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Numerical studies on effect of interpass time on distortion and residual stresses in multipass welding

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Abstract: Weld distortion and residual stresses are two major issues in the fabrication process. Numerical techniques are being tried out to accurately predict the structural integrity of the welding. Interpass time in the multipass welding is an important parameter which influences the weld distortion and residual stresses. In this study two pass tungsten inert gas (TIG) welding of 6 mm mild steel plates has been analyzed using Finite element analysis (FEA) software Sysweld and parametric study is conducted with different interpass time. The temperature distribution, distortion and residual stresses are calculated using three dimensional finite element model (FEM) considering phase transformations in the material. The transient thermo-metallurgical analysis followed by elasto-plastic analysis is carried out using temperature dependent and phase dependent material properties. The material deposition in the multipass welding is numerically simulated using *chewing gum method*, where dummy phase and dummy material are assigned for the element activation. The phase proportions are calculated by assigning suitable phase kinetics parameter extracted from continuous cooling transformation (CCT) diagram of a given material. Experiments are conducted for validation after given edge preparation and using same material as filler wire. The FEM analysis is carried out for eight cases with different time interval between passes, starting from 30 s to 240 s in the steps of 30 s. FEM results are verified with experimentally measured values. It is found that the time interval between passes has less influence on the residual stresses but significantly affects the distortion and phase proportion due to the first pass preheating effect on second pass and second pass postheating effect on first pass.

Introduction

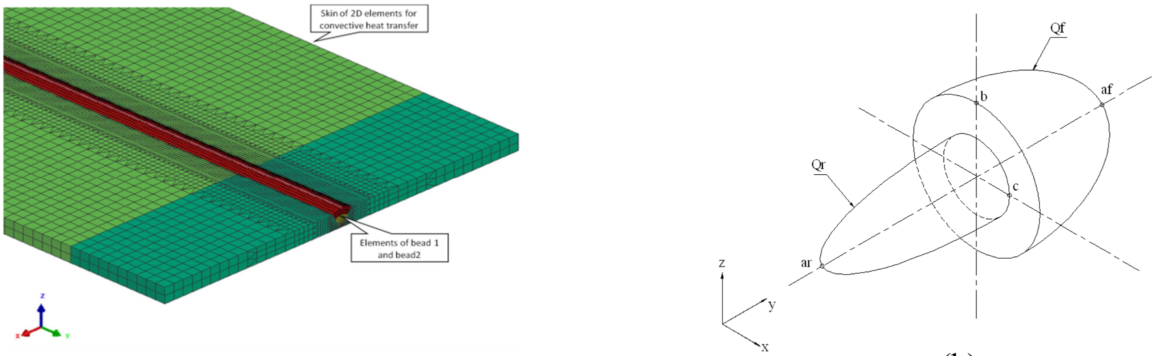
Finite element method is now a widely used tool in the product design and development. Its application in the manufacturing processes is a relatively new field. Industry is constantly looking towards improved productivity and quality as it is essential to optimize the design and process parameters. Welding is an important fabrication process whose study is paramount to ensure the integrity of the mechanical structures. Interpass time and interpass temperature are parameters which influence the weld distortion, residual stresses and affect the productivity of the fabrication process. If interpass time is reduced first pass has preheating effect on second pass and second pass has postweld heating effect on first pass.

Zhang et al. [1] used asymmetrical double-sided double arc welding to control the angular distortion. They studied influence of distance between two arcs on the distortion and found that the relationship between these two parameters is nonlinear. Brickstad and Josefson [2] studied the variation of axial and hoop stresses and their sensitivity to weld parameters such as pipe thickness, weld pass, net heat input, interpass temperature. They found that lower interpass temperature has less effect on residual stresses but higher interpass temperature can significantly influence the results. Amuda et al. [3] investigated the effect of interpass time and number of weld pass on the variations of hardness in the fusion zone (FZ) and heat affected zone (HAZ). It was found that the hardness in FZ and HAZ decreases as both the number of weld passes and interpass time increases because of tempering effect of subsequent passes.

Lee and Chang [4] conducted finite element analysis of high carbon steel multipass butt weld considering solid state phase transformation. It was concluded that volumetric increase during austenite to martensite phase transformation reduces longitudinal tensile residual stresses in the weld region and heat affected zone. Becker et al. [5] attempted to predict phase transformation, phase dependent material properties and residual stresses using experimentally determined CCT diagrams. Warren et al. [6] showed that inclusion of phase transformation significantly affects the predicted residual stresses in ferritic materials in the area close to weld zone and not so pronounced in the area adjacent to heat affected zone. In the present study, the influence of interpass time in multipass welding is investigated for a two pass TIG welding of mild steel using 3D finite element model. The transient thermo - metallurgical - mechanical analysis is carried out with different time gap between the two passes, starting from 30 s to 240 s in the steps of 30 s. The transient temperature distribution, longitudinal and transverse distortion, phase proportions and residual stresses are calculated for each case and plotted along with one case of experimental results.

Finite element model

A finite element mesh of two plates of 300 x 75 x 6 mm is shown in Fig. 1(a). The model has a fine mesh near the weld zone and a coarse mesh away from it. Meshed groups are created for two weld bead, path and direction of weld and a skin of 2D elements for convective heat transfer between workpiece to surrounding. Thermal properties conductivity, specific heat, density and mechanical properties Young's modulus, Poisson's ratio, thermal strain, yield strength and strain hardening are considered for a temperature range of 20 ^{o}C to 1500 ^{o}C. The material properties specified are at different temperature as well as for different phases of steel ferrite, bainite, martensite and austenite. The moving heat source is modeled using Goldak double ellipsoidal model as the process under study is tungsten inert gas (TIG) welding which is a slow speed process and double ellipsoidal model is most suitable for it [7]. The following Goldak parameters shown in Fig. 1(b) are assumed in this study: a_f = 4 mm; a_r = 7 mm; b = 4 mm and c= 3 mm. The values of Q_f and Q_r are front and rear heat source intensity in W/mm^3, are calculated using equation Q=ηVI and adjusted in proportion to match with the size and shape of molten zone.



(a) (b)

Figure 1: (a) Meshed Model, (b) Goldak double ellipsoidal heat source model

Filler material is modeled using a 'chewing gum method' [8], where elements of two beads are assigned dummy phase and dummy material whose thermal conductivity and stiffness values are assumed to be low. During the simulation of first pass, elements of first pass weld bead are assumed to be dummy phase, which get activated only if their nodal temperature value reaches more than melting point temperature of the material. During the simulation of first pass, elements of second pass weld bead are assumed to be dummy material and due to their low thermal conductivity and low Young's modulus they don't contribute in the computations. Finite element analysis is carried out in two stages, first thermo-metallurgical analysis in which transient nodal temperatures and phase proportions are calculated. This is followed by elasto-plastic mechanical analysis in which distortion and residual stresses are calculated using nodal temperature as input load. Thermo-metallurgical analysis uses temperature and phase dependent material properties conductivity, specific heat and density. The governing differential equation for heat conduction is given in Eqn.(1). The initial and boundary conditions for the model are initial nodal temperature is assumed to be ambient temperature and convective heat transfer is applied over the entire outer boundary of the model.

$$\frac{\partial}{\partial(x)}\left[k_x \frac{\partial T}{\partial x}\right] + \frac{\partial}{\partial(y)}\left[k_y \frac{\partial T}{\partial y}\right] + \frac{\partial}{\partial(z)}\left[k_z \frac{\partial T}{\partial z}\right] + q_{sup} = \rho c \frac{\partial T}{\partial t} \quad (1)$$

The solid state phase transformation effects are considered by including the phase dependent material properties as well as phase transformation kinetic models. The diffusion based phase transformations such as austenite to bainite are modeled using Leblond model (Eqn. 2). The diffusion less transformation such as austenite to martensite is modeled using Koinstinen Marburger (KM) model (Eqn. 3).

$$\frac{dP(T)}{dt} = f(\dot{T})\frac{P_{eq}(T)-P(T)}{\tau(T)} \quad (2)$$

$$P(T) = 1 - \exp(-b(M_s - T) \quad (3)$$

Elasto-plastic mechanical analysis is conducted considering large deformation and by using temperature as well as phase dependent material properties such as Young's modulus, Poisson's ratio, thermal strain, yield strength and stain hardening. Mechanical analysis uses the nodal temperature and phase proportion values calculated earlier as load input. The analysis is performed assuming strain hardening behavior as isotropic hardening and considering the large displacement theory. The boundary conditions applied are enough to arrest the rigid body motion, similarly in experimental procedure welding is done without any clamping. In mechanical analysis the results are computed by simultaneously considering variations of mechanical properties with temperature and thermal expansion or contraction due to phase transformation. There is significant influence of metallurgical structure and phase proportions on the mechanical properties. Especially, yield strength (Eqn. 4)and the thermal strains (Eqn. 5) are calculated as an average of individual phases, with a law of linear weighting.

$$\sigma_y^{\alpha}(\theta) = \sum P_i \sigma_i^{\alpha}(\theta) \quad (4)$$

$$\varepsilon^{th}(P,\theta) = \sum P_i \varepsilon_i^{th}(\theta) \quad (5)$$

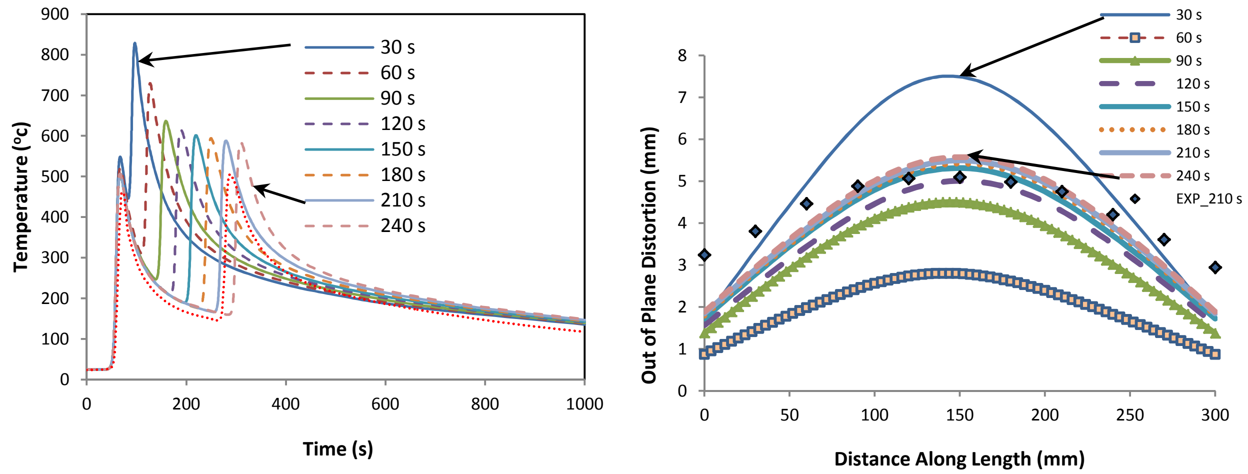
Two sets of thermal strains for ferritic and austenitic phase are estimated using dilatometric tests. Transformation plasticity which relates the difference of volume between the various phases is also included, which is the occurrence of plastic flow of weaker phase in the presence of stronger phase even when external stress is absent. The total strain which is sum of all the stains is given in Eqn. (6).

$$\varepsilon = \varepsilon^{e} + \varepsilon^{th} + \varepsilon^{pc} + \varepsilon^{tp} \quad (6)$$

Experiments are conducted to validate the FEM results with a interpass time of 210 s. The plate edges are milled for 30^o and 2 mm holes are drilled for fixing thermocouples. Two pass TIG welding is carried out with V=15 V, I=170 A, weld speed v=2.5 mm/s and using filler wires of same material. The temperature values are measured at a point 10 mm away from weldline, on both sides of weld using k-type thermocouple and National Instruments (NI) data acquisition system (DAQ). The out of plane distortion is measured along free edge on plate in the longitudinal direction and along mid-length of plate in the transverse direction using dial-gauge indicator whose least count is 0.01 mm. The computed distortion values are generally symmetric and therefore in experimental measurements the datum is set to ensure this symmetry of distortion.

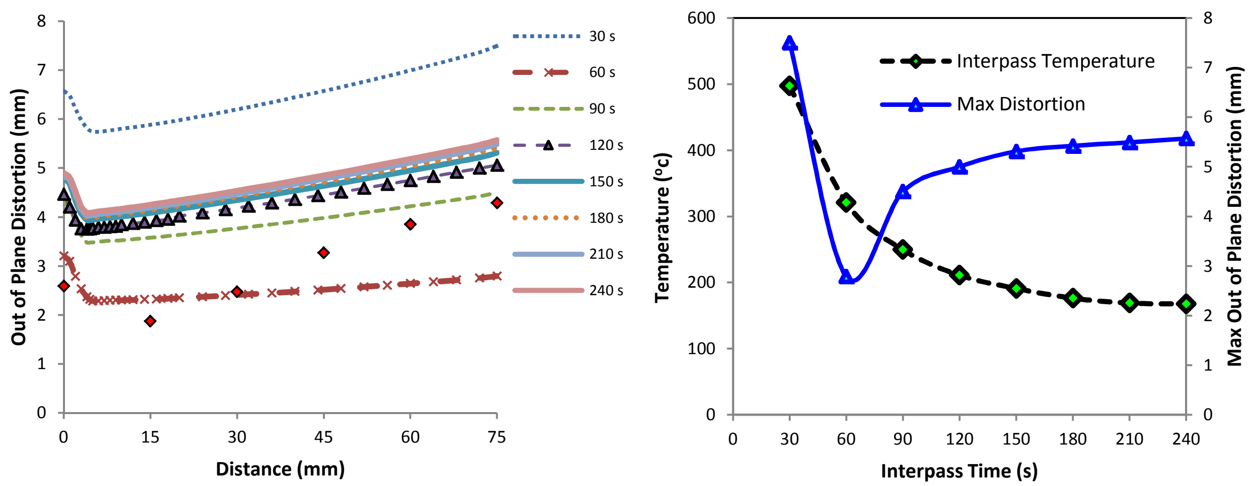
Results and discussion

The transient temperature of a point 10 mm away from weld line is shown in Fig. 2(a) for different interpass time cases. The experimental value with a interpass time of 210 s is also plotted for comparison and validation of finite element model. The plots clearly show that the maximum temperature of the second pass decreases with increase in time between two passes. It also shows very good match between FEM and experimental values in the the cooling region. Figures 2(b) & 3(a) show out of plane distortion measured along the free edge of longer side and in the transverse direction measured at mid length of the plate. The FEM out of plane distortion results are plotted for eight cases and compared with experimental values. The plate has undergone bending distortion in the longitudinal direction and angular distortion in the transverse direction. These plots clearly show the influence of interpass time on the distortion values. Distortion values are high for interpass time of 30 s and decreases rapidly for interpass time of 60 s and further it increases steadily with increase in time gap. The high distortion value at low interpass time is due to increased peak temperature which also increases the molten pool size, whereas for interpass time of 60 s seems to be the optimum time gap which reduces the molten pool size and hence distortions are at minimum for this case. Further with increase in interpass time the distortions increase steadily due to reduced postweld heating effects.



(a) (b)

Figure 2: (a) Temperature distribution with respect to time, (b) Out of Plane Distortion (Longitudinal Direction)



(a) (b)

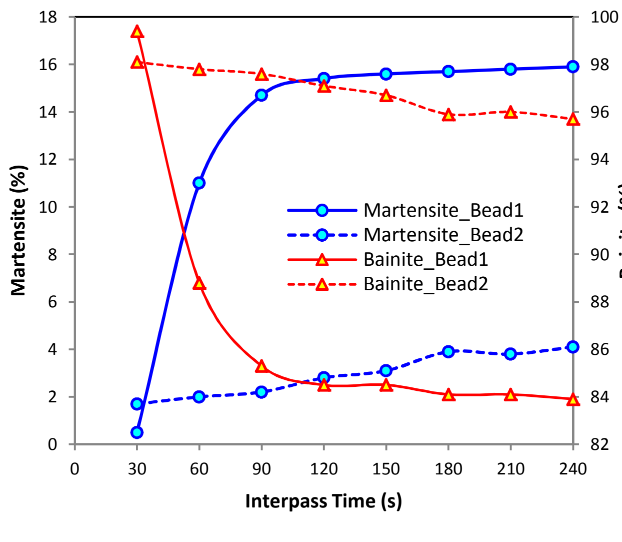
Figure 3: (a) Out of plane distortion (Transverse Direction), (b)Variation of Max. Distortion and Interpass Temperature

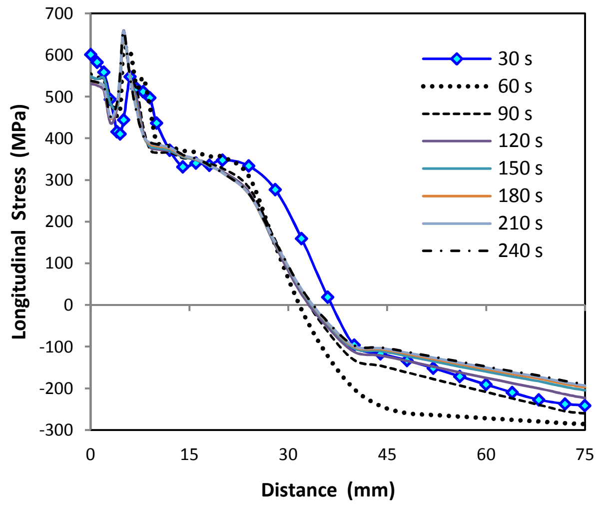
The variation of maximum distortion and interpass temperature with respect to interpass time is plotted and shown in Fig. 3(b). It shows the nonlinear decrease in interpass temperature with increase in interpass time. Figure 4(a) is plotted to represent the phase proportions in fusion zone of two beads at the end of welding and their variation with different interpass time. It can be observed that for smaller interpass time the martensite percentage in bead1 is less and it increases as the interpass time increases. This is due to the postweld heating effect at lower interpass time and high cooling rate because of higher thermal gradient with increased interpass time. Similarly the martensite percentage in bead2 increases with increase in interpass time but compare to the bead1 its value is less because it cools at slower rate. The bainite phase proportion values for different interpass time is also plotted for two bead. Their values increase or decrease with corresponding change in the martensite proportion values. The longitudinal residual stresses plotted in the transverse direction is plotted as shown in Fig. 4(b) for all the eight case. There is little effect of interpass time on the residual stresses. Although it can be observed that with increase in interpass time the residual stress in the fusion zone marginally decreases. The residual stress distribution for entire length show overall decrease for interpass time of 60 s and 90 s and it becomes less sensitive to further increase of time gap.

Conclusions

Parametric study of two pass welding is carried out using FEM by considering material phase transformations. Effect of interpass time on distortion and residual stresses is studied. Based on this study the following conclusions are drawn

- Reduced interpass time can influence the distortion and residual stresses due to the preheating effect on second pass and post heating effect on first pass
- The interpass time can significantly influence the phase transformations in the weldment, therefore a parametric study is essential to determine the suitable interpass time for the multipass welding of a given material





NOMENCLATURE.

η - arc efficiency
P_{ep}- proportion at phase equilibrium
Ms - martensite start temperature
Pi- proportion of phase i
ε - total strain
ε^{pc}- plastic strain
$\dot{T}$- heating or cooling rate
τ - delay time as a function of the temp.
b - law parameter
ε_i^{th} - thermal strain of phase i at temperature
ε^{e} - elastic strain
ε^{tp}- transformation plasticity

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References

[1] Zhang, H., Zhang, G., Cai, C., Gao, H., and Wu, L., 2008. "Fundamental studies on in-process controlling angular distortion in asymmetrical double-sided double arc welding". Journal of Materials Processing Technology, 205, pp. 214 – 223.
[2] Brickstad, B., and Josefson, B., 1998. "A parametric study of residual stresses in multi-pass buttwelded stainless steel pipes". International Journal of Pressure Vessels and Piping, 75(1), pp. 11–25.
[3] Amuda, M. O. H., Oladoye, A. M., Ojemeni, K., Agunsoye, J. O., and Subair, O. W., 2009. "Evaluating microstructural and hardness variations in time dependent multipass welded mild steel". Advanced Materials Research, 62-64, pp. 345–351.
[4] Hyung, L. C., and Chang, K. H., 2009. "Finite element simulation of the residual stresses in high strength carbon steel butt weld incorporating solid-state phase transformation". Computational Materials Science 46 (2009), 46, pp. 1014–1022.
[5] Becker, M., Jordan, C., Lachhander, S. K., Mengel, A., and Renauld, M., 2005. "Prediction and measurement of phase transformations, phase dependent properties and residual stresses in steels". Lockheed Martin, Schenectady, NY, USA , Technical Report.
[6] Warren, A. P., Bate, S. K., Charles, R., and Watson, C. T., 2006. "The effect of phase transformations on predicted values of residual stresses in welded ferritic components". Materials Science Forum, 524-525, pp. 827–832.
[7] Goldak, J., Chakravarti, A., and Bibby, M., 1984. "A new finite element model for welding heat sources". Metallurgical Transactions B, 15B, pp. 299–305.
[8] Sysweld, 2005. "Reference manual". ESI Group.