EFFECT OF WELD PARAMETERS ON RESIDUAL STRESS DISTRIBUTION IN FLUX CORED ARC WELDING OF HIGH STRENGTH LOW ALLOY STEEL

by
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Various types of high strength steels are increasingly used for producing welded structures with reduced weight and improved performance. Welding problems related to residual stress and distortion can arise, since yield stress of these steels are high, there is always a possibility of producing very high residual stresses in some locations near the weld. In general residual stresses become dangerous if they lead to local multi axiallity of tension stresses, which favour brittle fracture, knowledge of the residual stress distribution in welds is necessary in order to assess the risk of crack growth in service. The distribution of residual stresses after welding depends strongly on the weld parameters. Attempts were made to study the influence of weld parameters (arc voltage, travel speed, welding current) on residual stresses pattern of high strength low alloy steel weldments. This study was mainly performed by using X-ray stress analyzer.

INTRODUCTION

Welding process is widely used for joining together various components of structures. However, welded structures are by no means free from problems. Irrespective of what kind of welding process or technique is employed, welding, most commonly results in distortion and residual stress. It is well known that the steep thermal gradients produced during fusion welding promote complex deformation patterns in welded parts. The resultant residual stress distributions can give rise to distortion and under certain circumstances even lead to premature failure (1,2,3). Knowledge of residual stress field becomes essential as it should be used at the initial state of stress of the load carrying structure. Residual stress transverse to the weld may lead to formation of hot cracks (1,4,5) High tensile residual stresses are known to promote brittle fracture, corrosion cracking and fatigue in welded structures. On the other hand, compressive residual stresses tend to reduce the buckling strength (5,6).

The thermal cycle accompanying the welding process results in melting, solidification and non equilibrium and homogeneous solid phase transformations. These phenomena usually have mutual interaction. Therefore, residual stresses near welds are in most cases highly complex in nature. The evolution of residual stresses due to welding has been discussed by several authors (7 to 12). In principle, it is the consequence of non uniofrm plastic flow during the process. Of the number of causes, the primary ones contributing to the final stress state are :-

- ✱ Thermal Strains due to localized heating and cooling.
- ✱ Volume changes involved in localized phase transformation.
- ✱ Shrinkage stress

As shown in Figure 1(a), since expansion (due to heating or phase transformation) of the weld bead is hampered by the relatively bulk, elastic strains and thus stresses are produced. As the constraints to the weld bead expansion are different, the resulting stresses are predicted to have different distribution as indicated in Figure 1(b). Welding residual stresses arise not only because of the variation in shrinkage of differently heated areas but as a result of other effects such as surface quenching, phase transformation and combination of these effects as shown in Figure 2(7). The stresses generated during welding process can not be fully eliminated though their level can be reduced by controlling the welding parameters. The magnitude and distribution of residual stresses depend on several factors like, properties of the material to be joined, heat input during welding, type of weld, weld sequence, prewelding conditions and weld joint configurations. Considerable amount of attention has been paid by researchers in quantitative assessment and theoretical predictions of these factors (7, 8, 13, 14).

Most of the available experimental data on residual stresses in weldments are based on mechanical methods which are partially or wholly destructive. These methods are incapable of high resolution when stress distribution across the welds are to be determined. Often sharp variations in stress distributions exist within small distances on a weld surface. X-ray diffraction (XRD) provides a valuable tool for the nondestructive determination of the residual stress (line shift) as well as the plastic deformation (line broadening) as a function of position in a welded specimen. No other method is capable of providing both the types of information similtaneously, XRD is capable of resolving the stresses between locations which are 0.5 mm apart or even less. For this reason, the X-ray technique has been applied to the weldments, the results of which are presented in this paper.

The aim of the study was to show the effect of arc voltage, welding current and welding speed on residual stress distribution in the vicinity of weld bead made in high strength low alloy steel. Amongst the various welding processes, the Flux Cored Arc Welding (FCAW) being economical and versatile (15,16,17) holds a high promise for the welding or critical components. Therefore,. for the present investigation FCAW has been employed.

Experimental Procedure

The investigation was conducted on high strength low alloy steel Table 1, provides chemical and mechanical specifications of the base metal. Weld beads were de-

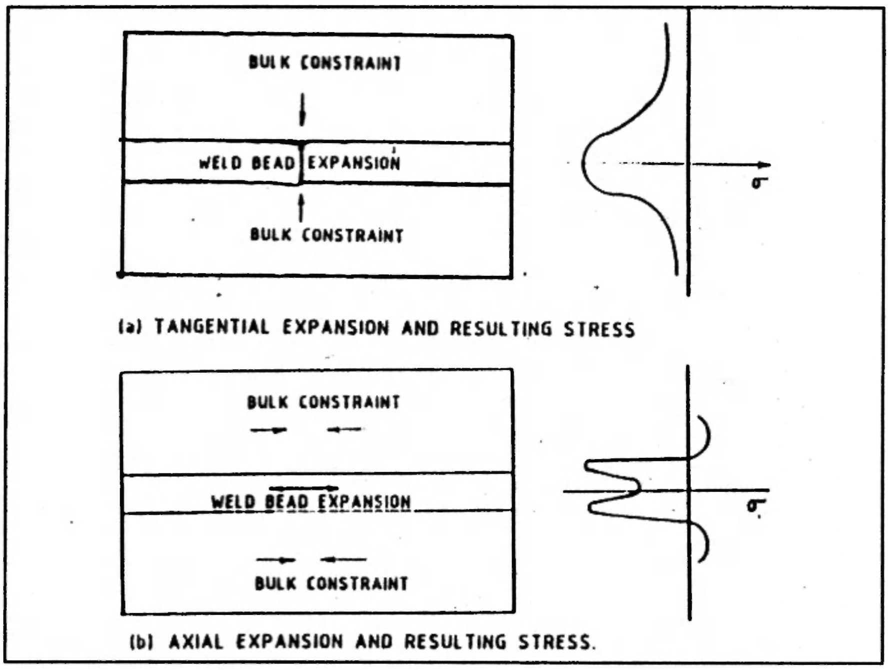

Fig 1 : Schematic representation of predicted transverse and axial residual stress due to bulk constraint to the expansion of the weld bead in the corresponding direction.

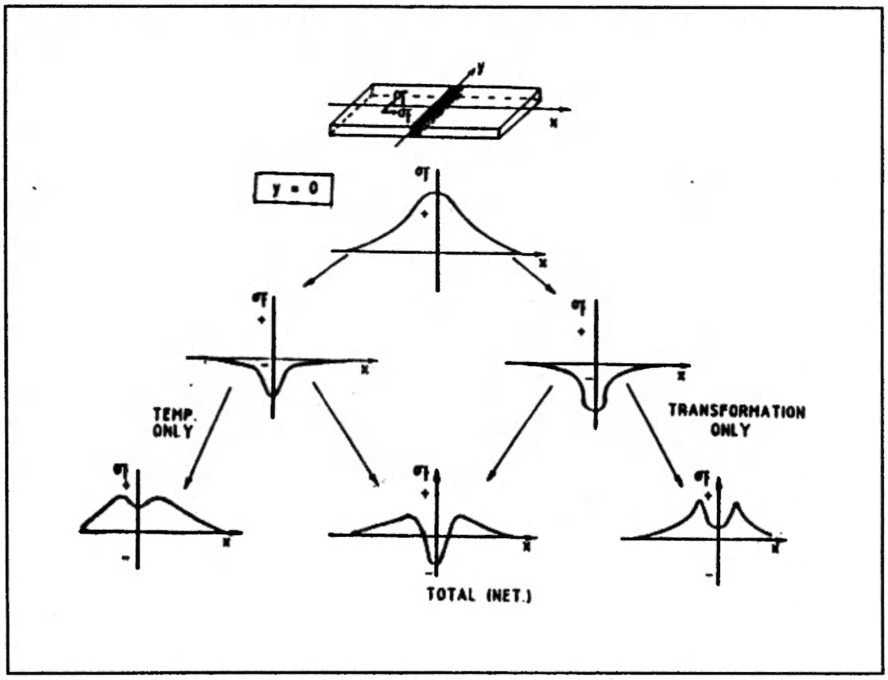

Fig 2 : Schematic illustration of transverse residual stress at the weld centreline caused by interaction of the shrinkage, quenching and transformation strains(7)'

Table 1 : Chemical and mechanical property specification of base metal

Chemical composition :

Element	C	Si	Mn	Cr	Mo	Zr	S	P
Wt%	0.3	0.55	0.75	0.78	0.27	0.08	0.01	0.015

Mechanical Properties :

Tensile strength (Kg/mm^2)	:	115
Yield strength (Kg/mm^2)	:	100
% slongation	:	7
CVN (kgm) at room temp	:	34

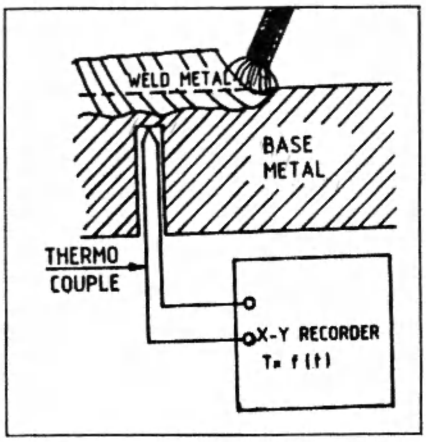

Fig 3 : Details of trhe thermal analysis set up for the measurement of HAZ transformation temperature.

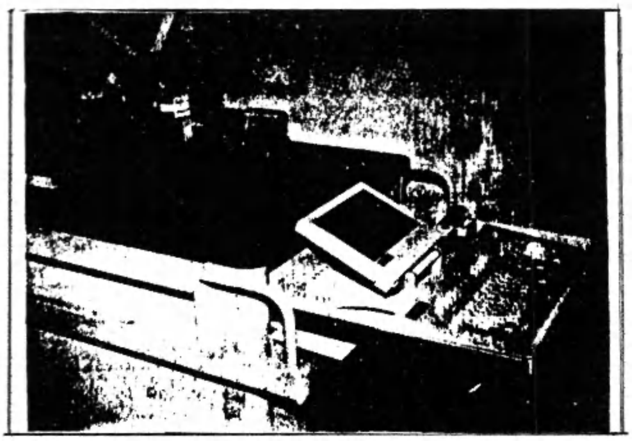

Fig 4a : X-Stress analyzer (Model No. X-2002) used in this investigation

posited using FCAW process. The welding parameters used for the bead on plate welds are shown in Table 2. The experimental technique used to get the weld thermal cycle under actual welding condition is shown in Figure 3. Preliminary bead on plate tests was conducted to determine the appropriate thermo couple position to produce a thermal analysis curve of the required sensitively. No external restraint was applied to the plates.

Stress Measurements

The residual stresses were measured by X-ray diffractometry. This technique while being entirely nondestructive, is widely used, particualrly for surface residual stress analysis. The X-ray technique measures stress indirectly by measuring the surface strain which is indicated by the position of a diffraction peak for crystal planes oriented at various angles to the surface of a specimen as described in detail in the literature(18). The stress is given by the gradient of a plot of the diffraction angle 20 against $\sin^2 \phi$, where ϕ is the angle between the diffracting planes and the specimen surface. In this study the measurement was performed by using the fast portable solid state X-ray camera AST model 2002. The X-ray stress analysis and the measurement set-up used is shown in Figure 4.

Fig 4b :Close up view of the geniometer

Cr K-alpha radiation was used to measure strains along (211) planes in steel. Each residual stress measurement was evaluated from at least seven measurements of lattice spacing spread over a range of orienta-

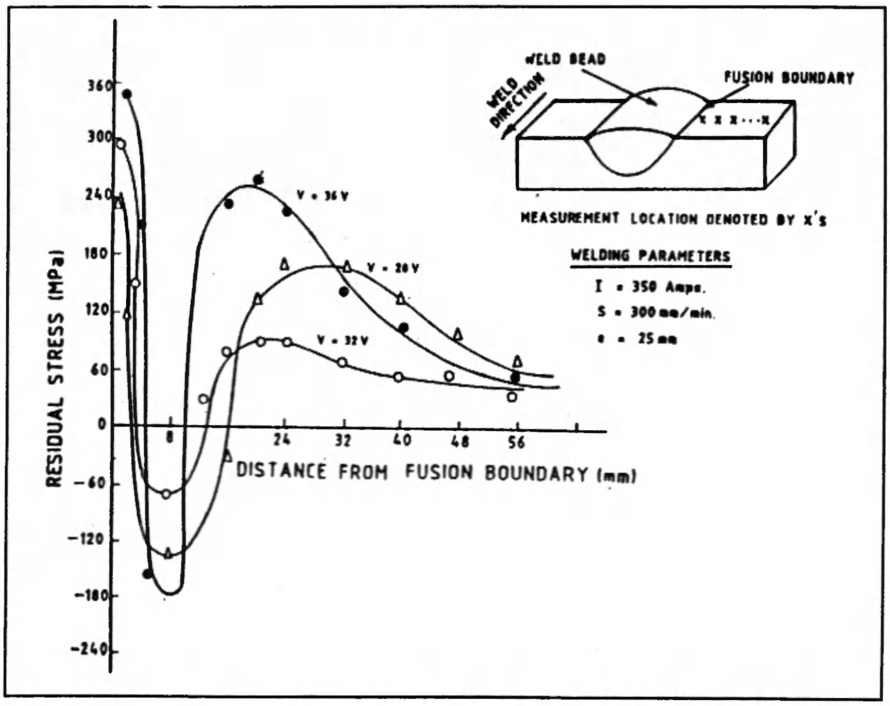

Fig 5 : Effect of arc-voltage on distribution of residual stress of right angles to the weld bead.

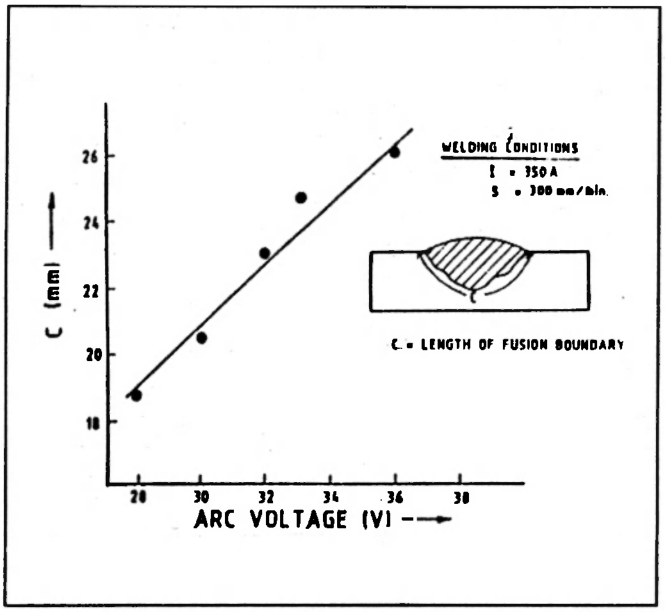

Fig 6 :Relation between arc voltage and length of gusion boundary

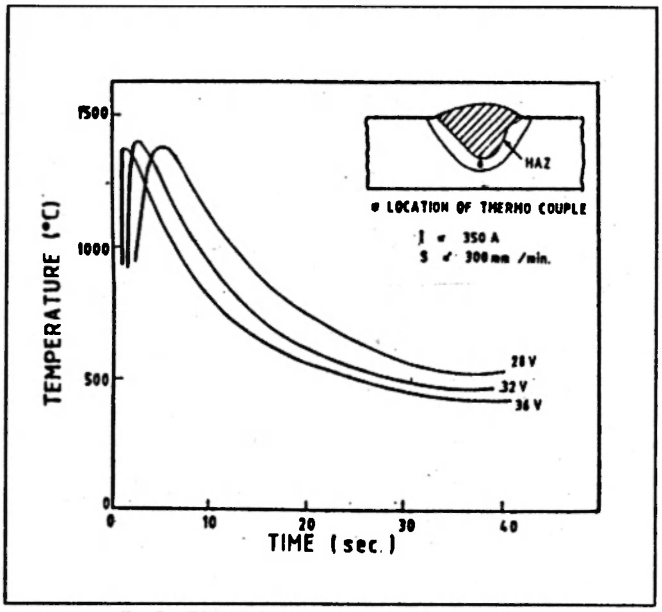

Fig 7 : Effect of arc voltage in thermal cycles.

tions to the surface of the specimen, the accuracy of stress measurements being approximately ±10 MPa. When some anisotropy was encountered., more measurements were done. In plates where the grain size influenced the measurements, the X-ray goniometer was oscillated by ±2°. For computation of the stresses from the measured strain data, appropriate X-ray elastic constants were used. The oxide layer present on the weld surface was mostly removed electrolytically followed by electrochemical polishing.

Results & Discussion

The residual stress pattern associated with welding in general shows tensile stresses of high magnitude in the weld region. This tapers off rapidly to become compressive in nature in HAZ, Beyond HAZ, the pattern approaches towards the stress value in the parent metal, unaffected by welding. The residual stress pattern varies in a complex manner, depending on a wide range of variables, including process parameters. The distribution of residual stresses at right angles to the weld bead in the vicinity of the weld with varying arc voltage, welding current and weld speed are shown in Figure 5,7,9. From the figures, it may be seen that the residual stress distribution curves are parabolic in nature. It appears that during arc welding, residual stresses of a relatively large magnitude are produced in the vicinity of the weld.

As can be seen from figure 5, maximum tensile residual stress in the HAZ has tendency to decrease with decrease in arc voltage and the width of compressive zone increases with a reduction in arc voltage from 36V to 28V. The residual stress distribution can be explained on the basis of cooling rate of the fusion and heat affected zone. Generally, steeper the cooling rate after welding, higher are the stresses to be expected. The arc voltage mainly determines the shape of the weld bead cross section and its external appreance. As the arc voltage is increased, bead width increases, but bead height decreases. Thus owing to its divergence, the arc is spread over a larger surface area, there by spreading the bead deposit over a wide area (2,17). The effect of this is, decreased heat input per unit length of fusion boundary (Q/C) with increased arc voltage as a result of increased fusion boundary length due to a wider cone of arc (Figure 6), This effect can be seen from the experimental data presented in Table 3. As a consequence of low Q/C, cooling rates would be high at higher voltages as can be seen from time temperature profiles (Figure 7).

The influence of the welding current on the magnitude and distribution of the stress is summarised in Figure 8. From the figure it is observed that the magnitude of residual stress decreases with increased welding current. This can be attributed to increase in Q/C with increased welding current. High value of Q/C results in low cooling rates. This leads to the observed low residual stresses at high welding current. Higher the heat input, lesser is the temperature difference experienced between the regions adjacent to the weld in the parent plate and the weldmetal. Consequently, the shrinkage variations are also less. Higher the shrinkage stress higher will be the magnitude of tensile stress. Further from figure it appears that the width of compressive zone increases with increasing in welding current from 200 A to 350 A. This result is likely due to a tempering effect caused by the heat retention in the weld zone.

In Figure 9 the effect of welding speed on residual stress distribution is presented. From the figure it may be seen with and increase in welding speed, the level of residual stress decreases. This can be attributed to high value of Q/C at high welding speeds(Table 3). At high welding speeds efficiency of energy by way of thermal conduction to the surrounding base metal (19). Thus under these conditions cooling rates are expected to be low at higher welding speeds.

CONCLUSIONS

The experimental data obtained from investigation lead to the following conclusions :-

The magnitude of the measured tensile residual stress near the weld (perpendicular to the direction of the weld) ranged from 140 Mpa to 360 Mpa.

Arc voltage has a significant effect on the magnitude of tensile residual stress. The minimum arc voltage of 28 V used in the present work provided the lowest tensile stress level.

The increasing welding current

Table 2 : Welding Parametres

Welding process	:	Flux coated arc welding
Filler wire	:	18Cr-8Ni-6Mn
Electrode extension(e)	:	25 mm
Preheat	:	None

Sl. No.	Speed (mm/min)	Voltage (Volts)	Current (amps)	Heat Input (KJ/mm)
1	300	36	350	2.52
2	300	32	350	2.24
3	300	28	350	1.96
4	300	32	250	1.6
5	400	28	350	1.47
6	450	28	350	1.3
7	300	32	200	1.28

Table 3 : Weld parametres-Heat input length of fusion boundary

Sl. No.	S	V	I	Q	C	Q/C
1	450	28	350	1.30	10	130
2	400	28	350	1.47	12	122.50
3	300	28	350	1.96	18.4	106.52
4	300	32	350	2.24	23	97.30
5	300	36	350	2.52	33	76.30
6	300	32	250	1.60	22	72.70
7	300	32	200	1.28	19	67.30

S = Welding speed (mm/min.)
V = Arc voltage (volts)
Q = Heat input (KJ/mm)
C = Fusion boundary length (mm)
Q/C = Heat input per unit length of fusion boundary (J/mm2)
I = Current (amp)

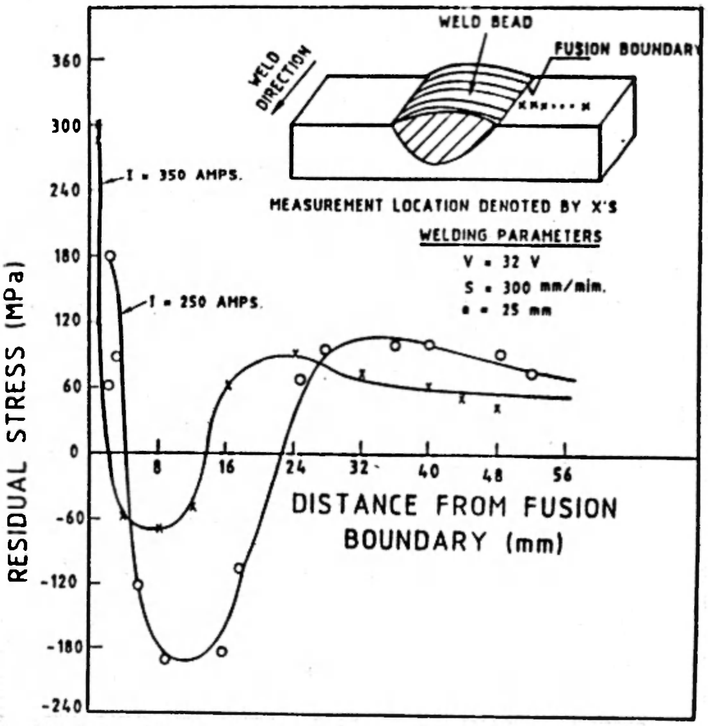

Fig 8 : Effect of welding current on distribution of residual stress at right angles to the weld bead and speed of welding causes a decrease in the magnitude of tensile residual stress. This is due to the heat input per unit length of fusion boundary (Q/C) increase with increasing welding current and welding speed.

The width of the compressive stress zone increases with increasing the Q/C.

The X-ray stress analyzer applied in this study provided a practical approach to the examination weldments.

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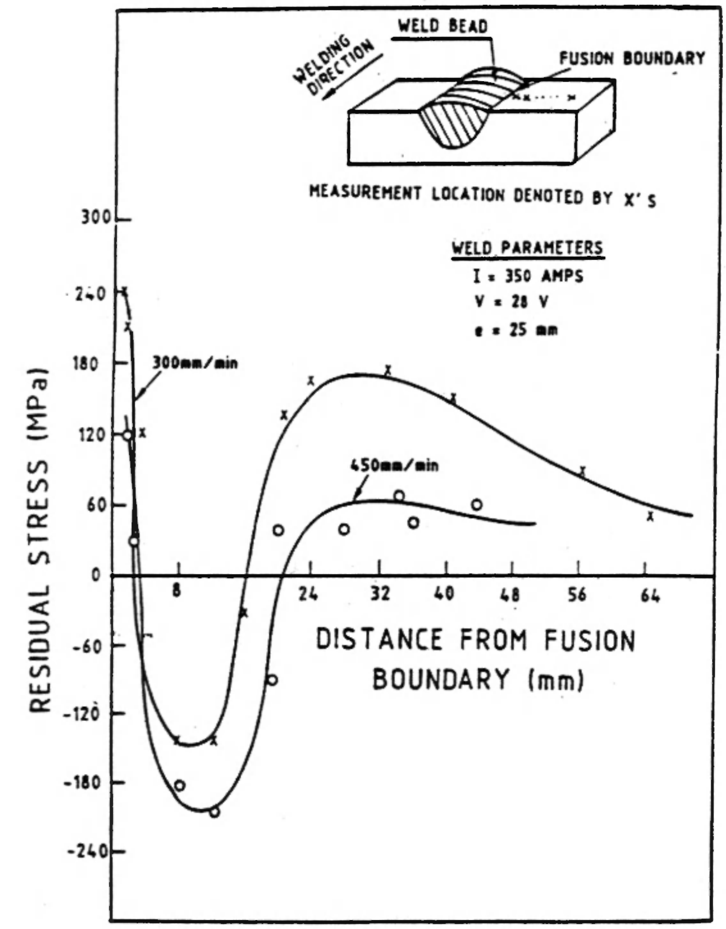

Fig 9 : Effect of welding speed on distribution of residual stress at right angles to the weld bead

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