaries, inclusions etc., which are below the surface of the polished and etched specimen and which make contact with the diamond pyramid indentor during testing.

In spite of the scatter it appears that two regions of embrittlement (as shown by an increase in hardness) exist, at approximately 9-10 m.m. and 18-20 mm. from the fusion boundary. Maximum ageing occurs within the first few hours and there is no subsequent further embrittlement over a period of ten weeks as shown by comparison of figures 4 and 5. Similar work carried out by Johnson[16] on another mild steel at the same time also showed the hardness peaks at approximately the same distances from the fusion boundary. The observation of embrittlement at 18-20 mm. is also in approximate agreement with Baker and Tipper[3] and Shepler[5]. Although in both cases the embrittlement is only small this could be accentuated by the presence of stress raisers or by a high nitrogen content steel.

From measurements of temperatures produced in the parent plate during welding[17], Figure 6, it can be seen by extrapolation that the region of peak hardness at 18-20 mm. corresponds to a maximum temperature of about 250°C. Similarly the hardness rise at 9-10 mm. corresponds to a maximum temperature of approximately 450°C. As reviewed in the introduction both of these temperatures have been shown by various workers to be associated with embrittled regions in the parent plate during welding.

It is important to remember that numerous fabrications today are produced using complicated multirun welding techniques which introduce complex stresses, both compressive and tensile, during the welding operation. In the presence of defects and imposed restraint to maintain the shape of the fabrication these magnified stresses can produce embrittlement of the parent plate and subsequent catastrophic failure of the welded joint, so that this region outside the heat affected zone is of considerable importance. The difficulties of investigating the region should not prevent an examination of its origin, extent, and exact significance.

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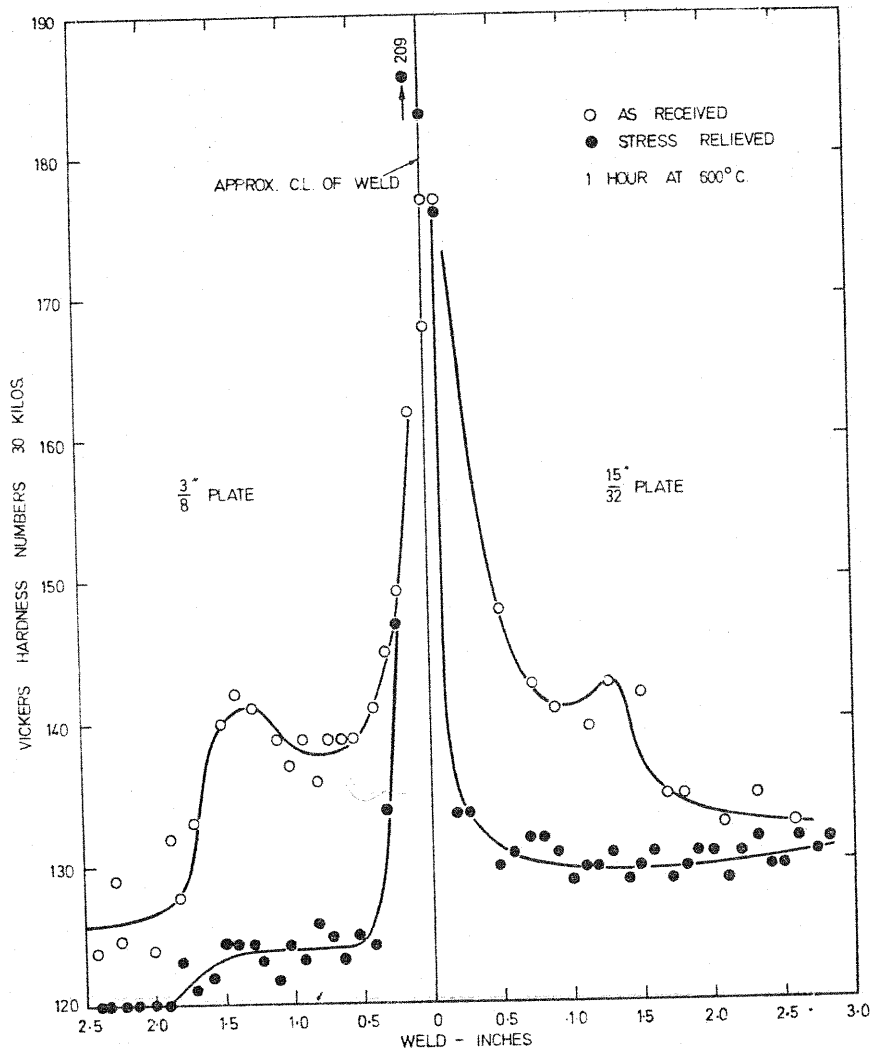   Apps. R.L.   1967.

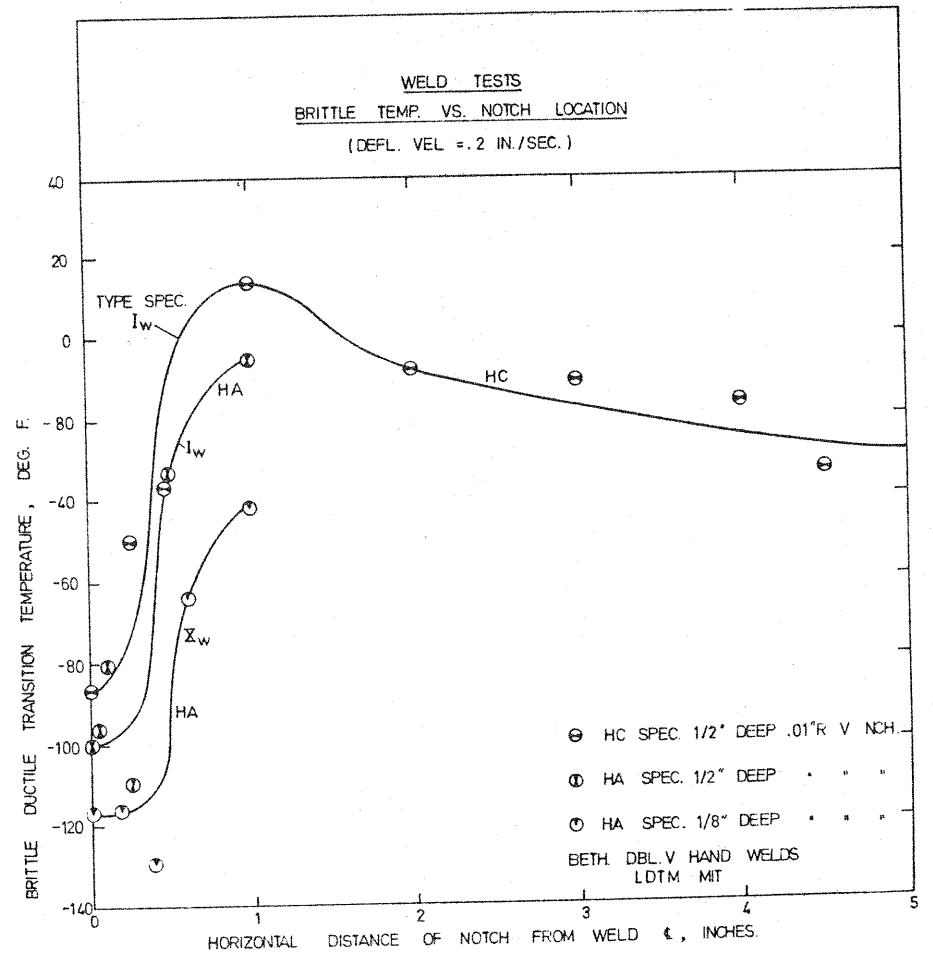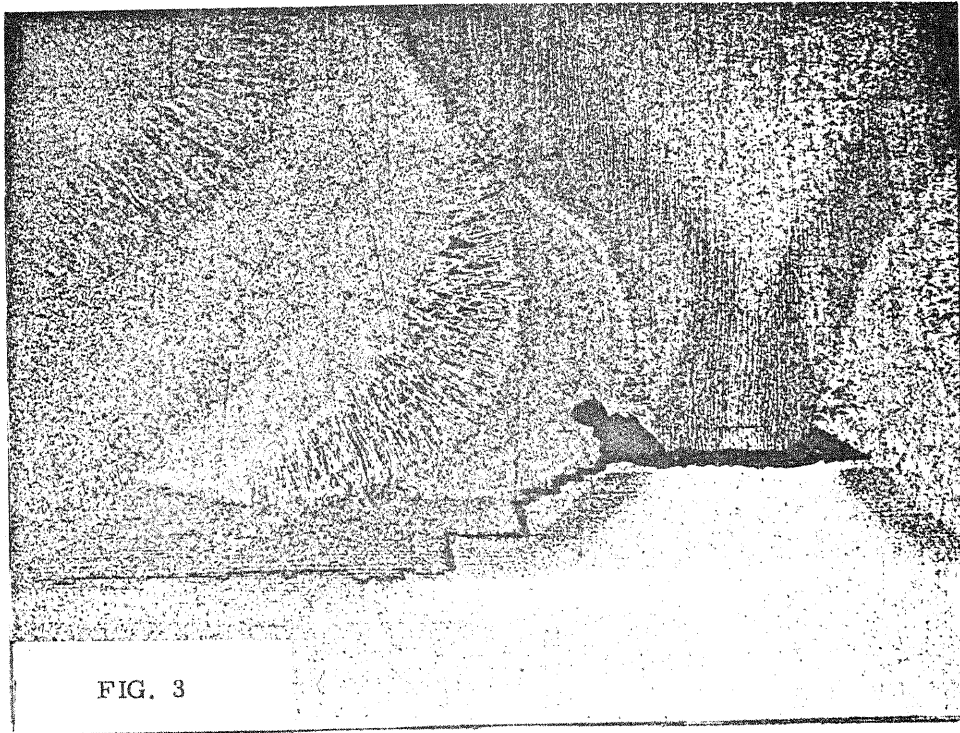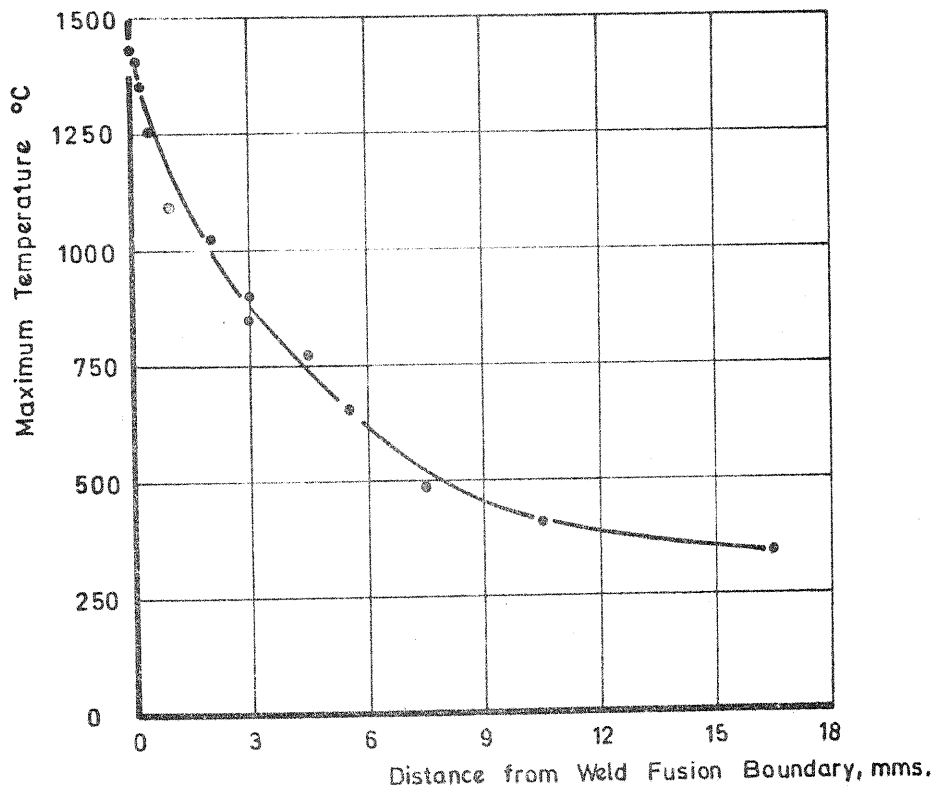FIG 1. HARDNESS SURVEY THROUGH THE WELD.

FIG. 2.

FIG. 3

FIG. 6 VARIATION OF THERMAL CYCLE PEAK TEMPERATURE
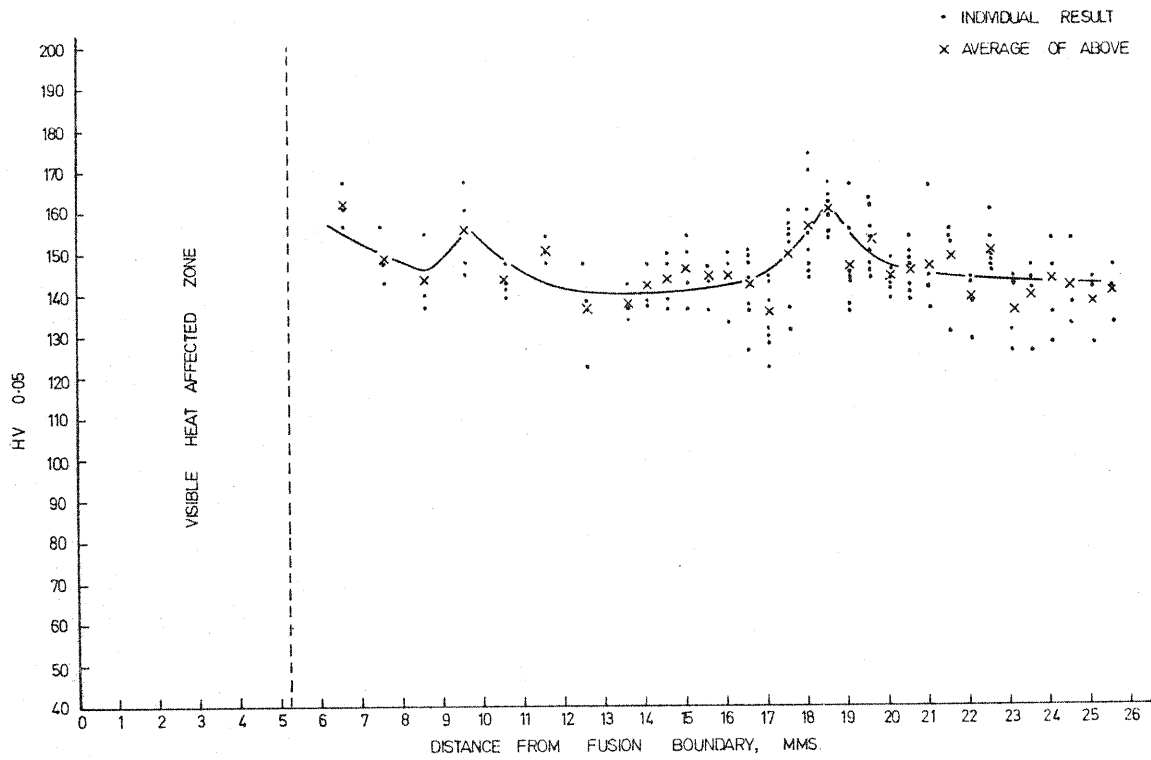WITH DISTANCE FROM THE FUSION BOUNDARY

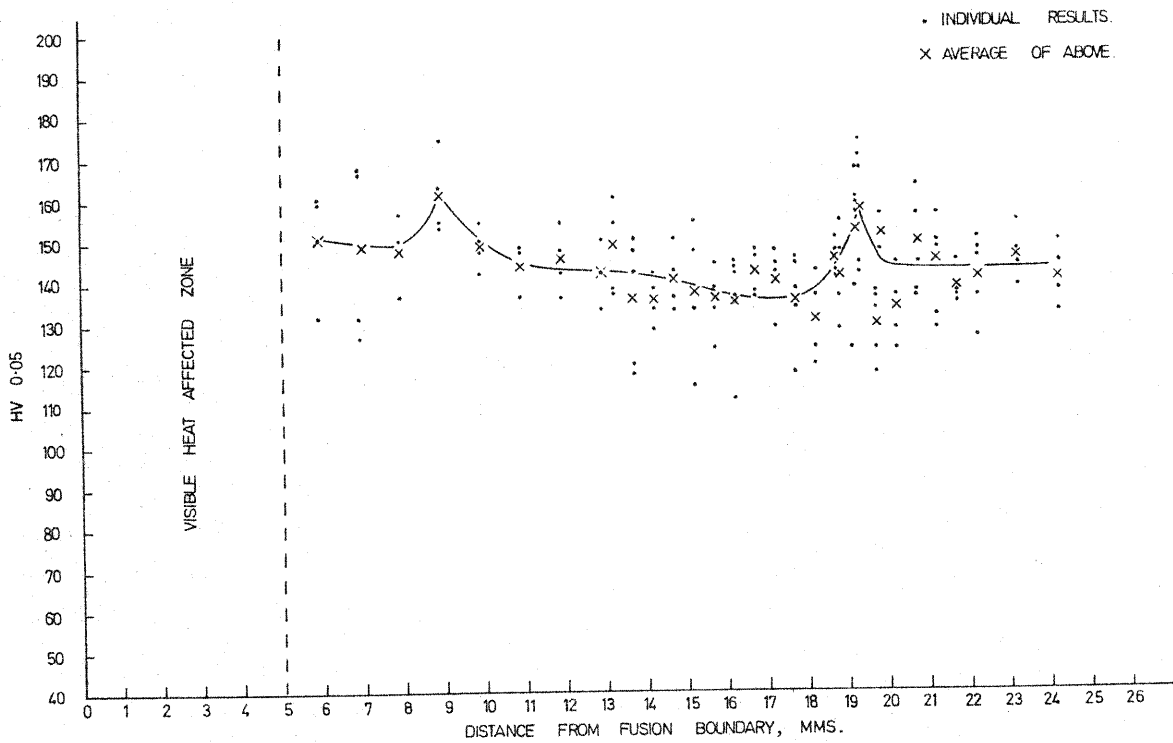FIG. 4. MICROHARDNESS SURVEY OF PARENT PLATE ADJACENT TO WELD IMMEDIATELY AFTER WELDING.

FIG. 5. MICROHARDNESS SURVEY OF PARENT PLATE ADJACENT TO WELD, TEN WEEKS AFTER WELDING.