FLASH BUTT WELD ABILITY OF DUAL PHASE STEEL SHEET STUDIED BY MICROSHEAR TEST METHOD

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Flash butt welding of dual phase steel sheet (3.7 mm) has been carried out by using different final jaw distances (FJD) of 20, 30 and 40 mm and their influence on weld thermal cycle has been studied. The influence of variation in FJD on the micro-structure, microhardness and microshear strength across the weld are investigated. The mechanical properties such as ultimate tensile strength and reduction in cross sectional area of different region of heat affected zone (HAZ) are estimated by using the corresponding microshear test results. The variation in FJD has been found to affect the weld thermal cycle significantly so the microstructure and mechanical peroperties of the weldment. The region of HAZ at a distance of about 6.0 mm from the weld centre has been found to be the weakest region of HAZ where temperature during welding rises put to about 620 ± 20° C resulting into tempering of martensite in it. The use of microshear test method has been found very much effective to study the mechanical properties of various regions of HAZ at an interval of 0.7 mm. The studies infer that the use of a comparatively higher FJD of the order of 40 mm may be beneficial for improving the post weld formability of dual phase steel due to reduction in variation of mechanical properties observed at different regions of HAZ.

INTRODUCTION

The joining of metals or alloys by resistance or fusion welding processes produce weldment having regions of different mechanical properties in it. These regions of different properties can be indentified as weld deposit (in case of using filler metal), fusion zone and heat affected zone (HAZ). For critical estimation of weld ability of any material it is essential to understand the variation in property across the weld with a specific attention to the zone like weld centre line, fusion line and the zones of HAZ where a markable change in microstructure takes place. For a long time to fulfil this desire the microhardness study across the weld is commonly being used and to get a more practical data regarding their tensile and toughness properties the notch test is favoured where, the notch root is placed at the zones of interest. Though the notch test methods are found effective to a great extent, still in number of casses the use of this procedure is restricted due to difficulties in correct placing of the notch at the zone of interest and economic reasons. Moreover in case of thin sheet weldment, of the order of thickness about 1-4 mm, the notch test procedure can not be performed satisfactorily due to non availability of specimens of required size. However, in this regard the microshear test procedure developed recently at the technical university of West Berlin has found quite helpful and effective (1-3). So far in number of investigations the microshear test procedure has been used successfully to study the weld ability of different materials under various welding process and the results have been found in agreement to the same produced by using microhardness and other test procedures (4, 5). The microshear test has also been found to show a more distinct difference in case of slight changes in the properties compared to the conventional testing method (1). Keeping in view the above merits of microshear test, in this work an effort has been made to study the flash butt weld ability of dual phase steel sheet, produced under different weld thermal cycles, by using microshear test method.

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SCOPE OF THE INVESTIGATION

The newly developed dual phase steel is a class of high strength low alloy steel having microstructure of martensite colonies in ferrite matrix, which results into high strength in combination with good formability (6). This steel has gathered a wide spread attention of automobile industries especially for making car wheels produced by using flash butt welding process (7-9). However this effort has faced considerable difficultes due to formation of a comparatively softer tempered martensite region at heat affected zone (HAZ) (7-11) which, weakens the weldment by providing an early necking in this region during post weld forming operation (8). Thus to improve its weld ability it is necessary to study the mechanical properties of this zone in detail so that the problem of early necking, restiricting the weld joint to undergo a deformation of required degree during post weld forming, can be encountered methodically. The softening of this zone occuring during welding is already physically indentified by microhardness testing (5, 9, 10) where local plastic deformation is involved. However due to non availability of any suitable method no work has been carried out so far to study the behaviour of this zone under gross plastic deformation resulting from a mechanical loading leading to fracture. Morever the formability of weldment, which is necessary for fabrication of automobile components like wheels etc. (8, 9), is largely governed by the flow characteristic of different microstructural regions of its HAZ. Thus, in this regards the estimation of gross deformation behaviour of these regions under uniaxial loading may be very much helpful. The microshear test, being an efficient process for revealing the mechanical properties of micro section of the weldment, is choosen in this work to use for achieveing the goal mentioned above.

EXPERIMENTAL

The hot rolled dual phase steel plates of thickness 3.7 mm having chemical composition as shown in Table I were welded by flash butt welding process, where the

Table I

Chemical Composition of Base Metal

	C	Mn	Si	Cr	Mo	S	P
Wt %	0.09	1.3	1.1	0.45	0.32	0.01	0.02

contact area of the joint was kept as 3.7 x 106 mm^2. The plate surface was cleaned mechanically before welding. The schematic diagram of welding process has been shown in Fig. 1. During welding the plates were gripped

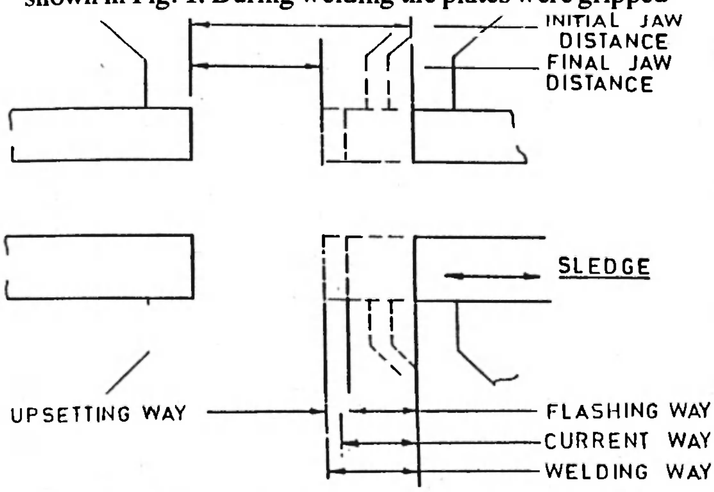


Fig. 1. : Schematic diagram of flash butt welding process.

by the jaws having self cooling arrangement with the help of chilled water flow through them. Out of two gripps one was fixed and the other one moved during welding from its initial position put to a certain distance called as "Welding Way" and at the end of welding the existing gap between the grip was designated as final jaw distance (FJD). Within the welding way during movement of the grip put to a certain distance (current way) the current passed through the plates and the grip traversed rest of the welding way without current. Within current way the grip moved put to certain distance (flashing way) when the material flashed out as sparks from the contanct surface of the plates. The welding process experienced an upsetting operation during movement of grip from the end of flashing way put to rest of the welding way. During welding the current and voltage were kept constant at about 17.4 KA and 6.0 volt respectively. In order to vary the weld thermal cycle the final jaw distance was varied to 20, 30 and 40 mm where, current way, flashing way and welding way were kept constant. The weld thermal cycle at different distance from the weld centre was obtained by suitable placing of Pt-(Pt-Rd) (0.5 mm ϕ) thermocouple on the plate surface as schematically shown in Fig.2. The exact distance of thermocouple from the weld centre was determined, under optical microscope, on the welded specimen prepared metallographically. The thermal data was recorded with the help of X-Y recorder and a parallely connected multichannel digital temperature recorder.

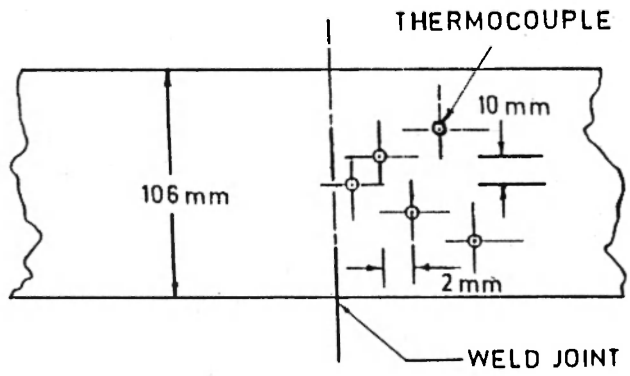


Fig. 2. : Schematic diagram of the placing of thermocouple on the plate.

The transverse sections of weld joint and base metal were prepared by standard metallographic procedure and etched in 2 % nital solution. Influence of various welding conditions on the microstructure of weldment was studied under optical and scanning electron microscopes. The amount of inclusions present in the matrix was estimated under optical microscope by standard point counting method (12).

The microhardness measurement acriss the weld and on base metal was carried out at a load of $490°5.10^{-3}$N on the specimens prepared metallographically. However for identification of different phases in the matrix the microhardness measurement was carried out at a load of $49°05.10^{-3}$N.

The microshear test was carried out on base metal and also on the weldment by using 50 mm long specimen having cross sectional area, S_0, of (1.5×1.5 mm^2). The detail of the microshear test setup has been shown schematically in Fig. 3. The welded specimens were etched in alcholic nitric acid solution. Before shearing

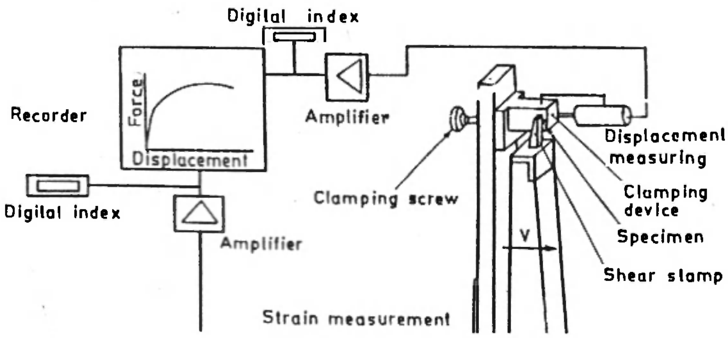


Fig. 3. : Schematic diagram of the microshear test set up.

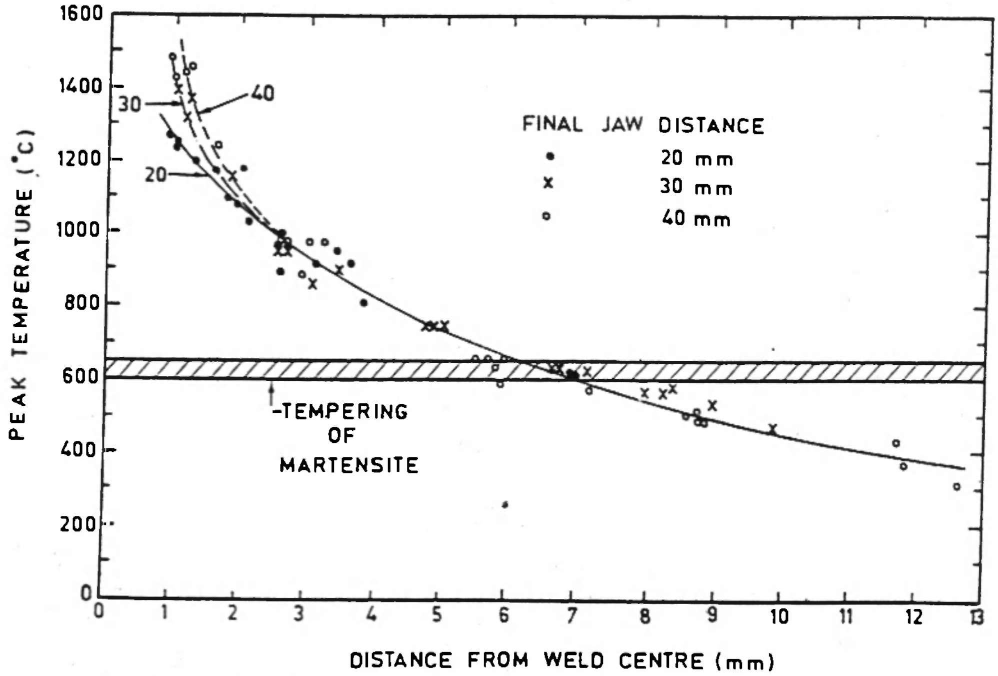


Fig. 4. : Typical behaviour of thermal distribution during welding at different final jaw distance.

the weld centre was identified and the HAZ was suitably divided into parts at an interval of 0.7 mm with reference to the weld centre. One end of the specimen was fixed in a clamp and a shear tool cutt through the projected part at an interval decided above. During test the maximum shear force, F_m, was recorded and the maximum shear strength, τ_m, was determined as

$$\tau_m = \frac{F_m}{S_0} (N/mm^2) \qquad \ldots\ldots (i)$$

The portion of sheared area, <97, is estimated as

$$\alpha = \left(1 - \frac{S_m}{S_0}\right) 100(\%) \qquad ££ (ii)$$

Where, the F_m is the cross sectional area of the specimen at the monent of fracture. The ultimate tensile strength, R_m, and the reduction in cross sectional area, Z are estimated by using the relationships (1) as

$$R_m = [2.04\,\tau_m - 228](N/mm^2) \qquad \ldots\ldots (iii)$$

and

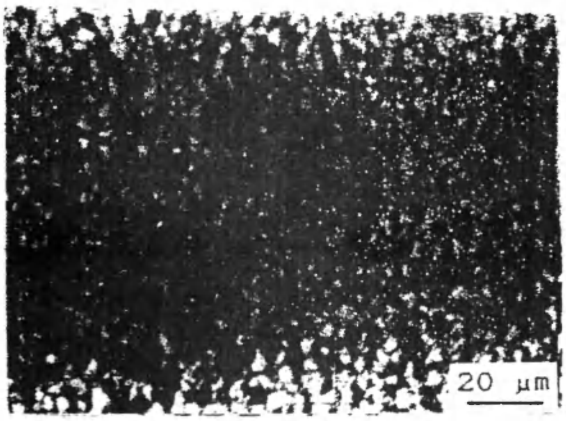
$$Z = [1.50(\alpha) - 1.45](\%) \qquad \ldots\ldots (iv)$$

The tensile properties of the base metal were also evaluated by using standard (DIN 50120) flat tensile specimens collected from the parent sheet of dual phase steel.

RESULTS AND DISCUSSIONS

In case of flash butt welding the jaws gripping the sample are having self cooling arrangement. Thus their distance from the weld centre must have a considerable influence on weld thermal cycle, such as the peak temperature of different regions of the weldment with reference to its centre as shown in Fig. 4. This is in agreement to the earlier work (13) where it is observed that the variation in FJD affects the behaviour of phase transformation at weld centre and HAZ. The Fig. 3 also shows that the increase in FJD, resulting into an increase in jaw distance from the weld centre, enhances the peak temperature of the central part of the weld due to reduction in simultaneous cooling effect of the jaw on it during welding. However the influence of FJD on the peak temperature of any region of the weldment has been found significant put to a distance of about 2.0 mm from the weld centre. It is noted that the increase in distance from the weld centre reduces the peak temperature of any region of HAZ. Within about 4.0 mm from weld centre the peak temperature lies in the range beyond the AC_1 of the dual phase steel and in the region within about 6.0 - 7.0 mm from weld centre the peak temperature lies in the range of 620 ± 20^{0}C, which is martensite tempering temperature of dual phase steel (5, 9, 13).

The optical and scanning electron micrographs of base metal, showing the martensite (M) colonies at Ferrite (F) matrix identified by their microhardness as about 420 VHN and 210 VHN respectively are presented in Figs. 5 (i and ii) respectively. The micrograph shows the presence of inclusion in the matrix. The amount of inclusion is estimated as about 7 - 9 vol %.

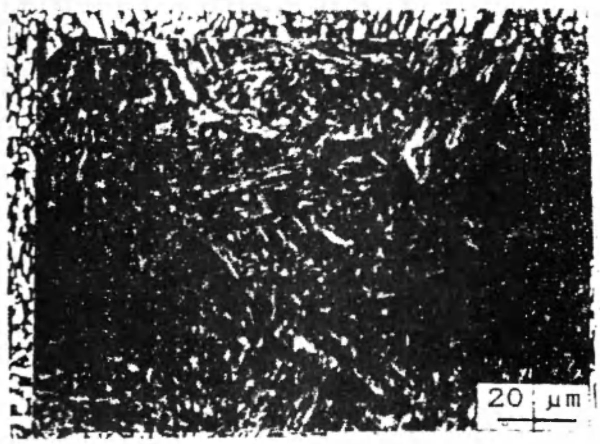


(i)

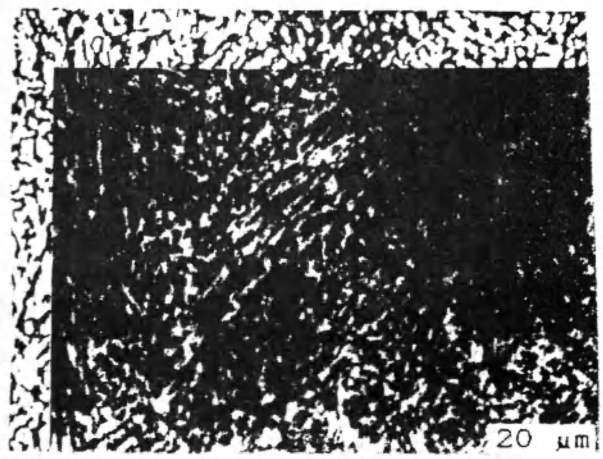
(ii)

Fig 5. : Microstructure of base metal revealed under (i) optical microscope and (ii) scanning electron microscope.

From the above discussion of weld thermal cycle it is clearly understood that, during flash butt welding of dual phase steel the change in final distance must have an effect on the microstructure of weld centre and different region of HAZ. The influence of variation in FJD from 20 to 40 mm on the microstructure of weld centre has been shown in Fig. 6 (i and ii) respectively. The microstructures show that the enhancement in welding temperature with the increase in FJD has coarsened the morphology of weld centre consists of accicular ferrite and bainite/martensite. It has been observed that with the increase in distance from the weld centre the morphology of HAZ, primarily consists of bainite, is refined. But the morphology of HAZ has been found to

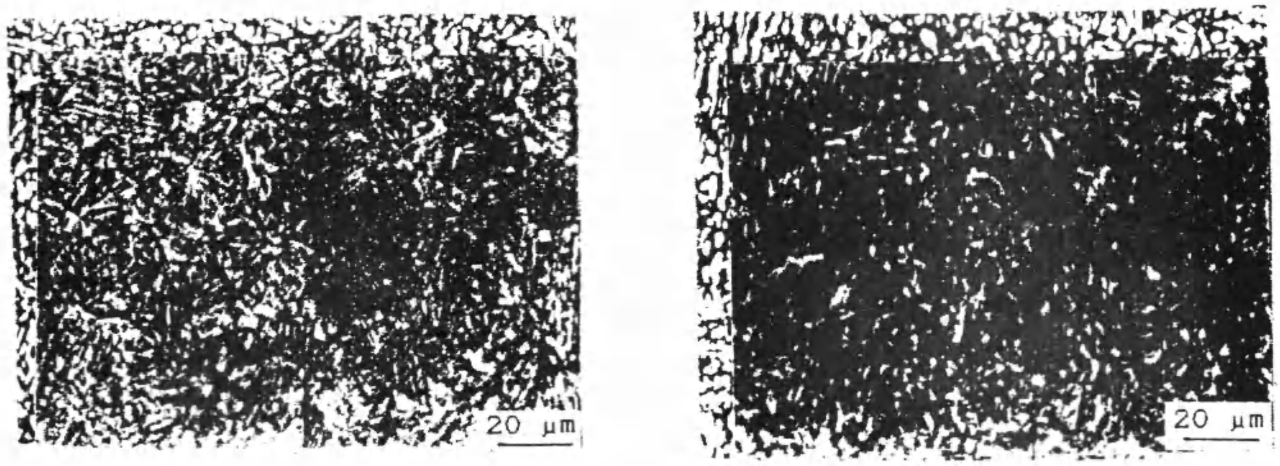


(i)



(ii)

Fig. 6. : Influence of final jaw distance (FJD) on the microstructure of weld centre ; (i) FJD = 20 mm and (ii) FJD = 40 mm.



(i) *(ii)*

Fig. 7. : Influence of final jaw distance (FJD) on the microstructure of HAZ at a distance of about 1.0 mm from the weld centre ; (i) FJD = 20 mm and (ii) FJD = 40 mm.

be comparatively coarser, due to higher welding temperature, when higher FJD is used as shown in Fig. 7 (i and ii) representing the weldment prepared at FJD of 20 and 40 mm respectively. However 2.0 mm the coarse bainite transformation has been found to be reduced and the microstructure is predominantly found to consist of polygonal ferrite along with dark patches of martensite/bainite. The typical microstructure of this kind observed at a distance of about 4.0 mm from weld centre is presented in Fig. 8. Finally at s distance of about 6.0 mm from the weld centre the microstructure of HAZ has been found to consist of ferrite and tempered martensite (TM) colonies Fig. 9 (i and ii) identified by their comparatively low microhardness of the order of 310 VHN. This is in agreement to the weld thermal cycle

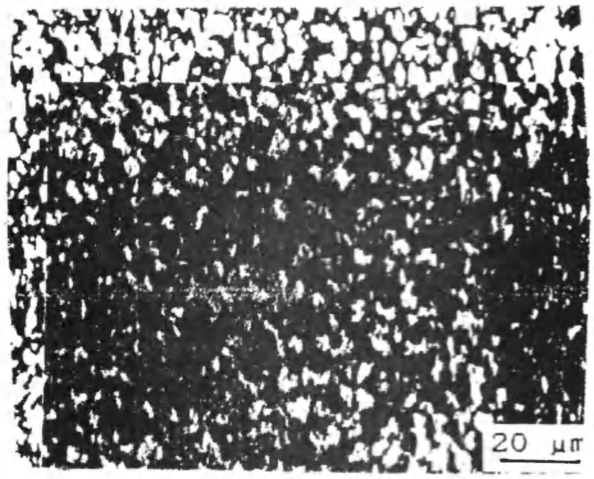
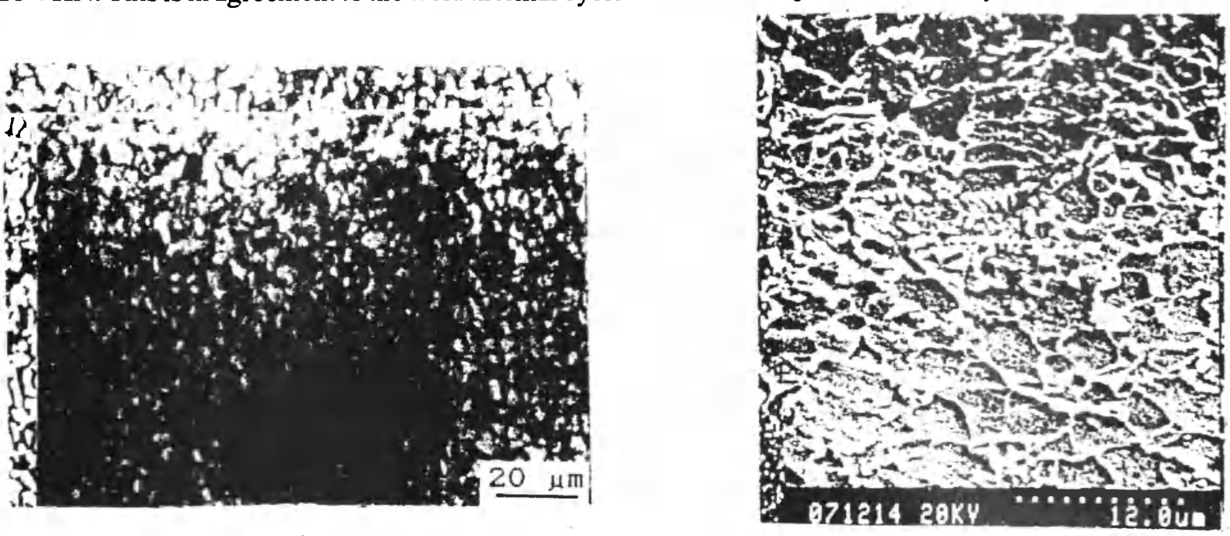


Fig. 8. : Typical microstructure of HAZ at a distance of about 4.0 mm from the weld centre.



(i) *(ii)*

Fig. 9. : Typical microstructure of HAZ at a distance of about 6.0 mm from the weld centre revealed under (i) optical microscope and (ii) scanning electron microscope.

data presented in Fig. 4, which shows that during welding the peak temperature of this region is raised put to martensite tempering range of dual phase steel.

The above observations clearly show that the HAZ of flash butt welded dual phase steel is always having regions of distinctly different microstructure and their morphology varies with a change in welding parameter such as the FJD. Thus they must have different mechanical properties. During welding at different FJD of 20, 30 and 40 mm the variation in microhardness across the weld has been shown in Fig. 10. The figure shows that the microhardness of HAZ increases with the increase in distance from the weld centre put to about 2.0 mm, primarily due to refinement of its microstructure stated above, followed by a decrease in it with a further increase in distance from the weld centre due to reduction in bainite/martensite transformation in this region. However it is interesting to note that due to coarsening of microstructure, caused by comparatively higher welding temperature, the peak hardness of HAZ at a distance of 2.0 mm from the weld centre is relatively lower in case of using a FJD of 40 mm than that observed where the FJD of 20 and 30 mm is used. At a distance of about 6.0 mm from the weld centre the microhardness has been found to come down even below the base metal due to tempering of martensite in this region. It can also be noted that the microhardness of tempered martensite region is comparatively higher than the other when the welding is carried out at FJD of 40 mm. Thus in this case the difference in hardness between the regions of HAZ, where the peak and lowest hardness are observed, is reduced. This may be helpful in improving the post weld formability of flash butt welded dual phase steel as here the HAZ may provide a comparatively better flow characteristics.

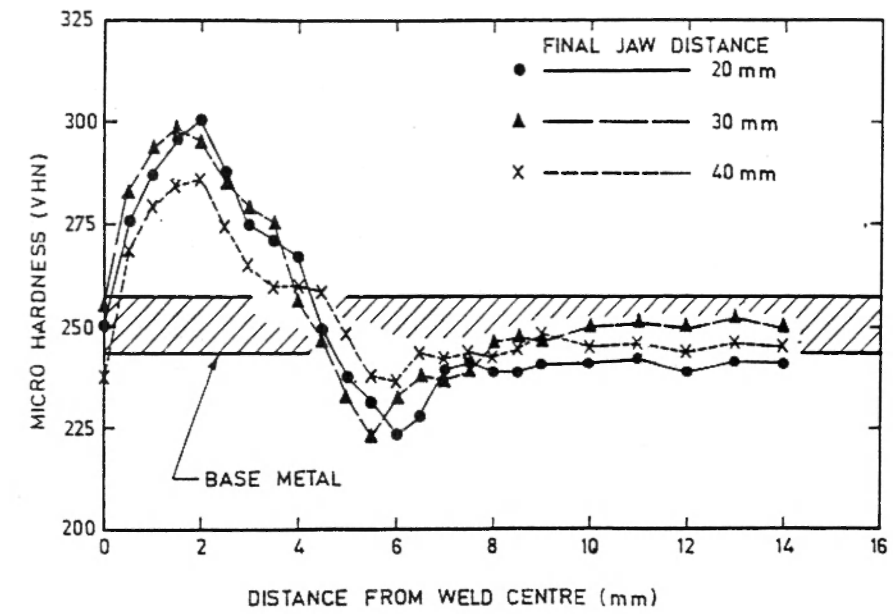


Fig. 10 : Microhardness across the weld prepared at different final jaw distance of 20, 30, and 40 mm.

Table II					
The Mechanical Properties of Base Metal					
Test Method	Microshear Strength (N/mm^2)	Ultimate Tensile Strength (N/mm^2)	Yield Strength (N/mm^2)	Reduction in cross-sectional Area (%)	Elongation (%)
Tensile test	—	720 ± 2	470 ± 4	44 ± 2	22 ± 3
Microshear test	455 - 471	698 - 730	—	42.1 - 45.2	—

The microshear strength of the base material has been shown in Table II. The tensile properties of the base metal such as its ultimate tensile strength and reduction in cross sectional area measured by using tensile test specimen and also estimated from the microshear strength by using the equations (iii) and (iv) respectively are also presented in Table II. It is observed that the estimated tensile properties are in close approximation to the measured value of the same. However, a comparatively larger seattering observed in the tensile properties estimated with the help of microshear test may have caused primarily by the presence of a significant amount of inclusion has been found to affect the mechanical properties of base metal comparatively more incase of microshear test due to small size of the specimen than that observed in case of tensile test. The elongation of base metal measured during tensile test is also presented in Table II. The typical contineous yielding behaviour of dual phase base metal observed in its tensile load vrs. extension diagram is presented in Fig. 11. The force vrs. sheared distance diagram ploted during microshear test of the base metal carried out at an interval of 0.7 mm has been shown in Fig. 12. The curves depicted in Fig. 12 also show that during microshear test the shearing at an interval of 0.7 mm does not have any significant influence on the flow characteristic of the material. Thus one can assume that the use of microshear test accross the weld may provide

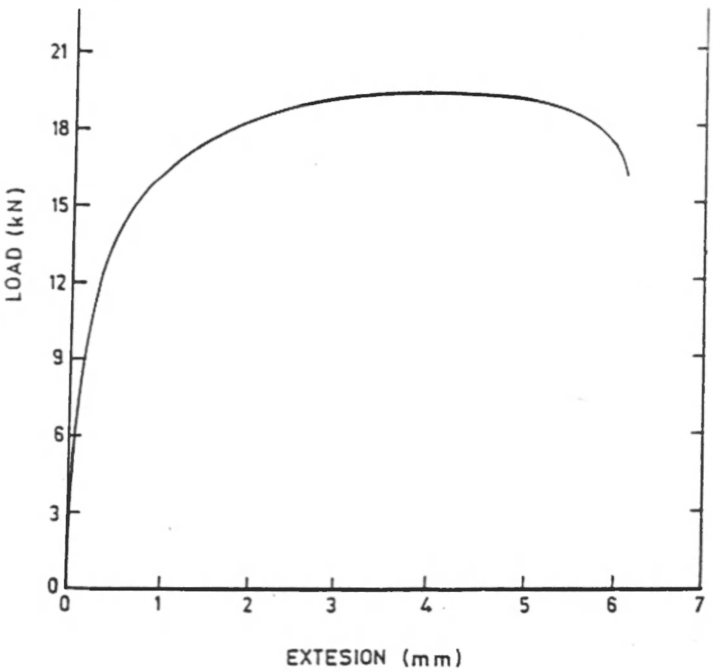


Fig. 11. : Typical tensile load Vrs. extension diagram of dual phase steel base metal.

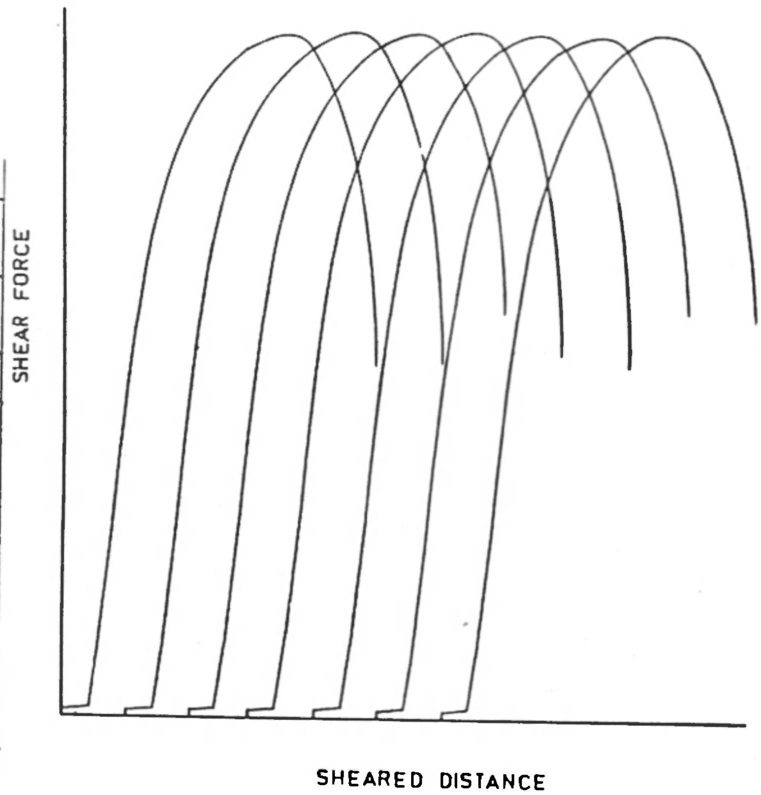


Fig. 12. : Typical characteristic of force Vrs. sheared distance diagram observed during microshear test of the base metal.

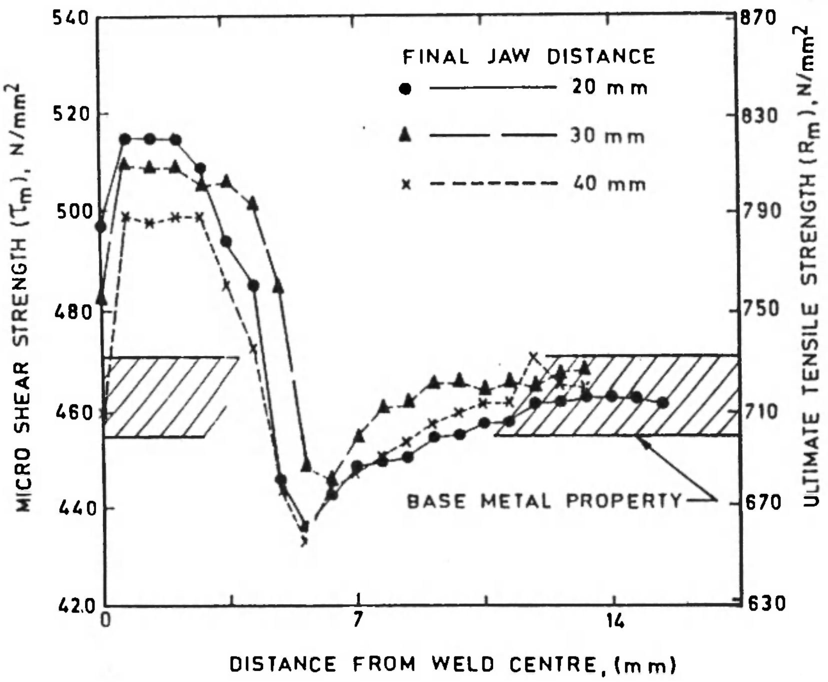


Fig. 13 : Microshear strength and corresponding ultimate tensile strength across the weld prepared at different FJD of 20, 30 and 40 mm

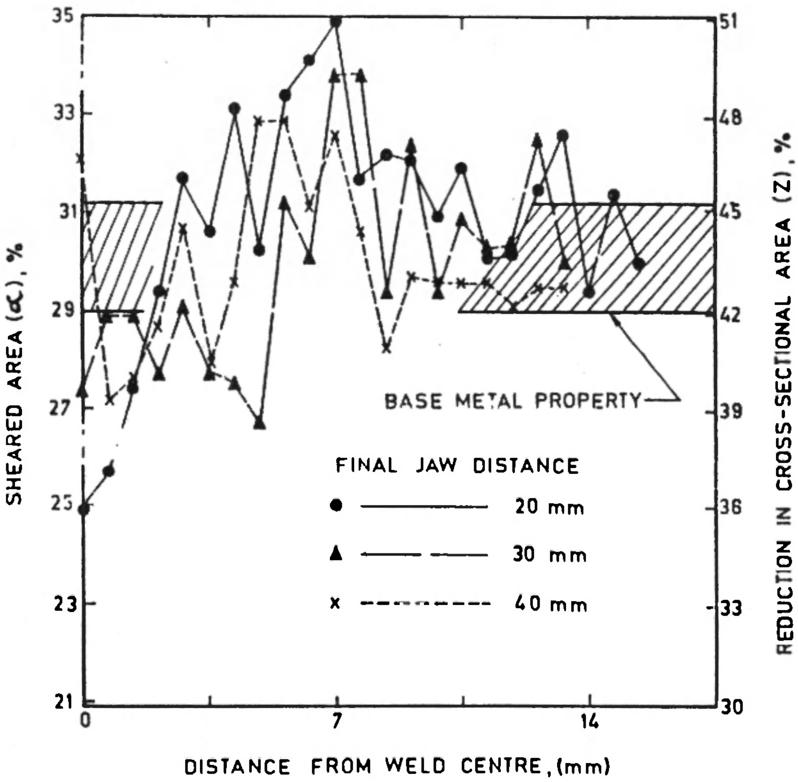


Fig. 14. : Sheared area and corresponding reduction in cross sectional area across the weld prepared at different FJD of 20, 30 and 40 mm.

an useful data regarding the mechanical properties of different regions of HAZ.

The nature of variation in microshear strength and estimated corresponding ultimate tensile strength of different regions of HAZ across the weld, prepared at different FJD of 20, 30 and 40 mm, are shown in Fig. 13. The behaviour of microshear strength of different regions of HAZ has been found to show a similar characteristic to the same observed in case of their microhardness depicted in Fig. 10. This may be justified because both the microshear and microhardness properties as well as the tensile properties are to a great extent related to the resistance to deformation of the matrix.

Due to difference in morphology of various regions of HAZ the sheared area, α, of them before fracture under microshear test must be different. The behaviour of variation in sheared area of different regions of HAZ across the weld, prepared at different FJD of 20, 30 and 40 mm, and their corresponding estimated (equ. iv) reduction in cross sectional area, are shown in Fig. 14. The characteristic of the curves presented in Fig. 14 show a good agreement to the results of microhardness and mechanical properties (τ_m and R_m) across the weld depicted in Fig. 10 and 13 respectively. It is observed that the regions of HAZ having comparatively higher hardness and strength show a comparatively, lower value of α and z, whereas the tempered martensite region of HAZ being the softest region shows a large response to α and z. However, here also it is interesting to note that during welding at a comparatively higher FJD of 40 mm the variation in values of a and z observed at different regions of HAZ is reduced considerably which may improve the post weld forming of flash butt welded dual phase steel by providing a capacity to withstand higher degree of deformation.

CONCLUSION

The present investigation shows that the microshear test method can be used more effectively to study the weld ability of steel sheet of thickness about 3.7 mm, by determining the mechanical properties of various regions of the weldment at an interval of 0.7 mm. During flash butt welding of dual phase steel sheet (3.7 mm) the variation in final jaw distance has been found to affect the weld thermal cycle significantly. The tempered martensite region observed at a distance of about 6.0 mm from the weld centre, where the temperature is raised put to about 620 ± 20°C, has been found as a region even weaker than the base metal. The studies infer that the use of a comparatively higher final jaw distance (40 mm) during flash butt welding of dual phase steel may be beneficial to improve the post weld formability of dual phase steel due to reduction in variation of mechanical properties observed at different regions of HAZ.

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