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Effect Of Welding Conditions On Residual Stresses And Heat Source Distribution On Temperature Variations On Butt Welds : A Review

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ABSTRACT

Fusion welding is a joining process in which the coalescence of metals is accomplished by fusion. Owing to localized heating by the welding process and subsequent rapid cooling, residual stresses can arise in the weld itself and in the base metal. Residual stresses attributed to welding pose significant problems in the accurate fabrication of structures because those stresses heavily induce brittle fracturing and degrade the buckling strength of welded structures. Therefore, estimating the magnitude and distribution of welding residual stresses and characterizing the effects of certain welding conditions on the residual stresses are deemed necessary. The transient temperature distributions and temperature variations of the welded plates during welding were predicted and the fusion zone and heat affected zone were obtained.

Keyword: residual stresses , transient temperature history .

1.INTRODUCTION

Fusion welding is a joining process in which the coalescence of metals is achieved by fusion. This form of welding has been widely employed in fabricating structures such as ships, offshore structures, steel bridges, and pressure vessels. Owing to localized heating by the welding process and subsequent rapid cooling, residual stresses can arise in the weld itself and in the base metal. Such stresses are usually of yield point magnitude. Residual stresses attributed to welding pose significant problems in the accurate fabrication of structures because those stresses heavily induce brittle fracturing and degrade the buckling strength of welded structures.

Therefore, estimating the magnitude and distribution of welding residual stresses and characterizing the effects of certain welding conditions on the residual stresses are relevant tasks.

A metal inert gas (MIG) welding process consists of heating, melting and solidification of parent metals and a filler material in localized fusion zone by a transient heat source to form a joint between the parent metals. The heat source causes highly non-uniform temperature distributions across the joint and the parent metals.Therefore, the thermal expansion and contraction during heating and subsequently cooling as well as material plastic deformation at elevated temperatures result in inevitable distortions and residual stresses in the joint and the parent metals, which greatly affects the fabrication tolerance and quality.[5]

Residual stresses during welding are unavoidable and their effects on welded structures cannot be disregarded. Design and fabrication conditions, such as the structure thickness, joint design, welding conditions and welding sequence, must be altered so that the adverse effects of residual stresses can be reduced to acceptable levels. In this work, we predict the residual stresses during one-pass arc welding in a steel plate using ansys finite element techniques. The effects of travel speed, specimen size, external mechanical constraints and preheat on residual stresses are also discussed. [6]

2.SIMULATION OF PLATE BUT JOINT WELDING

Welding residual stress distribution is calculated by ansys finite element techniques. Theoretical considerations can be assessed either by a thermal or a mechanical model.

2.1. Governing equations

When a volume is bounded by an arbitrary surface S, the balance relation of the heat flow is expressed by

$$-\left(\frac{\delta R_X}{\delta x}+\frac{\delta R_Y}{\delta y}+\frac{\delta R_z}{\delta z}\right)+Q\left(x,y,z,t\right)$$
$$=\rho C\frac{\partial T(x,y,z,t)}{\partial t} \qquad (1)$$

Where R_X , R_Y , R_z are the rates of heat flow per unit area ,$T\left(x,y,z,t\right)$ is current temperature,

$Q(x,y,z,t)$ is rate of internal heat generation , ρ is density , C is specific heat and t is time .

The model can be completed by introducing the fourier heat flow as

$$R_X = -k_x \frac{\delta T}{\delta x} \qquad (2a)$$

$$R_Y = -k_y \frac{\delta T}{\delta y} \qquad (2b)$$

$$R_z = -k_z \frac{\delta T}{\delta z} \qquad (2c)$$

Where k_x, k_y, k_z are the thermal conductivities in the x,y,z directions respectively .

By considering that the process in the material non-linear,the parameters k_x, k_y, k_z, ρ, C are function of temperature .

Inserting eqns (2a),(2b),(2c) into eqn (1) yields

$$\frac{\delta}{\delta x}\left(k_x \frac{\delta T}{\delta x}\right) + \frac{\delta}{\delta y}\left(k_y \frac{\delta T}{\delta y}\right) + \frac{\delta}{\delta z}\left(k_z \frac{\delta T}{\delta z}\right) + Q = \rho C \frac{\delta T}{\delta t} \qquad (3)$$

Eqn (3) is the differential equation governing heat conduction in a solid body .The general solution is obtained by accepting the initial and boundry conditions .

initial condition

$$T(x,y,z,0) = T_0(x,y,z) \qquad (4)$$

Boundry condition

$$\frac{\delta}{\delta x}\left(k_x \frac{\delta T}{\delta x} N_x\right) + \frac{\delta}{\delta y}\left(k_y \frac{\delta T}{\delta y} N_y\right) + \frac{\delta}{\delta z}\left(k_z \frac{\delta T}{\delta z} N_z\right) + q_s + h_c(T - T_\infty) + h_r(T - T_r) = 0 \qquad (5)$$

Where N_x, N_y, N_z are direction cosines of the outward drawn normal to boundry , h_c is convection heat transfer coefficient, h_r is radiation heat transfer coefficient , q_s is boundry heat flux , T_∞ is surrounding temperature , T_r is temperature of radiation heat source.

The radiation heat transfer coefficient is expressed as

$$h_r = \sigma \varepsilon F(T^2 + T_r^{\,2})(T + T_r) \qquad (6)$$

In which σ is Stefan –Boltzmzn constant , ε is effective emissivity and F is configuration factor.

2.2 Material properties

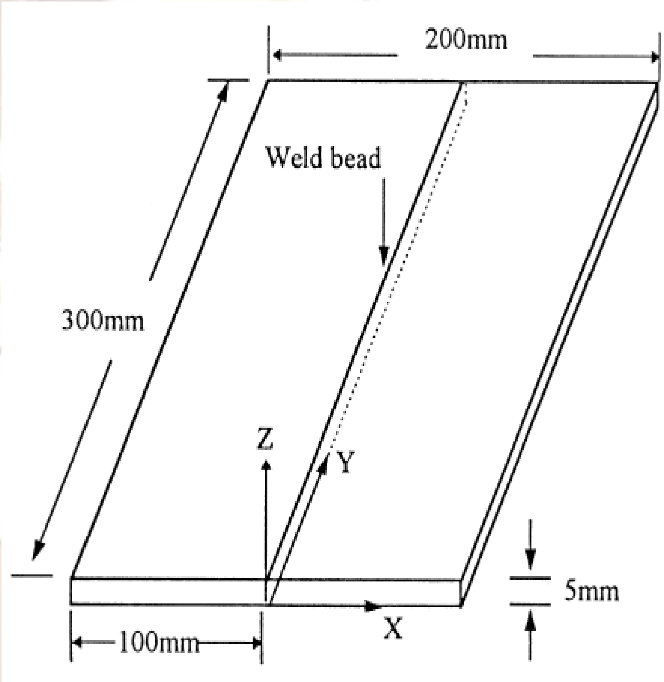
Since welding processes undergo a high temperature cycle and exhibit material properties that are temperaturedependant, the transient temperature can be calculated by an extrapolation method with a two-time interval as

$$T(\tau) = T(t - \Delta t) + \frac{\tau}{\Delta t}\left[T(t - \Delta t) - T(t - 2\Delta t)\right] \qquad (7)$$

Let g denote the temperature-dependent material coefficient, i.e. the function of $T(\tau)$. The material coefficient at time *t* can be expressed as

$$g = \frac{1}{\Delta t} \int_{t-\Delta t}^{t} g\left[T(\tau)\right] d\tau \qquad (8)$$

Fig.1.Geometry of butt-welded plates



2.3 Mechanical model analysis

Two basic sets of equations relating to the mechanical model, the equilibrium equations and the constitutive equations, are considered as follows.

(a) Equations of equilibrium

$$\sigma_{ij,j} + \rho b_i = 0 \qquad (9a)$$

And

$$\sigma_{ij} = \sigma_{ji} \qquad (9b)$$

where σ_{ij} is the stress tensor and *bi* is the body force.

(b) Constitutive equations for a thermal elasto-plastic material.

The thermal elasto-plastic material model, based on the von Mises yield criterion and the isotropic strain hardening rule, is considered. Stress–strain relations can be written as

$$[d\sigma]=\left[D^{ep}\right][d\varepsilon]-\left[C^{th}\right]dT \qquad (10)$$

And

$$\left[D^{ep}\right]=\left[D^{e}\right]+\left[D^{p}\right] \qquad (11)$$

Where $\left[D^{e}\right]$ elastic stiffness matrix , $\left[D^{p}\right]$ is plastic stiffness matrix , $\left[C^{th}\right]$ is thermal stiffness matrix , $d\varepsilon$ is strain increment and dT is the temperature increment.[6]

3. ESTIMATION OF WELDING RESIDUAL STRESSES

3.1.Analyzed model

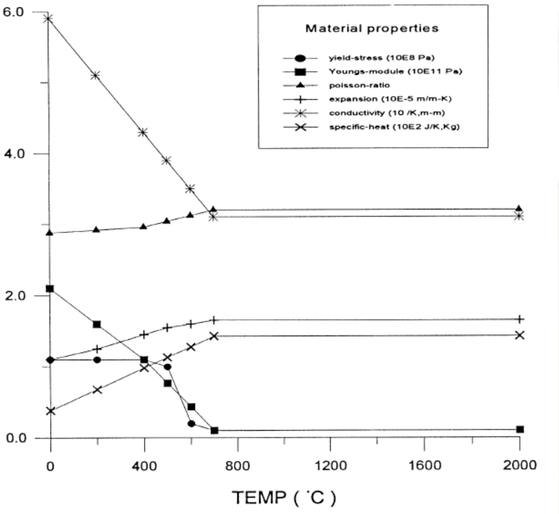


Fig.2 Mechanical properties of welded plates

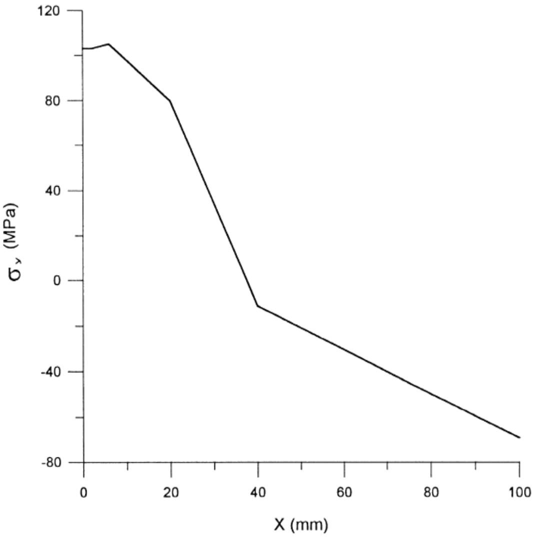
Fig. 1 depicts the specimen in this study. Analysis is performed on two long plates of 300 mm length and 100 mm width by butt welding. The magnitude of heat input is characterized by a welding current I . 110 A, voltage V . 20 V, welding speed v . 5 mm/s and the efficiency of heat-input Eff . 0.7. Fig.2 displays the material's thermal and mechanical properties.

Evaluating the three-dimensional residual stresses may require a considerable amount of computational time and cost. Herein, a two-dimensional axisymmetric model was designed to calculate the residual stress of the plate by the ansys finite element code. Four-node thermalstructure couple elements were also used .

3.2. Results and discussion

A stress acting parallel to the direction of the weld bead is known as a longitudinal stress, denoted by the term σ_x. Fig. 3 depicts the distributions of longitudinal residual stress along the x direction. High tensile stresses occur in regions near the weld due to a resistance contraction of the material as cooling commences. Also, for self-equilibrating purposes, compressive stresses occur in regions removed from the weld. The maximum stress value is as high as the material's yield stress.

Fig.3.The longitudinal stress along X direction



A stress acting normal to the direction of the weld bead, is known as a transverse stress, denoted by the term σ_x.Fig.4 illustrates the distributions of transverse residual stress σ_x along the y direction. at the middle of the plate, and the compressive stresses occur at the ends of the weld.

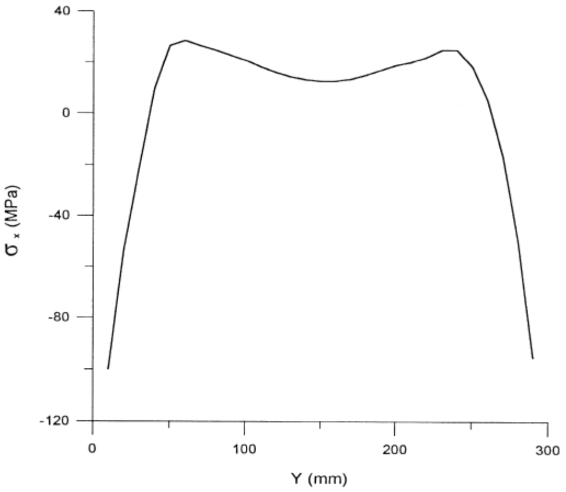


Fig.4.The transerverse stress along y direction

4. THE EFFECT OF WELDING CONDITIONS CONDITIONS ON RESIDUAL STRESSES

In welded structures, reducing the residual stresses during an early stage of design and fabrication is of priority concern. For this reason, the effects of certain welding conditions on the residual stresses are characterized in the following.

4.1. Effects of specimen length

A butt-welded plate joint of thin plate is considered as a model for analysis under the welding conditions mentioned earlier. The specimen's width is assumed to be 200 mm, and the length of specimen varies as 50 mm, 100 mm, 200 mm and 400 mm. Fig. 5 summarizes the effect of specimen length on transverse residual stresses. This figure indicates that the transverse residual stresses are tensile in the central areas and compressive in the areas near the plate ends. Notably, the high tensile stresses in the central region decrease with increasing length of the specimen.

4.2. Effects of specimen thickness

Welds were made with some heat input. Fig. 6 presents the distributions of longitudinal residual stresses at the top surface with various specimen thicknesses, i.e. 5 mm, 8 mm, 12 mm, in the weld metal of a butt joint.

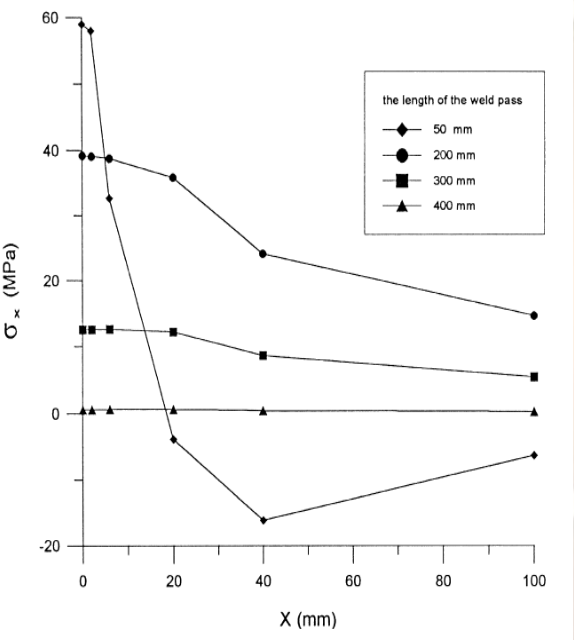


Fig.5. The effect of specimen length on transerverse residual stresses

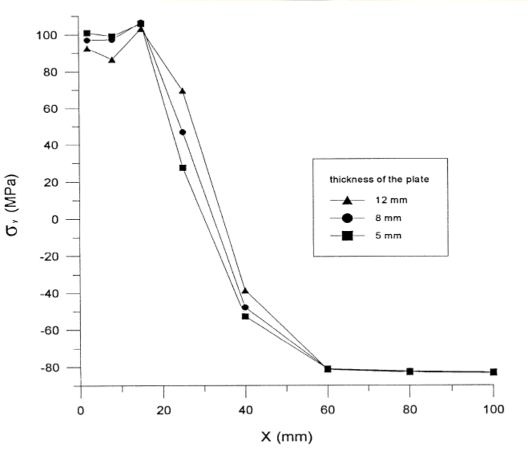


Fig.6.effect of specimen thickness on Longitudinal residual stresses

The tensile stress always appears only in the areas near the fusion zone. The fact that the absorption energy per unit volume in a thin weldment exceeds that in thick ones accounts for why the residual stresses increased with decreasing specimen thickness .

4.3 Effects of travel speed

Approximately the same weld size was produced with various travel speeds of 3.33 mm/s, 7 mm/s and 10 mm/s. A higher welding speed not only reduces the amount of adjacent material affected by the heat of the arc, but also progressively decreases the residual stresses, as shown in Fig. 7.

The important difference lies in the fact that the higher speed welding technique produced a slightly narrower isotherm. This isotherm's width influences the transverse shrinkage of butt welds, accounting for why faster welding speeds generally result in less residual stresses.

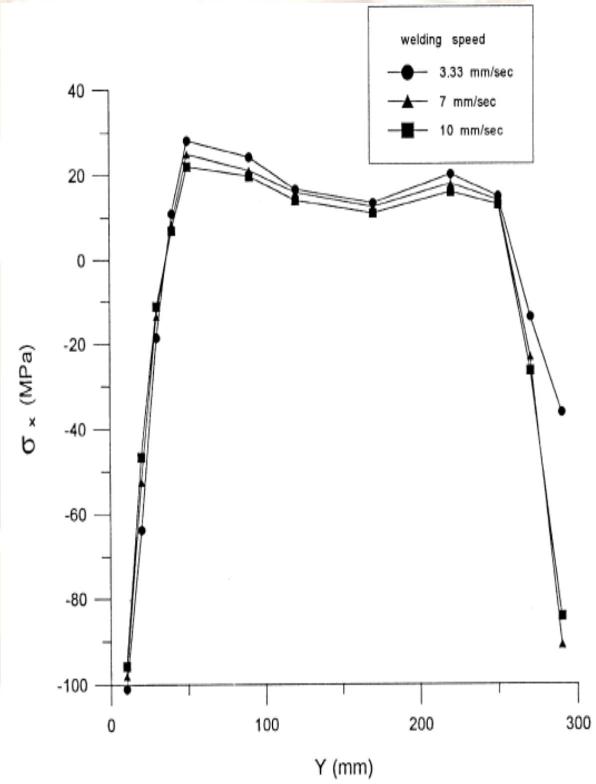


Fig.7. The effect of travel speed on transerverse residual stresses

4.4. Effects of external mechanical constraints

The thermal and mechanical behavior of weldments could be readily manipulated through external constraints. For a circumstance in which the lateral contraction of the joint is restrained by an external constraint, Fig. 8 depicts the distribution of transverse residual stresses. Moreover, the fact that the degree of the transverse shrinkage of a restrained joint is reduced accounts for why the magnitude of the residual stresses with a restrained joint is larger than that estimated with an unrestrained joint.

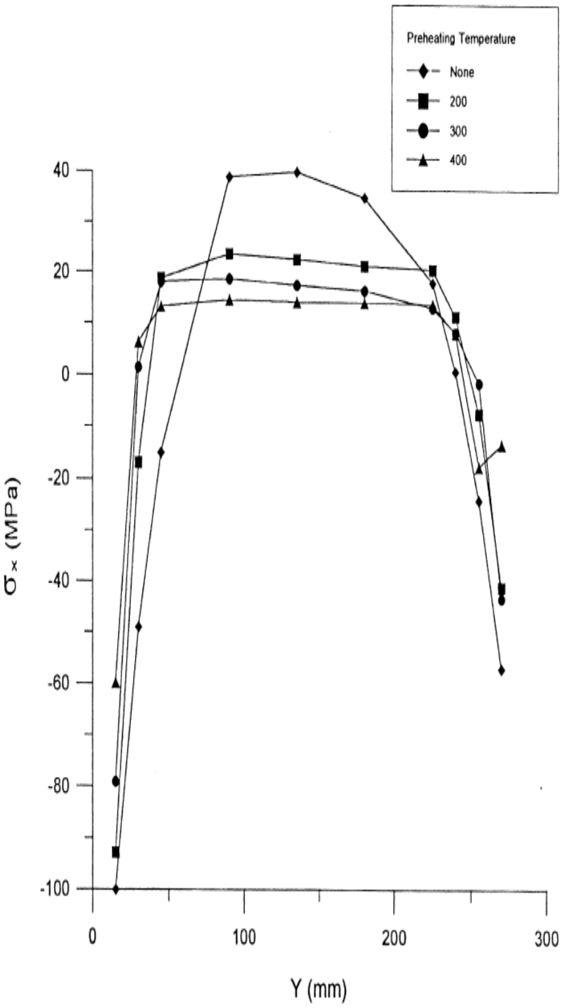


Fig.8.The effect of mechanical constraint on transerverse residual stresses

4.5. Effects of preheating

The residual stresses depend on the final equilibrium temperature of the temperature–stress cycle.Preheating treatments are used primarily to influence the time at temperature and cooling rates within the weldment, thereby reducing the residual stresses. Herein, the specimen was preheated homogeneously up to 200^{0}C, 300^0 C and 400^0 C. Fig. 9 summarizes those results and shows that transverse residual stresses significantly reduce after applying the preheating treatment.

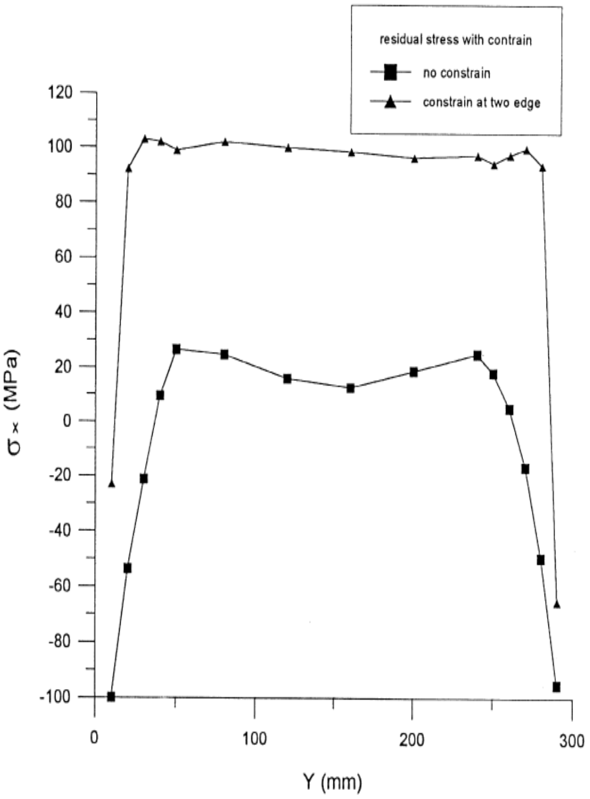


Fig.9.The effect of preheating on transerverse residual stresses

4.6. Effects of heat source parameters on temperature

Variations of the heat source distribution and magnitude affect the shape and boundaries of FZ and HAZ . The fusion zone has been decreased when the parameters have been increased, representing lower values of peak heat fluxes applied on the plate. It also causes obvious changes of peak temperatures in FZ and has a noticeable effect on temperature distributions in the areas close to HAZ (Fig. 10). The temperature decreases are non-linear with the increase of the heat source parameters of *a*, *b*, *c*f and *c*r. There is a greater temperature change when *a* = *b* = *c*f are increased from 5 to 6mmthan that they are increased from 4 to 5 mm. It shows that peak temperatures and temperature distributionsare sensitive to small changes of heat source distributions.[5,6]

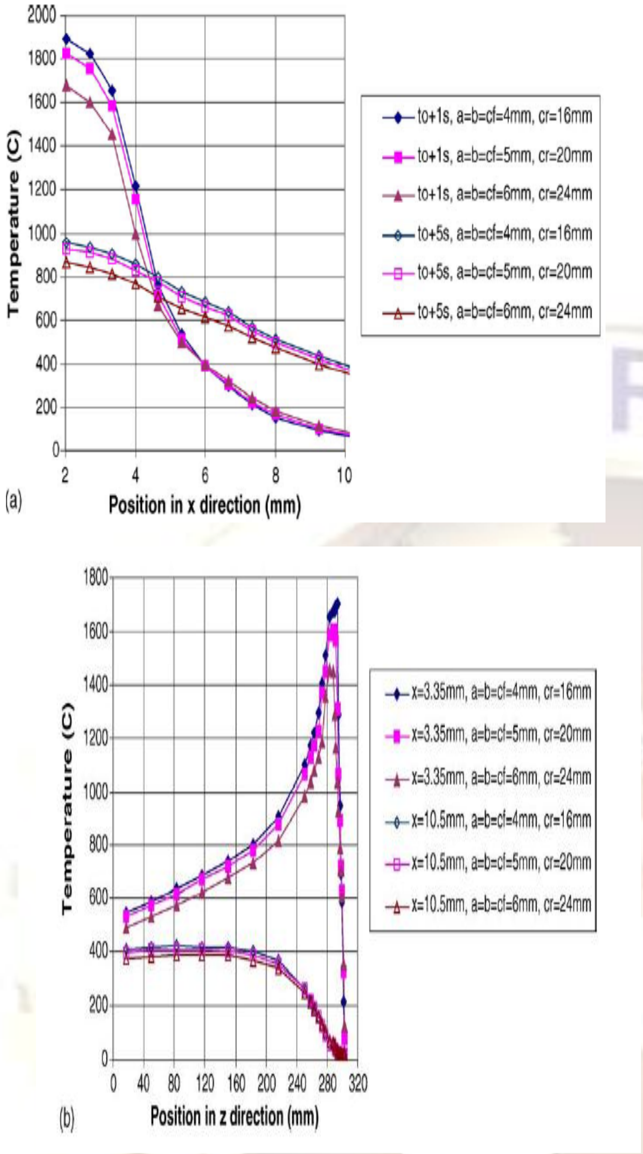


Fig. 10. Effects of heat source parameters on temperature: (a) along transverse direction and (b) along longitudinal direction.

5. CONCLUSIONS

1. For the residual stresses distribution in a butt weld, the middle weld bead is in tension and the magnitude of this stress equals the yield stress. The ends of the weld are in compression.
2. The peak transverse residual stresses in the central region decrease with an increasing specimen length.
3. The tensile residual stresses in the region near the fusion zone increase with a decreasing specimen thickness.
4. A higher welding speed reduces the amount ofadjacent material affected by the heat of the arc and progressively decreases the residual stresses.
5. The magnitude of the residual stresses with a restrained joint is larger than that estimated with an unrestrained joint.
6. Owing to the preheating treatment, the weldment significantly reduces the residual stresses .

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