International Journal of Engineering & Technology, 7 (4.10) (2018) 95-98

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper



Temperature Field and Residual Stress of Butt Welding for IN182 Plate

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Abstract

The welding process is a nonlinear phenomenon in nature which leads to deformation and residual stresses in weldments. To overcome the structural changes in the weldments the computational packages can be effectively used for analyzing the changes in its life. Inconel superalloys have excellent mechanical properties and are used in the industrial applications. The present simulation is carried out for single pass butt-joint. Simulation studies are used for effective selection of process parameters for improving mechanical properties in the weld structures. In this work, coupled thermo-mechanical simulation process was carried out for predicting the temperatures, distortion and residual stress distribution in the weldments using Finite element analysis at the transverse direction on the welded surface.

Keywords: *GTAW welding process, Heat flux, FEA, Transientanalysis, Residual stress*.

1. Introduction

Welding is one of the important manufacturing process and Inconel materials are typically used in the manufacture of ships, automobiles, chemical industries, gas turbine components and aerospace etc. In weld structures, the weld residual stresses and distortions are caused due to the presence of localized heat in the weld beads. Distortion in weldments leads to inaccuracy in dimensions and causes difficulty during assemblies and increases the fabrication overheads. Changheui Jang et al[1] have reported the dissimilar welding for understanding the behavior of microstructural and mechanical properties in the weldments.

Welding process includes transient thermal heating and undergoes expansion and contraction, based on the physical properties of the materials. The welded components will be subjected to residual stresses and undergo distortion in the structures. The welding simulation of the butt joints with thermal history, residual stresses and distortion in weldment for similar and dissimilar weldings were been carried out in various zones in weld surface[2-3]. The dissimilar joining of SS316 to IN182 was carried out to study the micro hardness and micro structural properties[4]. A three-dimensional model of the joint for tube-block with J-groove for austenitic stainless steel was simulated using Quick Welder software to understand the residual stress and distortions developed in multi-pass joints [5].

Welding of thin plate structures was simulated for distortions which cause an effect in the assembly of the structures. The welding distortion of weldments was estimated by simulation with two step computational approach by a thermo-elastic–plastic finite element method and an elastic finite element method [6-7]. The two and three-dimensional welding simulations on stainless steel tube SUS304 by GTWA was carried out with ABAQUS finite element analysis for understanding the thermal behavior of the material transient condition that leads to residual stress in the simulated structures [8]. The welding simulation on stainless steels of different grades have been reported with two and three-dimensional finite element models using the appropriate heat flux for laser beam and arc welding process to be aware of heat transfer and its response on distortion and residual stresses [9-10]. Simulation of welding of multipass pipe girth thick plate was investigated with two-dimensional axisymmetric model using finite element analysis for residual stress [11].

In this paper, thermo-mechanical analysis has been carried out for the temperature distribution and studied residual stress distribution with single pass butt welded joint of Inconel 182 alloys.The double ellipsoidal heat flux was used for simulation,which helps to optimise parameters for reducing the residual stresses in the weldments.

2. Finite Element Analysis

For the analysis, the thermal element SOLID 90[12] which is a higher order version of the three dimensional eight node thermal element SOLID70 and has 20 nodes with a single degree of freedom, temperature at each node is used. The 20-node elements have compatible temperature shapes and are well suited to model curved boundaries. If the model containing this element is also to be analyzed structurally, the element should be replaced by the equivalent structural element. The geometry, node locations, and the coordinate system of the element are shown in Fig.1. Fig.2 shows the well known double ellipsoidal heat source model, which was proposed by Goladk[13] for three-dimensional numerical welding simulation for arc welding process. The temperature dependent thermal and mechanical properties are shown in Fig.3a and structural properties like yield strength, young modulus Poisson's ratio and thermal expansion are shown in Fig.3b.

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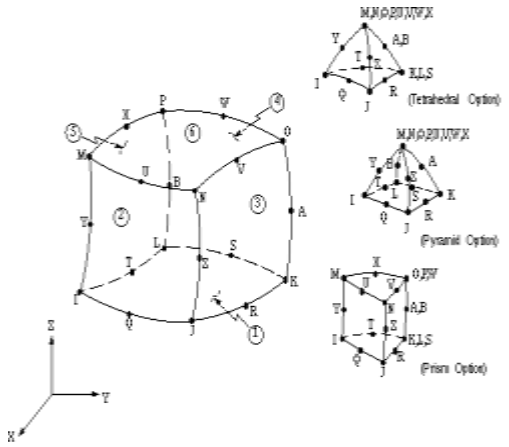


Fig.1: Solid 90 3-D 20-Node Thermal Solid

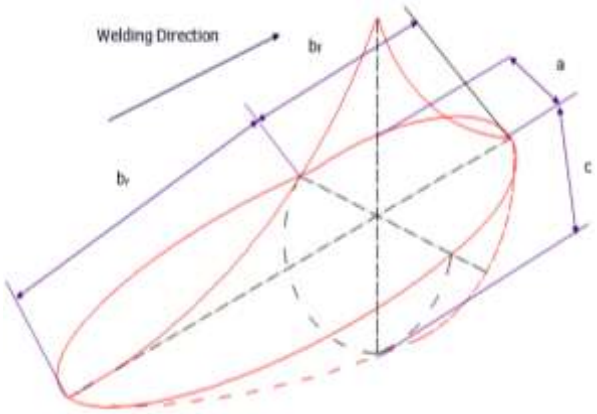
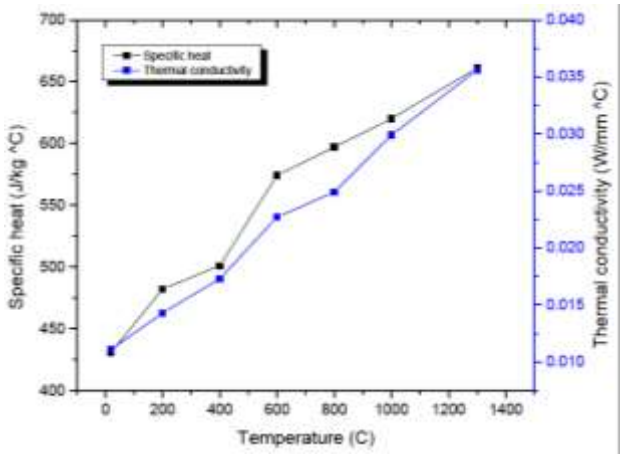
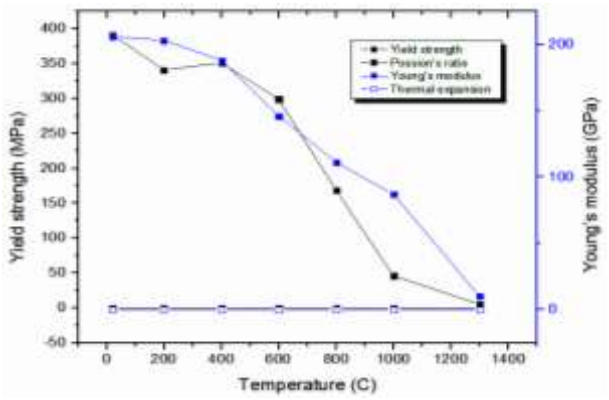


Fig.2: Double Ellipsoidal heat flux



a Temperature vs Thermal properties



b Temperature vs Mechanical properties

Fig.3: thermo-Mechanical Properties of the material

In fusion welding processes, the transient thermal problem involves heat conduction equation through suitable boundary conditions. For quasi-steady state heat conduction, the governing equation may be written as

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+Q=-\rho C_p v\frac{\partial T}{\partial t} \quad (1)$$

Where $\rho, c_p, k,$ Tand t refers to material density, specific heat, thermal conductivity, temperature and time respectively, V is the welding speed along Y-direction and Q represents heat generation per unit time per unit volume. It is assumed that both the base metal and the weld metal are isotropic materials, so the conductivities in x, y and z directions have identical value. In principle, the volumetric heat flux (q_v) for the welding process is given by the following equation:

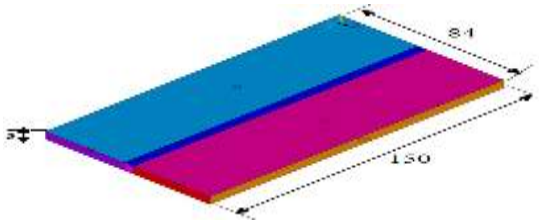
$$Q_v=\frac{h\ VI}{V_H} \quad (2)$$

Where V is the arc voltage, I is the welding current, V_H is the volume of heat source, and η is the arc efficiency. The model adapted is double ellipsoidal heat source model to calculate the heat distribution for the processes as shown in Fig. 2. Double ellipsoid, with a, b, c as semi-axes in three directions:

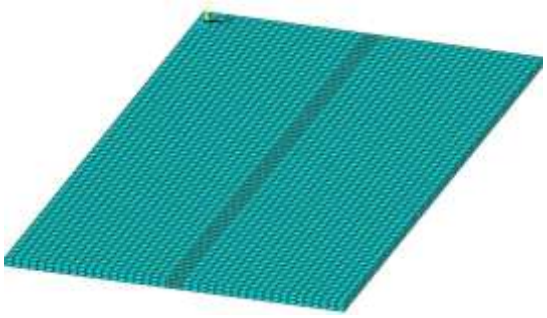
$$Q(x,y,z)=\frac{6\sqrt{3}r_f Q}{abc\pi\sqrt{\pi}}\exp\left(-\frac{3x^2}{c^2{}_{hf}}-\frac{3y^2}{a^2{}_h}-\frac{3z^2}{b^2{}_h}\right) \quad (3)$$

The combined convection and radiation boundary condition is used on the top surface, a combined heat transfer coefficient was calculated from the relationship where ε is the emissivity or degree of blackness of the surface of the body. A value of 0.5 was assumed for ε as recommended for steel

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



a. Weld model



b. Model with meshing

Fig.5: Modelling in the ANSYS

The model was developed using ANSYS APDL language. The geometry of the model was 80* 150* 5mm as shown in Fig.5a. The meshing of the model was done with tetrahedral volumetricmesh option with a size of 0.03 and is shown in Fig. 5b. The fine mesh was used at the fusion zone along the length. The finite element meshing can be used in both thermal and mechanical analysis for thermal history and stress distributions in the weldment.

3. Results and Discussions

3.1. Thermal Analysis

The transient thermal analysis was carried out with a speed of 3.75 mm/secfor the time period of 40sec and the simulation is allowed to run for 1000 sec, so that the weldment cools down to ambient temperature. The simulation of GTAW process is carried out with double ellipsodial surface heat flux and the nodal temperature of weldment is varied from 325 K to 1545K as shown in Fig.6.The temperature distribution in the weldment is measured in the transverse direction as shown in Fig.7.and covering various zones of weldment.

The temperature peaks keep on reducing in the transverse direction. The temperature away from the fusion zone is not influenced by the welding parameters. The heat transfer rate on the top surface is high when compared with the bottom surface.

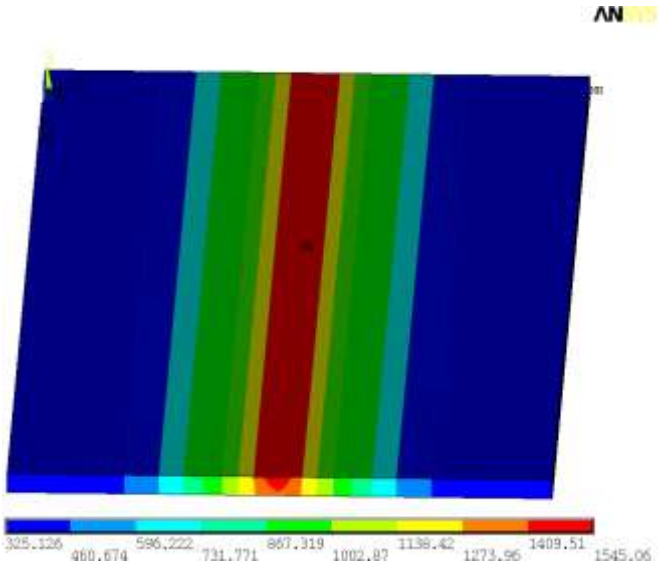


Fig. 6: Nodal solutions of temperature

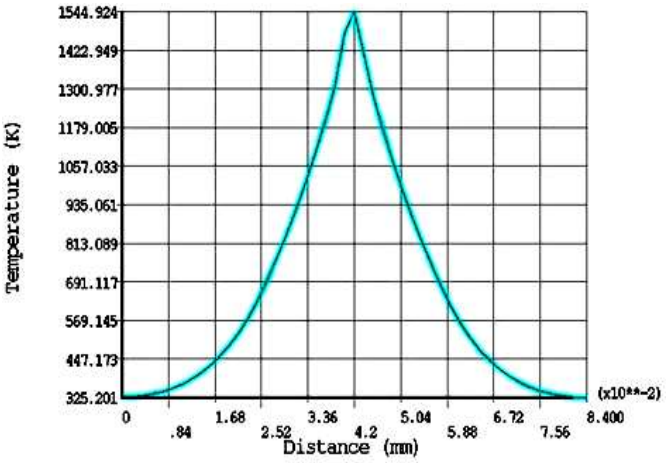


Fig. 7: Temperature distribution in transverse direction

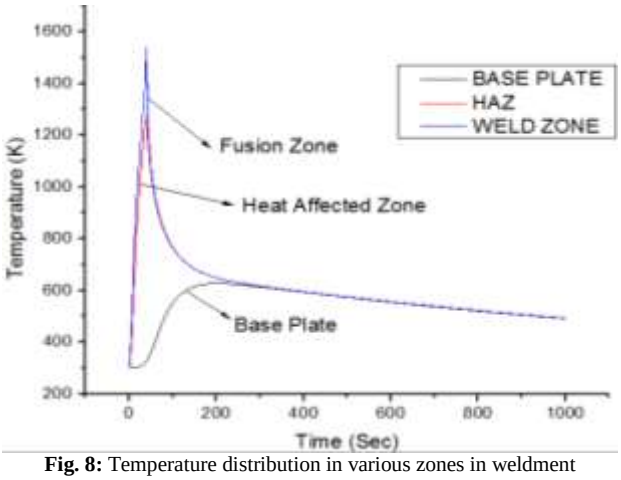


Fig. 8: Temperature distribution in various zones in weldment

From Fig.8,it can be seen that the temperaturesat fusion zone, heat affected zone and base plate are 1545 K, 1230K and 595K respectively.To underatand the thermal behaviour of weldment on weld surface, the temperatures in weldment are trending down from centre to end of the plate. After 1000 sec of the welding time of simulation, the base plate temperature has not reached to ambient temperature. The entire document should be in Times New Roman. The font sizes to be used are specified in Table 1.

3.2. Structural Analysis

In the sequence coupling of the welding process the thermal element is switched to structural element for the static structural analysis. The transient thermal element solid 90 is changed to solid 186 in structural analysis. The structural change of the weldment like distortion and residual stress are influenced by welding parameters, and the changes can be verified by computational approach. In Fig.9, the distortion in the weldment was very low which is not making any effect on the structure changes. The welding parameters employed for the present simulations process are effective and doesn't cause any effect on the dimensions of the weld model.

The residual stress causes due to heating and cooling cycles of the weldments. The residual stress distribution is shown in Fig.10 and the stress distribution was high at the ends of the weldment. The stress is varied from compression to tension in the weldments with -233 MPa to 564 MPa.

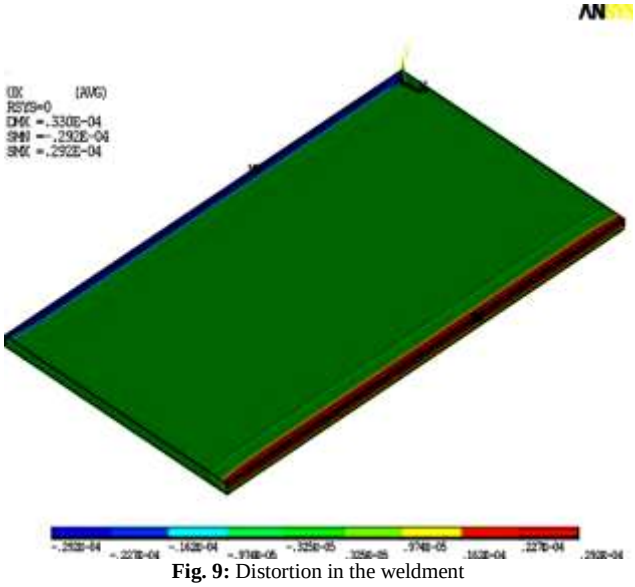


Fig. 9: Distortion in the weldment

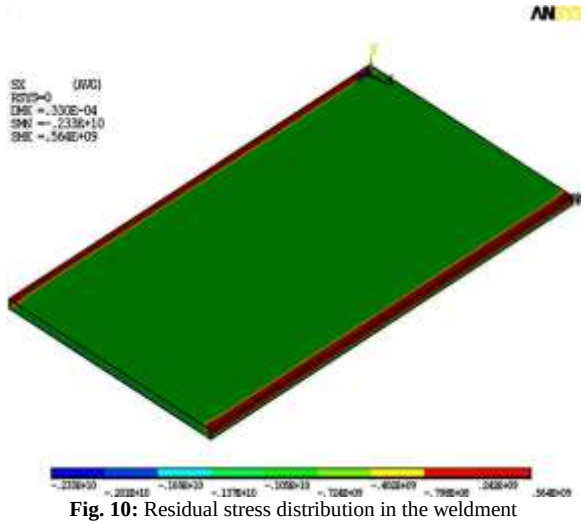


Fig. 10: Residual stress distribution in the weldment

4. Conclusion

The single pass butt joint with thermo-mechanical simulation process was established for Inconel 182 for GTAW process. The temperature distribution rate in the welding process differs with respect to load apply time for the welding process. The maximum temperature distribution is about 1544 K at the fusion zone. The distortion in the weldment was low of 0.03mm dueto its high density and low thermal expansion in the weld material, which helps to reduce the risk in the dimensional inaccuaracy of the weldment for the present welding parameters. The compressive residual stresses of -105 MPa are observed in fusion and heat affect zones and residual stresses are end up with tension at both the ends of 564 MPa at the base plates and the residual stresses are balanced in the weldment.

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