Influence of some Upset Butt Welding Parameters on the Weld Properties of HSLA Steel

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Summary

The effect of variation in some upset butt welding parameters such as, current way(10-12mm) and welding way(14-20mm) on the microstructure and hardness of different region of HAZ and the toughness of the weld in high strength low alloy steel weldment have been studied. The weldment has been found to have a coarse grain bainite at the central region of the weld followed by a region of fine grain tempered martensite at both the ends of it . The increase in current way and welding way coarsens and refines the central region microstructure of the weld respectively. In the weldment a high hardness has normally been found at the weld centre. The increase in welding way enhances the hardness of central region of the weld. The increase in current way shows a sharp increase in hardness at the weld centre especially when it is kept at 12mm. The increase in current way from 10-11.5mm moderately increases the C_V impact energy of the weld centre followed by a sharp increases with a further increase in it to 12mm. The increase in welding way has been found to decrease the C_V impact energy of the weld centre.

1. Introduction

The high strength alloy(HSLA) steels have received a wide acceptance in various structural applications such as pipelines [1] offshore plateforms [2,3] etc., due to their higher yield strength to tensile strength and strength to weight ratios. During fabrication of these structures welding of various components is a common practice. As such a due consideration on the weldability of HSLA steels under various welding processes has become a fact of immense importance.The weldability of HSLA steels has so far been studied under different welding processes starting from the manual metal arc welding to the highly sophisticated processes like electron beam and laser beam welding. However, unfortunately not much literature is available on the weldability of these steels under flash butt welding and upset butt welding processes which are having a high degree of automation and higher rate of production over a range of section, size and shape of the components.

So far as the mechanical properties of the weldment are concerned, the toughness of the joint has been given a primary importance in any structural application. During flash butt welding of steel, in general the weld has been found to possess a low toughness [4]. In flash butt welding and upset butt welding processes the extent of current flow and welding way considerably affect the weld properties due to their influence on the thermal cycle and the extent of upsetting in the weld. Considering the above facts, in this investigation, an effort has been made to determine the effect of current way and welding way on the microstructure and mechanical properties such as the hardness and toughness of the weld centre, in case of upsett butt welds of a High Strength Low Alloy (HSLA) steel.

2. Experimentation

2.1 Welding Procedure

The HSLA steel having chemical composition as shown in table-I, and of cross section 36 mm x 10 mm was upset butt welded in a flash butt welding machine by keeping its welding speed sufficiently high so that the welding is performed without flashing. The schematic diagram of the welding process has been shown in fig.1. In this process out of two self cooling gripping jaws of the welding machine, one is fixed and the other one moves during welding upto a certain distance

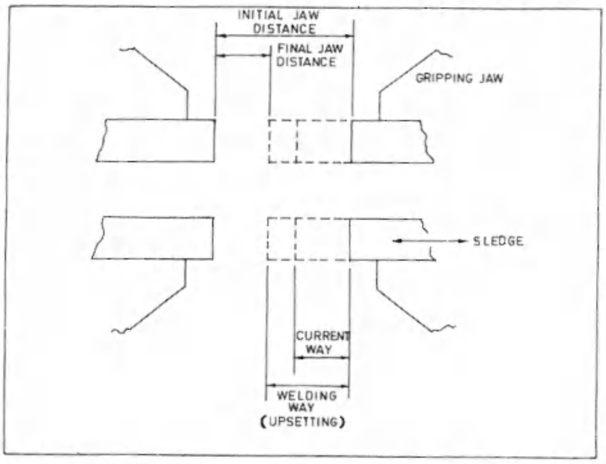

Fig. 1 Schematic diagram of the welding process.

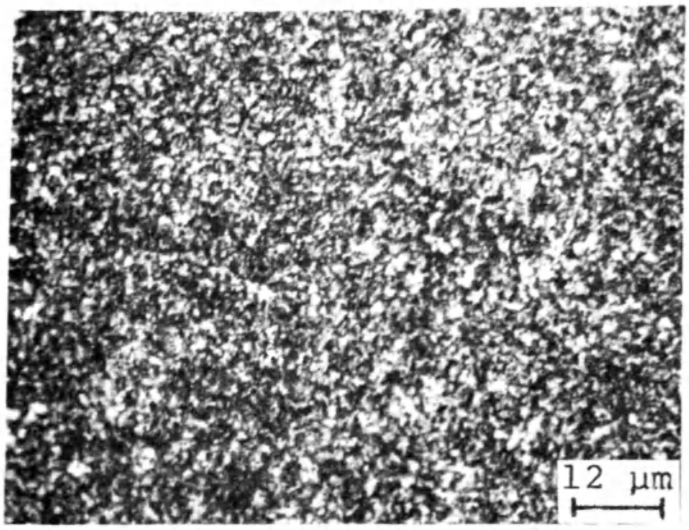

Fig. 2 Microstructure of the fine grain region of HAZ.

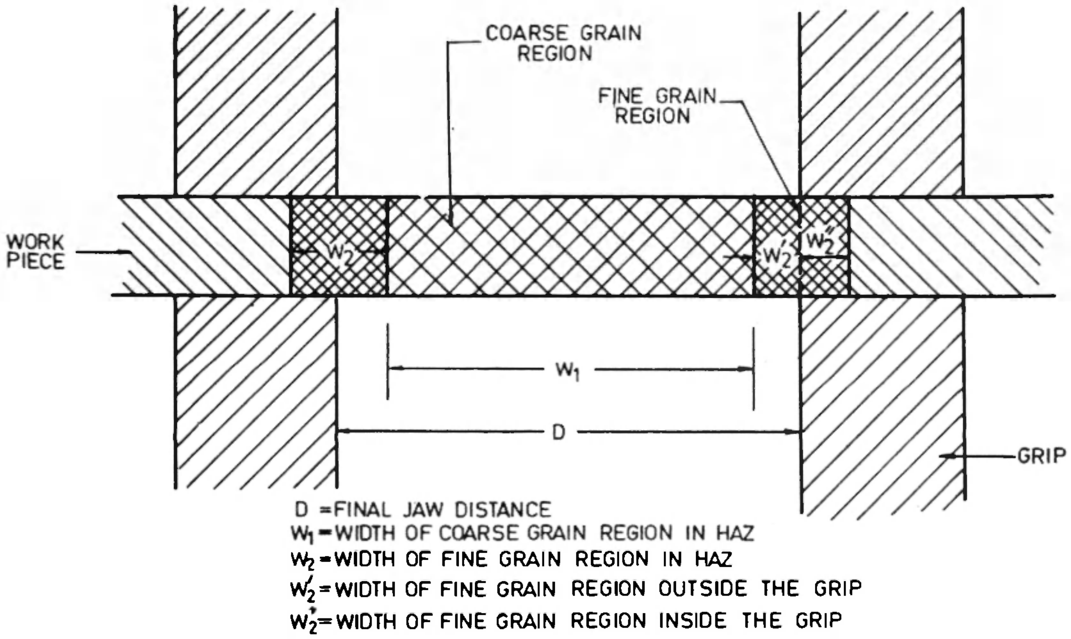

Fig. 3 Schematic diagram of the location of different microstructural region in HAZ.

called the "Welding Way" and the resulting gap between the gripping jaws is called the "final jaw distance" (Fig.1). Within the welding way, during movement of the jaw upto a certain distance (current way) the current flows through the jaw and the jaw traverses rest of the welding way without current. The work piece experiences an upsetting operation during the entire welding way. The schedule of the welding parameters used in this work has been shown in table-II.

Chemical Composition of SAIL-MA300

Material	Chemical composition (Wt.%)					
	C	Si	Mn	Nb	P	S
HSLA (SAIL-MA 300)	0.16	0.226	1.6	0.072	0.022	0.028

Schedule of the welding parameters used in this work

Sl. No.	Current way (mm)	Welding way (mm)	Upsetting Pressure (bar)	Clamping Pressure (bar)	Initial Jaw distance (mm)	Final Jaw distance (mm)
1.	10	15	65	100	30	15
2.	11	15	65	100	30	15
3.	11.5	15	65	100	30	15
4.	12	15	65	100	30	15
5.	11	14	65	100	30	16
6.	11	17	65	100	30	13
7.	11	20	65	100	30	10

2.2 Microstructure Study

The specimens collected from each weld were prepared by standard metallographic procedure and etched in 2% nital solution. Under a given set of other welding parameters, the effects of variation in current way from 10mm to 12mm and also the variation in welding way from 14mm upto 20mm on the widths of various microstructural regions in heat affected zone (HAZ) were studied under optical microscope.

2.3 Hardness Test

The influence of various welding parameters on the distribution of hardness in the weldment between its centreline to base metal was studied under Vicker's hardness tester at a load of 10 kg.

2.4 Impact Test

At a given welding way of 15 mm the effect of variation in current way from 10-12mm and at a given current way of 11mm the effect of variation in welding way from 14-20mm, on the toughness of weld centre was studied by carrying out charpy V-notch impact (C_V) test at the temperature of 233K. The dimension of the impact specimens was 10x10x55 mm having a 2mm deep 45° V-notch of root radius 0.25mm placed at the centre line of the weld.

3. **Results**

3.1 Microstructure of HAZ

The heat affected zone of the weldments produced by upset butt welding process is found to have two distinct zones consisting of coarse and fine grain microstructures. The coarse microstructural region is observed at the central region of the weld having bainite and acicular proeutectoid ferrite. The fine microstructural regions having fine grains of possibly tempered martensite as typically shown in fig.2 are found on both sides adjacent to the coarse microstructural region towards the grip The location of these different microstructural regions in a weldment have been shown schematically in fig.3 where, D is the final jaw distance, W_1 is the width of coarse microstructural region and W_2 is the width of fine microstructural region. At all combinations of process parameters used in this work, it has been observed that the total width of HAZ estimated as $(W_1 + 2W_2)$ is always more than the final jaw distance D. This behaviour indicates that the fine microstructural regions existing at both ends of W_1 are extended upto a certain distance within the gripping area. In fig.3 the widths of fine microstructural regions present outside and inside the gripping area are shown as W'_2 and W''_2 respectively. The W'_2 is estimated as

$$W'_2 = (D-W_1)/2 \quad .... \quad (1)$$

and W''_2 is estimated as

$$W''_2 = [(W_1 + 2W_2)-D]/2 \quad .... \quad (2)$$

At a given level of current (66 KVA) the effects of duration of current flow controlled by variation in current way from 10mm upto 12mm and the resulting movement of the jaw beyond the current way from 5mm to 3mm respectively, on the width of HAZ $(W_1 + 2W_2)$, the widths of coarse (W_1) and fine (W_2) microstructural regions and the width of fine microstructural region (W'') within the gripping area in HAZ are shown in fig.4 where, the welding way (15mm) and the final jaw distance (15mm) are

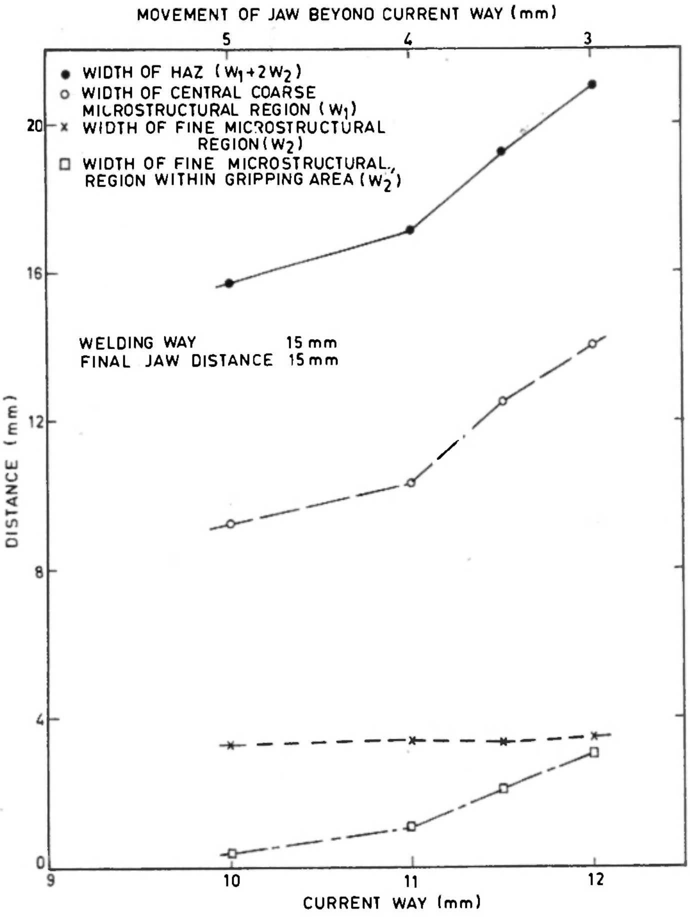

Fig. 4 Effect of current way on the width of different microstructural region in HAZ.

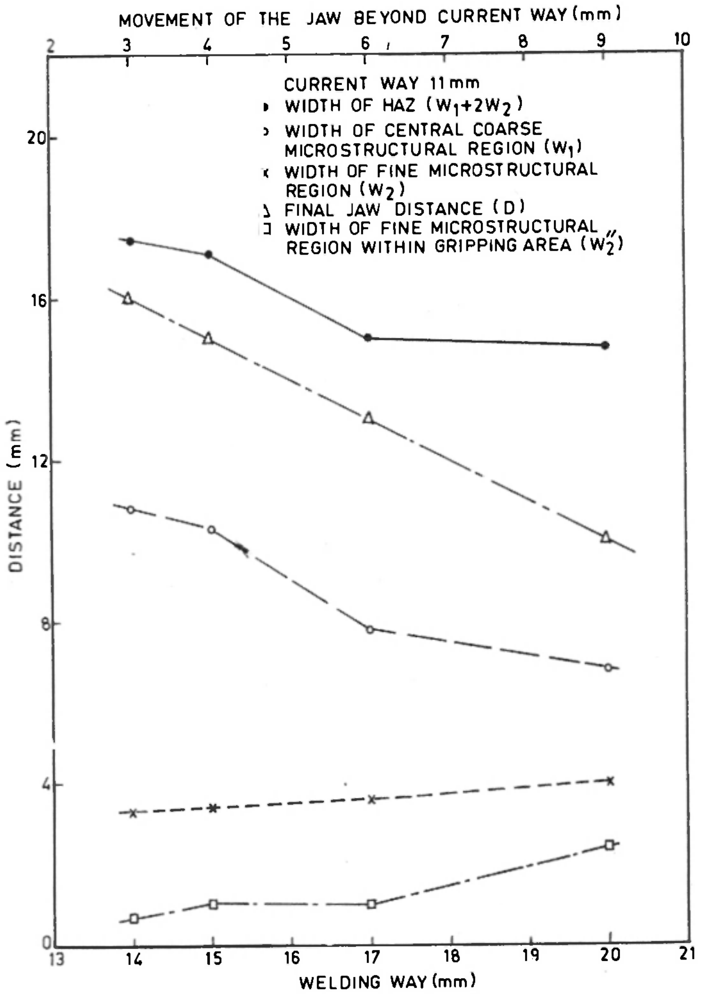

Fig. 5 Effect of welding way on the width of different microstructural region in HAZ.

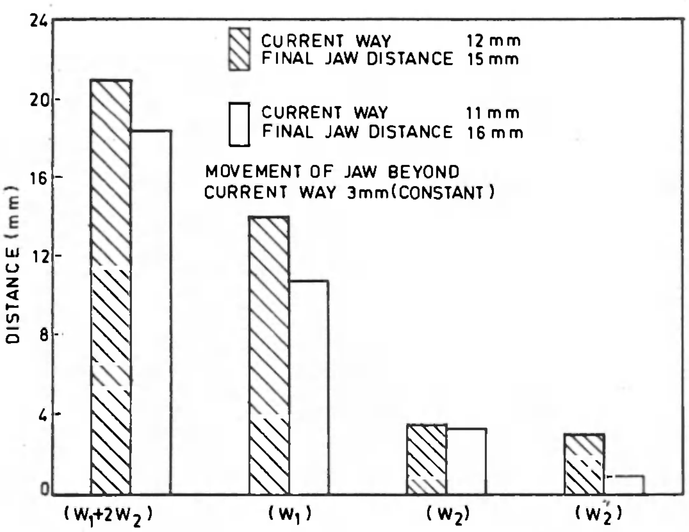

Fig. 6 At a given movement of Jaw beyond the current way the effect of current way on the width of different microstructural region in HAZ.

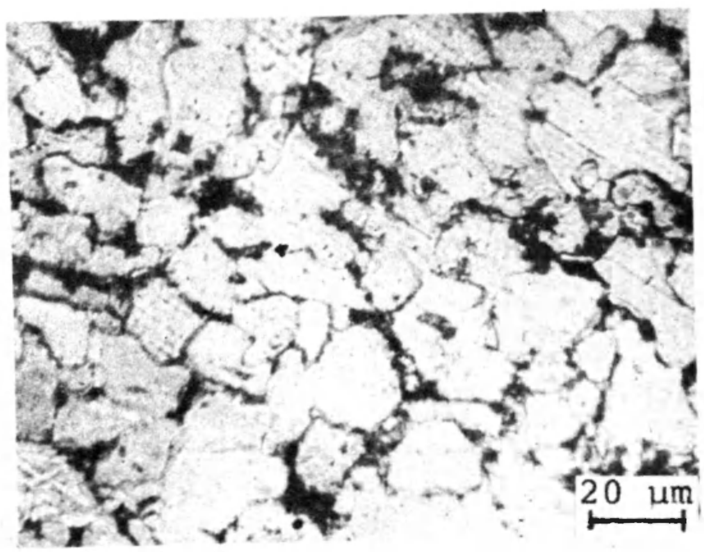

Fig. 7 Microstructure of base metal.

kept constant. The figure shows that the increase in current way from 10mm to 12mm enhances the value of ($W_1 + 2W_2$) and W_1 from 15.5mm to 21mm and 9.5mm to 14mm respectively. The rate of their increment are found significant during the increase in current way beyond 11mm. The increase in current way from 10mm to 12mm shows (fig.4) a tendency to increase the value of W_2 by 0.25mm. However, the same increase in current way increases the value of W''_2 from 0.35mm to 3.0mm and here the rate of its increase is also found significant during the increase of current way from 11mm to 12mm.

At a given current way of 11mm the effects of variation in welding way from 14mm upto 20mm and the resulting movement of the jaw beyond the current way from 3mm to 9mm respectively, on the final jaw distance(D), the width of HAZ ($W_1 + 2W_2$), the widths of coarse (W_1) and fine (W_2) microstructural regions and the width of fine microstructural regions within the gripping area (W''_2) in HAZ are shown in fig.5. The figure shows that the increase in welding way from 14mm to 20mm decreases the final jaw distance from 16mm to 10mm as the initial jaw distance is kept constant at 30mm. The width of HAZ and the width of coarse microstructural region of HAZ are found to decrease with the increase in welding way. The width of fine microstructural region existing at the end of HAZ is found to show a tendency to increase upto about 0.7 mm with the increase in welding way. The enhancement in welding way has also been found to extend the width of fine microstructural region within the gripping area. However, in case of the enhancement of welding way from 17mm to 20mm the rate of decrease in ($W_1 + 2W_2$) and W_1 have been found comparatively lower and the rate of increase in W_2 and W''_2 have been found to be comparatively higher than that observed in earlier range of welding way, when the movement of the jaw beyond the current way rises from 6mm to 9mm.

At a given movement of the jaw (3mm) beyond the current way the influence of variation in current way from 11mm to 12mm on the width of HAZ ($W_1 + 2W_2$), the widths of coarse (W_1) and fine (W_2) microstructural regions of HAZ and the width of fine microstructural region within the gripping area (W''_2) are shown in a histogram presented in fig.6, where, in the two cases the final jaw distances are kept at 16mm and 15mm respectively. The figure shows that inspite of reduction in final jaw distance the increase in current way increases the (W_1+ $2W_2$), W_1, W_2 and W''_2 of HAZ.

The microstructure of the base metal having ferrite and fine pearlite has been shown in fig.7. The change in microstructure at the central region of the weld with a variation in current way at the level of 10mm, 11mm and 12mm are shown in fig.8 (i), (ii) & (iii) respectively where, the welding way and the final jaw distance are kept constant at 15mm each. The microstructures reveal that the matrix contains coarse acicular ferrite(fig.8(iii) when the current way is kept at 12mm but a decrease in current way to 11mm and 10mm produces a comparatively finer morphology of acicular ferrite along with bainite in the matrix as shown in fig.8 (ii) and (i) respectively. However, during welding at the current way of 12mm a narrow decarburized zone of about 1.4mm in width, which is having a different microstructure from the one that has been observed (fig.8 (iii) in the HAZ adjacent to it, exists at the centre of the weld as shown in fig.9. The Zone consists of polygonal ferrite and bainite/fine pearlite.

At a given current way of 11mm the variation in the microstructures of the central region of the weldments produced during welding at varying welding way of 14mm, 17mm and 20mm are shown in fig.10 (i), (ii) and (iii) respectively where, the final jaw distances are also varied to 16mm, 13mm and 10 mm respectively The microstructures show that the morphology of the matrix containing acicular ferrite and bainite become finer with the increase in welding way.

3.2 Hardness Behaviour

At a given welding way of 15mm the effect of variation in current way at the levels of 10mm, 11mm and 12mm on the variation of hardness of the weld between its contreline and base metal are shown in fig.11. Similarly the hardness distribution in between the base metal and the centre line of the welds produced at different welding way of 14mm, 17mm and 20mm where, the current way is kept constant at 11mm are presented in fig.12. Both the figures mentioned above show that as one proceeds from the base metal towards the central region of the weld the hardness increases. It has been observed in fig.11 that the hardness of the weld centre increases abruptly upto about 168 VHN when the welding is carried out at the current way of 12mm. The hardness of the central region of the weld has been found to increase (fig.12) with the increase in welding way.

3.3 C_V - Impact Property

The influence of increase in current way from 10mm upto 12mm on the C_V impact energy

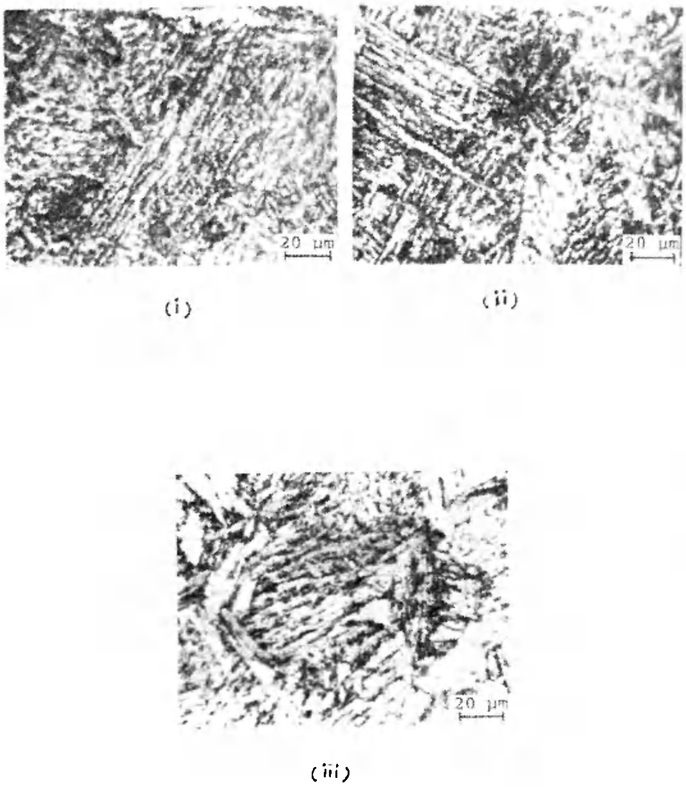

Fig. 8 Effect of current way on the microstructure of central region (W_1) of the weld;(i) 10mm, (ii) 11mm and (iii) 12mm.

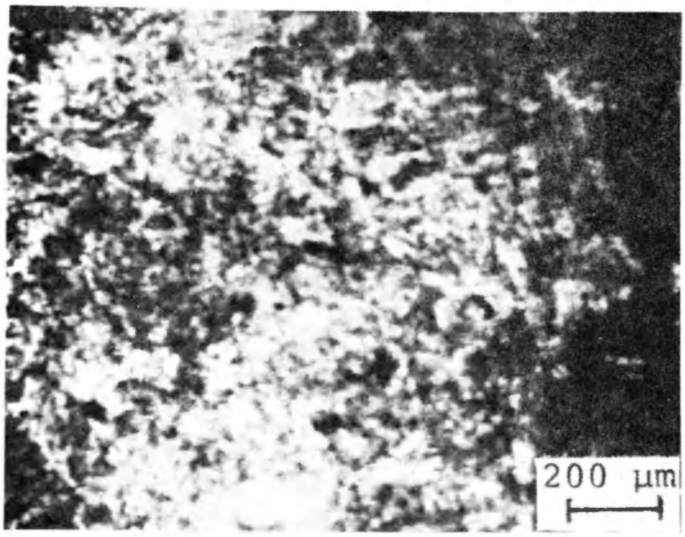

Fig. 9 Microstructure of the centre of an weld prepared at the current way of 12 mm.

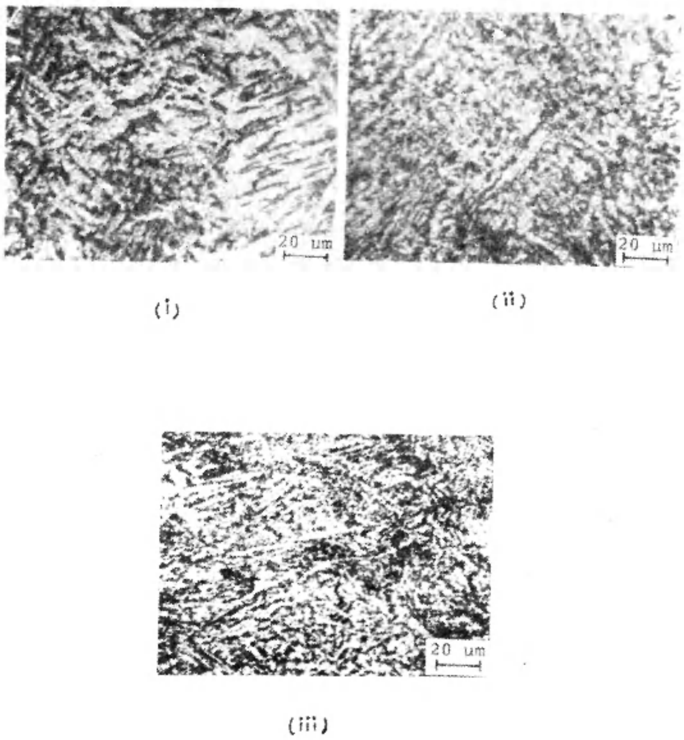

Fig.10 Effect of welding way on the microstructure of central region (W_1) of the weld;(i)14mm, (ii)17mm and (iii)20mm.

absorption at the weld centre tested at 233K has been shown in fig.13. The figure depicts that the increase in current way from 10mm upto 11.5mm gradually increases the impact energy of the weld centre. However, a further increase in current way to 12mm increases the impact energy of the weld centre significantly. At a given current way of 11mm the effect of increase in welding way from 14mm upto 20mm on the C_v impact energy absorption at the weld centre tested at 233K has been shown in fig.14. The figure shows that the increase in welding way decreases the impact energy absorption capacity of the weld centre.

4. Discussion

In the present welding process the movement of jaw upto a distance of current way results a smooth flow out of the fused material from the joint as bulging. Thus, it causes a reduction in amount of heat conducted from the joint to the region away from it by providing a higher surface area causing comparatively faster heat removal from the job. During the movement of the jaw beyond the current way the material gradually cooles down. As such during initial stage of welding way the hot material may continue to bulging out smoothly but, subsequently it starts offering an increasing resistance to plastic deformation. The extent of plastic deformation beyond a certain limit may cause a significant amount of heat generation in the weld. As the jaws gripping the job are having self cooling facility to they also influence the thermal cycle of the weld and its extent is governed by the final jaw distance. Thus, the thermal cycle of the upset butt weld is controlled by four phenomena (i) the heat input controlled by the level and duration of current flow (ii) the extent of heat removal due to bulging, (iii) the heat generation due to large plastic deformation and (iv) cooling under the influence of jaws.

4.1 Microstructure of HAZ

The increase in the width of HAZ ($W_1 + 2W_2$), the width of course microstructural region in HAZ (W_1) and the width of fine microstructural region within the gripping area of the jaw (W''_2) with the increase in current way (fig.4) are attributed to the increase in heat input. However, during the increase in current way upto, 11mm, possibly the movement of the jaw beyond current way as less as 4mm is sufficient to flow out maximum possible highly heated material from the joint resulting into significant removal of heat and keeps the rate of increase of ($W_1 + 2W_2$), W_1 and W''_2 comparatively low. In this period the heat generation due to plastic deformation can not be over-ruled but it may not be sufficient to rise the temperature to compensate the loss of heat mentioned above. In case of increase in current way beyond 11mm the available movement of the jaw further beyond the current way (4mm) becomes so less that the out flow of a significant amount of highly heated material from the joint is not achieved. Thus, a great extent of the heat input which is increased with the increase in current way from 11mm upto 12mm, enhances significantly the value of ($W_1 + 2W_2$), W_1 and W_2 and W''_2. This phenomena of heat input acting as a primary factor in controlling the width of various microstructural regions in HAZ is further confirmed in fig.6 where, at a given movement of the jaw beyond current way (3mm) inspite of a lower final jaw distance (15mm) the widths ($W_1 + 2W_2$), W_1, W_2 and W''_2 in the weldment produced at the current way of 12mm have been found higher than those observed in the weldments produced at the current way and final jaw distance of 11mm and 16mm respectively.

During the increase in current way from 10mm to 12mm, inspite of a significant increase in W''_2 a comparatively much slower rise in the value of W_2 may have occured because of significant reduction in W'_2 due to considerable increase in W_1 at a given final jaw distance of 15mm.

At a given initial jaw distance of 30mm the increase in welding way reduces the final jaw distance. Thus, at a given current way (heat input) of 11mm the increase in welding way reduces the width of HAZ ($W_1 + 2W_2$) and the width of coarse microstructural region (W_1) in HAZ (fig.5) by lowering the heating area of the weld due to closeness of the cooling jaws. However, in this regard the role of reduction in heat input due to less resistance heating resulting from the lowering of job length can not be ignored. The rate of reduction in (W_1+2W_2) and W_2 during the increase in welding way from 17mm to 20mm has become lower than that observed during the increase in welding way from 14mm to 17mm as shown in fig.5 possibly due to the heat generation in the weld due to excessive plastic deformation when, the movement of the jaw beyond the current way has been exceeded beyond 6mm The increase in W''_2 primarily depends on the intensity of heat adjacent to the jaw, which increases with the decrease in final jaw distance and the increase in amount of heat in the weld. Thus, the decrease in final jaw distance with the increase in welding way from

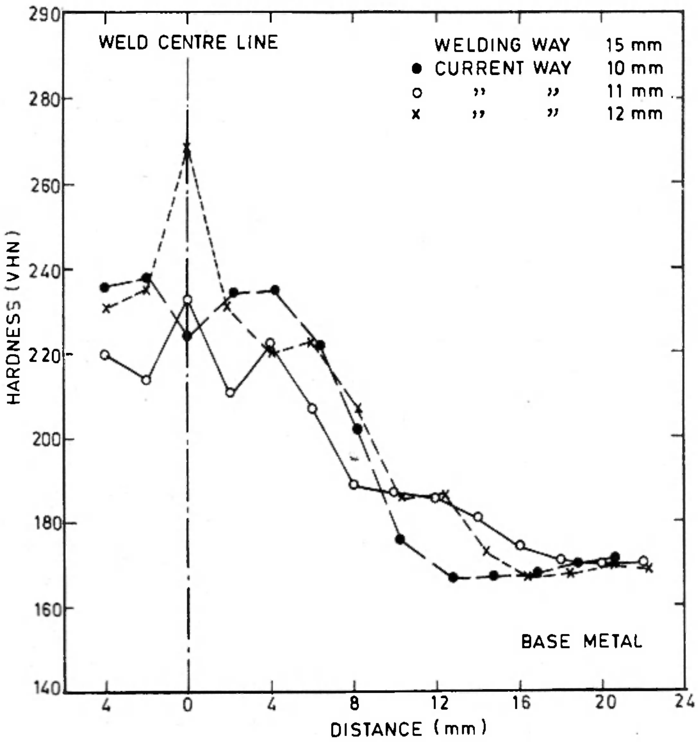

Fig.11 Effect of current way on the hardness behaviour across the weld.

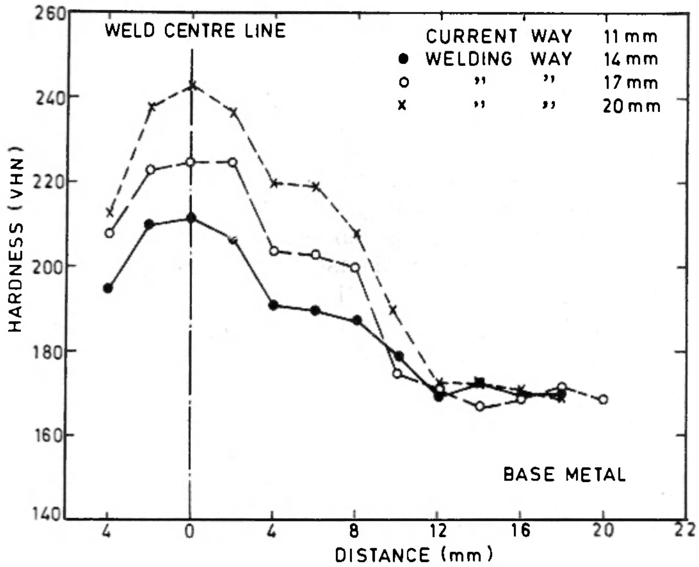

Fig.12 Effect of welding way on the hardness behaviour across the weld.

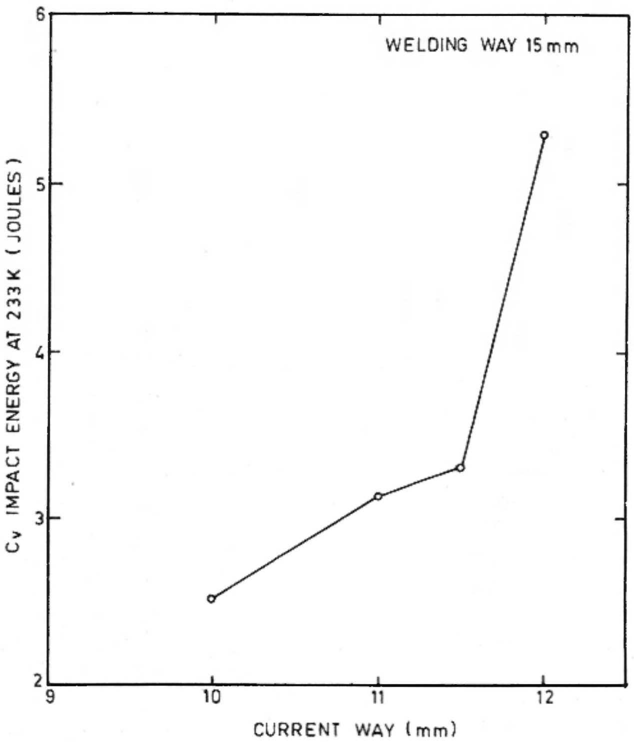

Fig.13 Effect of current way on the C_V impact value of the weld centre.

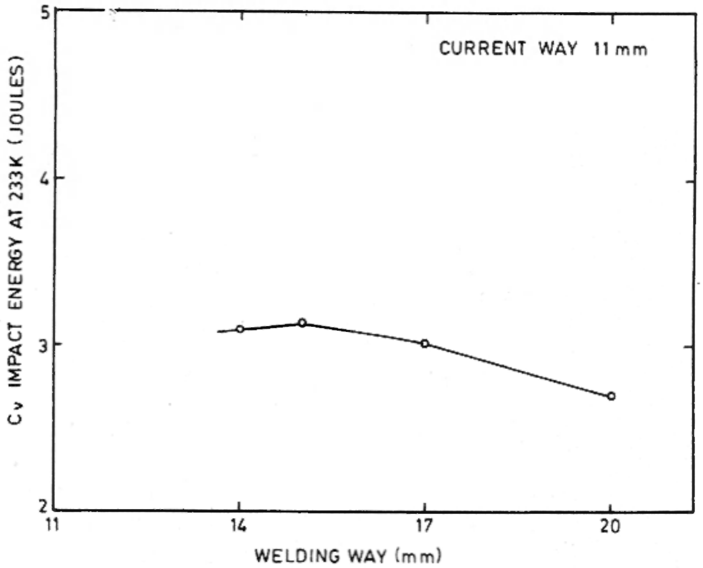

Fig.14 Effect of welding way on the C_V impact value of the weld centre.

14mm to 20mm has enhanced the W''_2 as shown in fig.5. However, in addition to this the heat generation due to excessive plastic deformation in the weld during the increase in welding way from 17mm to 20mm as discussed above has enhanced the rate of increase of W''_2 in this region than that observed in the earlier region (fig.5) of welding way. Inspite of the decrease in final jaw distance the increase in W_2 with the increase in welding way from 14mm to 20mm (fig.5) is primarily caused by the significant increase in W''_2 but, the extent of its increase has been found lower than that of W''_2 because the increase in welding way decrease W_2 at a comparatively lower rate than that of final jaw distance. Thus, it decreases the width (W''_2) of fine microstructural region outside the grip.

A suitable rate of cooling at the lower intercritical temperature range of the alloy exist at a certain distance within and adjacent to the grip may have caused the formation of fine grain microstructural region (W_2) possibly of tempered martensite as shown in fig.2. The existance of comparatively slow cooling at the central region of the weld in the upper intercritical temperature range of the alloy is primarily responsible for the formation of coarse microstructure consisting of acicular ferrite and bainite, in this region (W_1) as shown in the microstructures presented in fig.8(i), (ii) and (iii). The refinement of the microstructure of central region of the weld marked by the presence of a comparatively finer acicular ferrite with the decrease in current way as shown in fig.8(iii), (ii) and (i) where, the current way are kept at 12mm, 11mm and 10mm respectively may have attributed to the increase in the extent of plastic deformation within the intercritical temperature caused by a larger movement of the jaw beyond the current way (fig.4). Occurrence of the narrow microstructural (fig.9) region at the centre of the weld produced at the current way of 12mm having a significantly different morphology and consisting of comparatively fine grair ferrite and the patches of fine pearlite/bainite may have associated with micropolygonisation. The micropolygonisation may occur due to deformation at a suitable elevated temperature achieved at the current way of 12mm and is in agreement to the observation [5,6] reported earlier. The comparatively high cooling rate imposed by the reduction in final jaw distance in combination with the significant degree of deformation resulting from the considerable increase in the movement of jaw beyond the current way (fig.5), has refined the central region microstructure of the weld with the increase in welding way as shown in fig.10 (i), (ii) and (iii) where, the welding way is kept at 14mm, 17mm and 20mm respectively.

4.2 Hardness

In all the welds produced in this investigation the higher hardness observed in the central region of the welds (fig.11 and fig.12) than that of its adjacent region and the base metal is essentially caused by the formation of acicular ferrite and bainite in this region. The occurence of a substantial refinement in microstructure of the central region of the weld with the increase in welding way as discussed above may have attributed to a comparative increase in hardness of this regions as shown in fig.12. However, inspite of decarburization the abrupt increase in hardness observed at the centre of the weld produced at the current way of 12mm (fig.11) may have predominently caused by the occurence of micropolygonisation in this region.

4.3 C_V - Impact Property

The increase in the value of impact energy with the increase in current way (fig.13) has been caused due to presence of more/coarser ferrite in the matrix as shown in the microstructures presented in fig.8. It is interesting to note that a significant increase in amount of ferrite (fig.9) due to decarburization along with the possible micropolygonisation at the centre of the weld produced at the current way of 12mm has resulted in a steep increase in impact energy value of this region. Similarly the occurence of finer acicular ferrite in the central region of the weld with the increase in welding way as shown in the microstructure presented in fig.10(i), (ii) and (iii) has caused reduction in the impact energy as depicted in fig.14.

Acknowledgement

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