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Numerical Analysis of Effect of Process Parameters on Residual Stress in a Double Side TIG Welded Low Carbon Steel Plate

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ABSTRACT:*A 3D thermo-mechanical simulation model was developed to predict distribution of temperature and residual stresses during Tungsten Inert Gas (TIG) double-side arc welding (DSAW) process on a low carbon steel plate. An uncoupled thermal–mechanical finite element analysis is performed using ANSYS. In this study the effects of welding process parameters (welding speed and welding current) in the symmetrical and asymmetrical double-side TIG welding process were investigated. The simulated results show that the residual stresses are tensile at the weld pool region and as the distance from the weld line increase it tends to compressive. Also found that welding process parameters in welded structures are the most influential parameter for the occurrence and control of residual stresses.*

Keywords: Double side TIG welding, Finite element analysis, Residual stress

I. NTRODUCTION

TIG welding has been used in nuclear, aerospace, marine and high-pressure vessel applications. In the manual double-torch double-side TIG welding process consist of two welding torches simultaneously and respectively initiate arc and weld at the front side and the reverse side of joints to be welded. The advantages of double-torch double side arc welding (DSAW) are symmetrical weld with little or no angular distortion of the material and complete joint penetration with a fairly narrow weld, as there is a heat source on both surfaces of the metal. DSAW can produce both sides of the weld can have the same high quality surface appearance.

The DSAW process was developed [1] by Y. M. Zhang and S. B. Zhang in 1999.Y. Kwon et al. [2] developed an analytical thermal model of double sided arc welding (DSAW) using separate Gaussian distributed arc heat sources from a plasma arc welding (PAW) and gas tungsten arc welding torch on the top and bottom surfaces of the sheets.H.J. Zhanget al. [3] developed an asymmetrical two sided gas tungsten arc welding with wire feed in vertical up welding method for thick plates. Radaj [4] performedthe FE analyses in two steps first thermal analysis then followed by the mechanical analysis. Deng et al. [5] developed an uncoupled thermal mechanical three-dimensional finite element model (FEM) to investigate the residual stress and deformation in low carbon and medium carbon steels welded by TIG welding process. Joy Varghese V M et al. [6] presented a finite element model using ANSYS to predict the thermal distribution during spot welding of low carbon steel plate.

Here a modeling and simulation methodology that enabled the prediction of residual stresses, in a double-side TIG welding process is developed without considering micro structural developments such as grain evolution or grain boundary liquation. Here welding process parameters such as welding current and welding speed are varied to analyze the effect of these parameters on residual stress developed during double-torch double-sided TIG welding process.

II. FINITE ELEMENT ANALYSIS

An uncoupled thermal and structural finite element analyses were performed in ANSYS to calculate residual stresses. First thermal analysis is performed to acquire the temperature history during the welding process. Then mechanical analysis is performed using the temperature loads based on the previous thermal analysis. In structural analysis nodal temperature obtained from the thermal analysis are applied as thermal load for calculating the thermal stress.

Two plates made of low carbon steel are welded together using double-torch double-sided TIG welding process without use of filler material. The plate's dimensions are 100×50×8mm. Due to the symmetry only one half of the plate is modeled. Fig.1. shows a symmetric half finite element model used for the analyses and temperature-dependent thermal and mechanical properties of low carbon steel used in this analysis [6] are as shown in Fig.2.

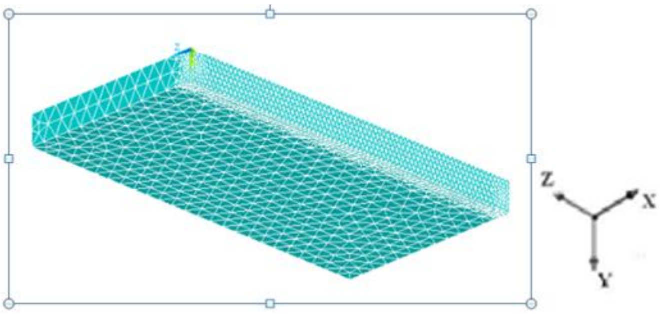
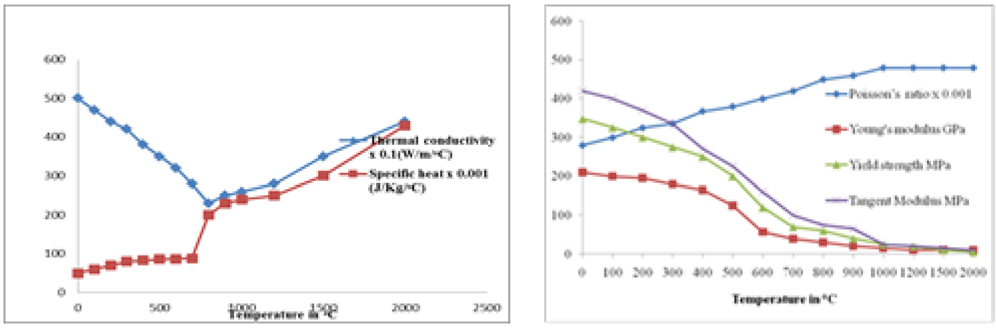


Fig.1. 3D Finite element mesh model



(a) (b)

Fig.2. (a) Thermal properties and (b) Mechanical properties

2.1 Thermal analysis

The three-dimensional 20 node brick elements were used for the thermal analysis. Using ANSYS preprocessor a fine mesh is generated at the weld line and comparatively coarse mesh used in areas away from weld line.

In this study, the heat from the moving welding arc is applied as a volumetric heat source with a double ellipsoidal distribution as proposed by Goldak et al. [7] and it is expressed as;

$$Q(x,y,z,t) = \frac{6\sqrt{3} f\eta VI}{abc\pi\sqrt{\pi}} e^{\left[-3\left(\frac{x+vt}{c}\right)^2 - 3\left(\frac{y}{b}\right)^2 - 3\left(\frac{z}{a}\right)^2\right]} \quad (1)$$

The schematic diagram of moving heat source is shown in in Fig.4. The double-torch DSAW process has two separate heat sources, one acting on the top surface and one on the bottom surface of the plate. The Goldak equation is modified to accommodate the bottom torch as

$$Q(x,y,z,t) = \frac{6\sqrt{3} f\eta VI}{abc\pi\sqrt{\pi}} e^{\left[-3\left(\frac{x+vt}{c}\right)^2 - 3\left(\frac{y-d}{b}\right)^2 - 3\left(\frac{z}{a}\right)^2\right]} \quad (2)$$

Where x, y and z are the local coordinates of the double ellipsoid model. f is the fraction of heat deposited in the weld region and η is the arc efficiency for the TIG welding process. V and I are the applied voltage and current, v is the speed of torch travel in mms-1, d is the thickness of the plate and t is the time in seconds. The parameters a, b and c are related to the characteristics of the welding heat source. The parameters of the heat source are chosen for this study is shown in table 1 as proposed by Goldak et al. [7].

Gaussian distributed heat sources as described by equation (1) & (2) were assumed to move over the top and bottom surfaces of the solid in the x direction with the welding speed v.

Table 1
Numerical values for heat source parameters.

Heat source parameters (fixed for all studies)			
Parameter	a	b	c

value	0.004	0.003	0.005

To consider the heat losses on the weld surface, both the thermal radiation and convective heat transfer are considered. To accommodate these losses a combined convection and radiation temperature-dependent heat transfer coefficient is used as proposed by Goldak et al. [7];

$$H = 24.1 \times 10^{-4} \times \varepsilon \times T^{1.61} \quad (3)$$

Where ε is the emissivity of the body surface which is taken as 0.8 and T is the temperature of the material surface. The solidification and melting temperatures are 1415ºC, and 1477ºC and the latent heat of 285000J/kg and were incorporated in the material model by increasing the specific heat at the melting temperature.

2.2 Mechanical analysis

Mechanical analysis is carried out for the same plates but the three-dimensional structural brick elements were used for the mechanical model. In the mechanical analysis, the temperature load histories obtained from the thermal analysis were used as thermal loads in the structural model. The temperature dependents mechanical properties of the material were used.

No constraints used in the welding process but in mechanical boundary condition is all displacement equals to zero at both ends of the plates.

During the welding process solid state phase transformation does not occur and also the total strain rate can be decomposed into three components as follows [6].

$$\varepsilon = \varepsilon_e + \varepsilon_p + \varepsilon_{th} \quad (4)$$

Where ε is the total strain produced, ε_e is the elastic strain, $\varepsilon_p$is the plastic strain and ε_{th} is the thermal strain. The elastic strain is modeled by using the isotropic Hook's law with temperature

III. RESULTS AND DISCUSSIONS

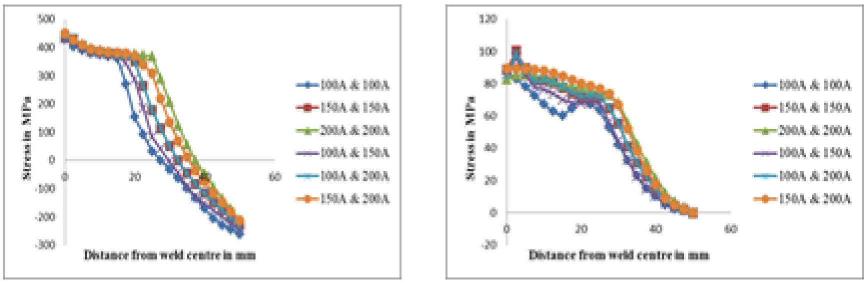
3.1 Residual Stress Distributions

3.1.1 Effect of Welding Current

In this study current of both TIG torches are symmetrically and asymmetrically varied. In symmetrical DSAW both torches are having same currents and in asymmetrical DSAW both torches are having different currents.

The longitudinal and transverse stress distributions are measured along the Z-direction 4mm below the top surface of the weld.

Fig.3. represents the residual distributions along longitudinal and transverse directions.It is seen that the longitudinal stress are tensile at the weld pool region and tends to compressive as the distance from the weld line increases. The plots of transverse residual stress are tensile all over the plate, but it is much lower than that of longitudinal stress.



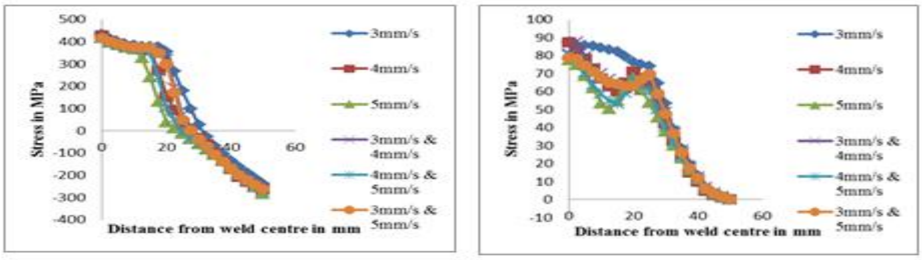
(a) (b)

Fig.3. Residual stress distributions for various welding currents in a double side TIG welded low carbon steel plate. (a) longitudinal and (b) transverse.

3.2.2 EFECT OF WELDING SPEED

In this study both TIG torches are moving symmetrically and asymmetrically. In symmetrical DSAW both torches moving at same speed and in asymmetrical DSAW both torches moving at different speed. The welding current used is 100A in all speeds.

In the asymmetrical DSAW process second heat cycle induced by fore pass can be regarded as a post heat action to the rear pass. Similarly, rear pass provides the fore pass with a preheat action. So the preheating and post heating reduces the temperature gradient of weld. These thermal interactions of two arcs affect not only the size of heat-affected zone, but also peak temperature and the rate of heating and cooling, which can be related to the instantaneous gradient of temperature in the plates. Fore pass TIG post heating provides the rear pass with a second thermal cycle and reduces the temperature gradient. Rear pass TIG preheating increases the maximum peak temperature and also reduces the temperature gradient of fore pass.



(a) (b)

Fig.4. Residual stress distributions for various welding speeds in a double side TIG welded low carbon steel plate. (a) longitudinal and (b) transverse.

From the Fig.4, it is seen that the longitudinal stress are tensile in nature at the weld pool region and as the distance from the weld line increase it tends to compressive. Similar plots are obtained in all cases. The transverse residual stresses are tensile and much lower than that of longitudinal stress.

IV. CONCLUSION

A 3D FE model is developed to analyze the effect of process parameters on residual stress in a double side TIG welding process. Some important findings are achieved in numerical simulation and shown in below:

1. A 3D thermo-mechanical model of the double side TIG welding process was developed Using FEM that includes two Gaussian distributed arcs on the top and bottom surfaces.
2. The longitudinal & transverse stress distributions are measured along the transverse line which is 4mm below the top surface of the weld. It is seen that the longitudinal stress are tensile at the weld pool region and as the distance from the weld line increase it tends to compressive. The transverse residual stress is tensile all over the plate, but it's much lower than that of longitudinal stress.
3. A parametric study on process variables such as welding current and welding speed were performed and its effects on residual stress were measured using FEM.
4. Currents variations affect the total heat input per unit volume and directly influence the temperature distributions and consequently the residual stress profiles in the weld plate.
5. The speed variation of top and bottom torches causes preheating and post heating effects on the weld plate.

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