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Multipass Welding

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Abstract:

Welding is an important metal joining process well established and widely used. For most domestic, commercial and even product s the thickness is less than 3mm and single pass welding is sufficient and well established. However, for high pressure applications like boilers, pipes and nuclear reactors the stainless steel sheets used are more than 3mm thick and are up to 20, 40 and 60mm thick. These plates, pipes are welded in sequence in multiple beads which form multiple pass welding process. This is a thermal and structural combined process this paper is about modeling for simulation using Abaqus. The thermal model, taking temperature dependent thermal and structural coefficients and the application of boundary conditions is discussed. This paper would help designers modeling and manufacturing multipass structures.

Introduction:

An aim of welding simulation is to evaluate the heat flux model, evaluate if melt temperature is reached in the fusion zone, evaluate the heat effected region and find the distortion and residual stresses. Further, evaluate actual distortions and residual stresses.

As per the customer & product or structural requirement process optimization can be done from case to case. Welding is a transient model with conduction, convection and radiation happening simultaneously, how these are incorporated in simulation along with the flow phenomenon of molten metal, phase transformations and latent heat modeling are some of the challenges.

Hong Li [1] has done a 3D numerical simulation using elastic plastic model, a double ellipsoid heat source and a penetration assembly model. The elastic dynamic strains consisting of elastic, plastic and thermal strains are obtained. Dean Deng [3] has used Abaqus software uncoupled 3D and 2D finite element modeling and compared with experimental results. Suresh Akella et al [4] have done single pass welding simulation for conduction & plasma modes of welding process.

Theory:

Welding is a coupled thermal structural problem. In multipass welding bead by bead is welded along the length of the weld. One of the optimizations required is number of welds and the sequence of weld to obtain minimum distortion & residual stresses.

The thermal analysis is done first with time dependent properties as given in Table 1. The heat model used in most analysis is the one suggested by Goldak [2] with the heat flux divided into four half, ff, and rare half fr, The ratio depends on process say fr=0.6 and ff is 1.4 in one study. The leading front has a steeper temperature gradient than in the rear.

$f_f + f_r = 2$ (1)

From the focal point at any distance r in the x, y & z coordinate system,

$$q(r) = \frac{6\sqrt{3\,frQ}}{\Pi^{3/2}abc}\, e^{-3[\,\left(\frac{x}{ar}\right)^2 + \left(\frac{y}{b}\right)^2 + \left(\frac{z}{c}\right)^2]} \qquad (2)$$

$$q(r) = \frac{6\sqrt{3\,ffQ}}{\Pi^{3/2}abc}\, e^{-3[\,\left(\frac{x}{af}\right)^2 + \left(\frac{y}{b}\right)^2 + \left(\frac{z}{c}\right)^2]} \qquad (3)$$

Along the weld the x axis, front ellipse length is af and rare length is ar, could be uneven axis lengths in the fore and rare. b is axis length in the lateral or transverse direction along y and for the 3D ellipsoid in the z axis along bead thickness the length is c. The3D heat flux ellipsoid is described by the lengths of axes, af, ar, b, c which depend on the flow of heat in the material we may call a weld process parameter. Total weld heat Q is a combination of the two parts of weld represented in front eq (1) and rare eq (2) of the position of the torch or beam.

Q=q(r) front +q(r) rare (4)

This heat equation is used with some accuracy for Tig, TIG welding and also used in simulation of Electron beam Welding, EBW and Laser Beam welding LBW, but with less accuracy as these are not shallow welds but with penetration. The position of the beam moves with a velocity v, along the direction of weld. Governing equation for transient heat transfer is given as [3]. Say if TIG welding heat, Q is the product of Voltage, Current and efficiency of power supply.

$\partial T/\partial t\ \rho C(x,y,z,t) = .(q(x,y,z,t) + Q(x,y,z,t))$ (5)

Where ρ is the density of the material, C is the specific heat capacity, T is the temperature, q is the heat flux vector, Q is the heat generated internally, say heat of phase transformation, t is temperature, is the spatial gradient operator. This equation is taken with Fourier heat flux constitutive equation of conduction as

Q= -KT

Q= -KT
(6)

The conductive heat flow is controlled by the temperature dependent Conductivity coefficient, K.

Numerical Simulation:
Heat Convection & Radiation and boundary conditions:

The objective of welding is to obtain a melting temperature by providing the required heat to have a joint with minimum beads for the required thickness of material to be welded. The estimation can be done in ABAQUS which provides a plug in to give the weld parameters, moving heat source and defining the weld beads. In [3] Radiation Qr, is combined with convection to form a combined heat transfer coefficient, hr,

Qr =σ (T-Ta)*(T +Ta) (T2+Ta2) (7)

Where, σ is the Stephen Boltzmann's constant and Ta is the ambient temperature. With this definition radiation heat, a quadratic function of radiation is transformed to a linear equation and can be combined with Convection heat Qc, given by

Qc = h (T-Ta) (8)

The two heats Qr and Qc are combined with the definition of Combined Heat coefficient hr given as

hr = 0.68T* 10-8 (W/mm2) for 0<T<500oC (9)

hr = 0.231T -0.82.1)*10-6 for T>500oC (10)

and Total heat Qrc=hr (T-Ta) (11)

These equations are used for boundary conditions at all free boundaries including the boundary generated by the previous weld passes.Figure 1. Shows the exponential growth of combined heat transfer coefficient which is modeled below and above 500oC separately. Higher the temperature more heat transfers from surface boundary. The specific heat change is a slow change between 0.5 and 0.7 in the temperature range up to 1500oC as given in Figure 2. Similarly thermal expansion is nearly linear shown in Figure 3. It is not used in model. Finally temperature dependent conductivity is shown in Figure 4.

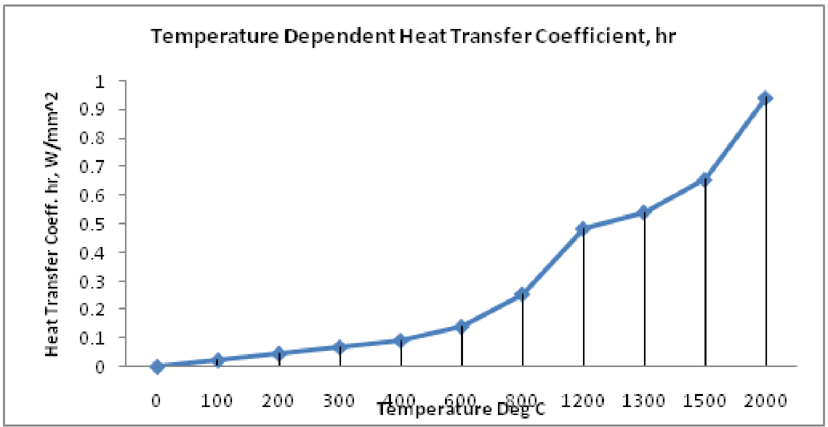

Figure 1. Temperature vs Heat transfer coefficient.

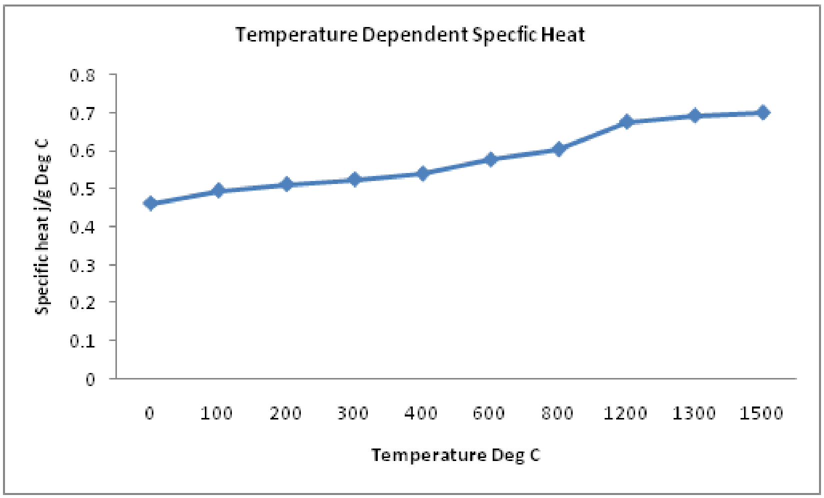

Figure 2. Temperature vs Specific heat

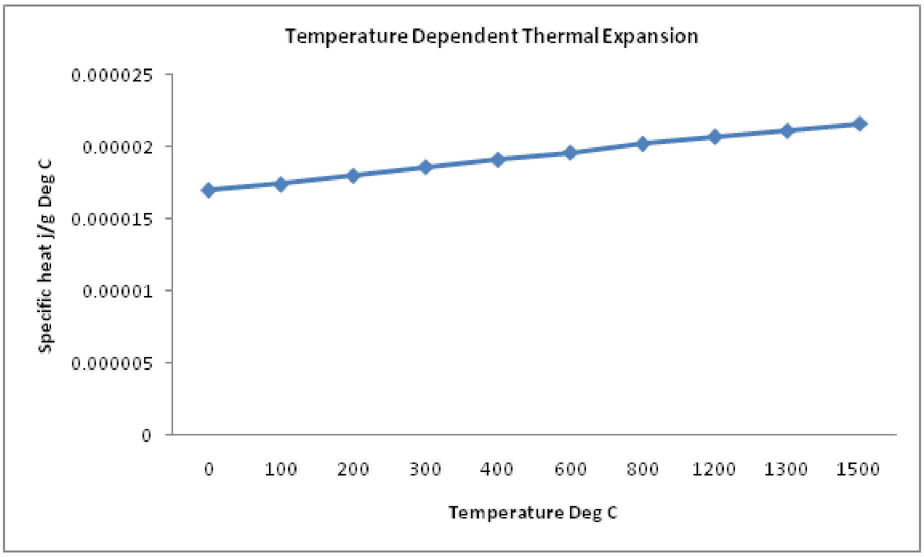

Figure 3. Temperature vs Thermal Expansion

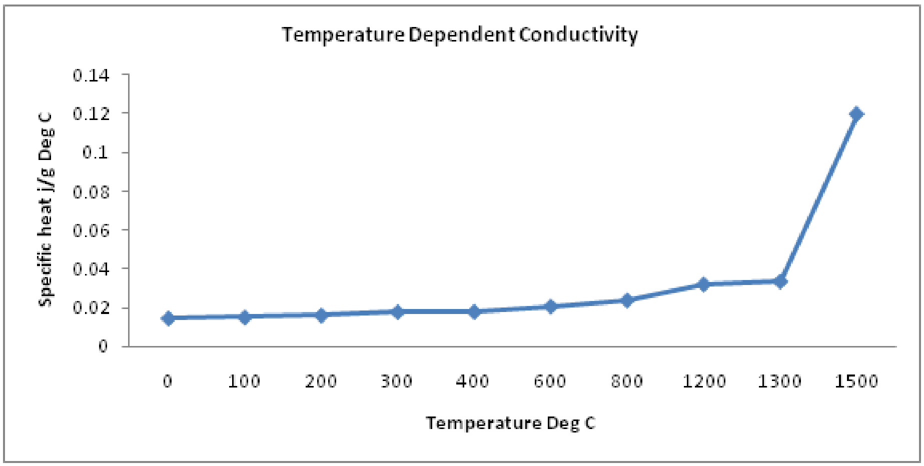

Figure 4. Temperature vs Conductivity

Structural Analysis:

The thermal analysis is given as input load for the structural analysis to calculate distortion and residual stresses which are the required final output. In this part of the sequential analysis correct boundary conditions are given and the temperature dependent structural properties shown in figures 5 to 8 are used.

Density of a material reduces non linearly with increase of temperature as given in Figure 5. Yield stress reduces to near zero from 250 MPa at 1500oC shown in Figure 6. Similarly, Young's modulus reduces to near zero from 190 GPa at 1500oC shown in Figure 7. Poisson's ratio has a slight variation about 0.3 shown in Figure 8.

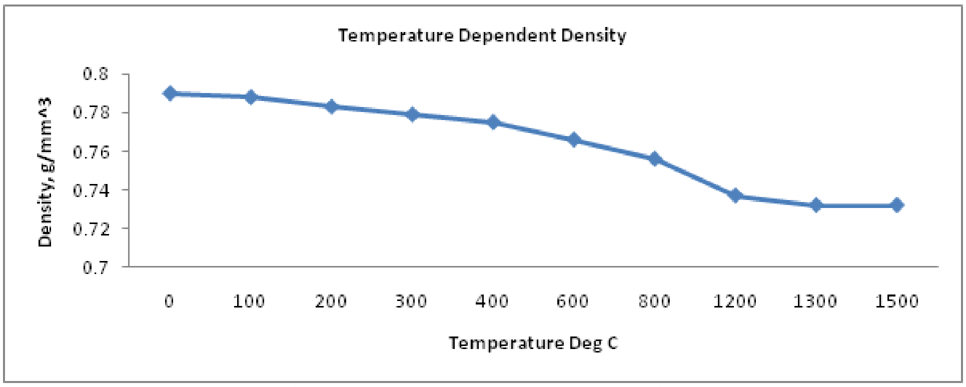

Figure 5. Temperature vs Density

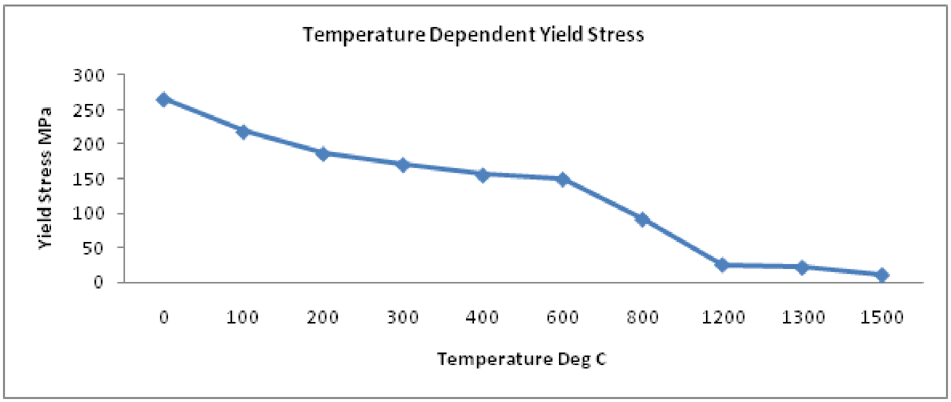

Figure 6. Temperature vs Yield Stress

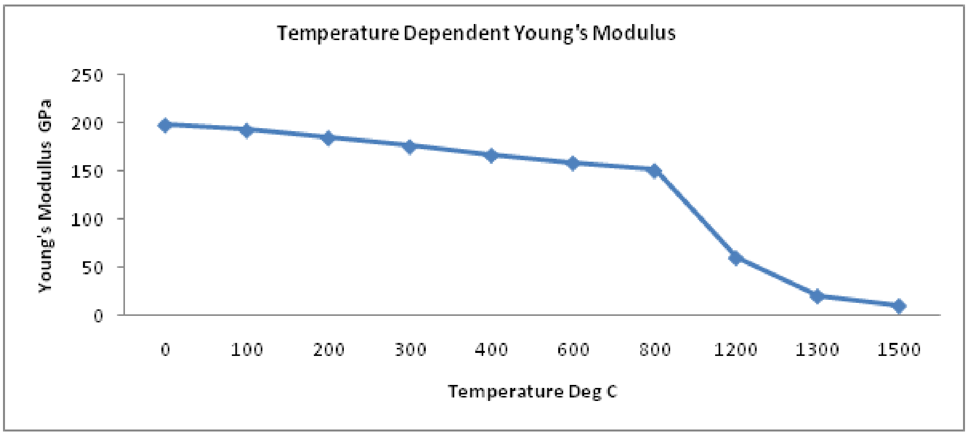

Figure 7. Temperature vs. Young's Modulud

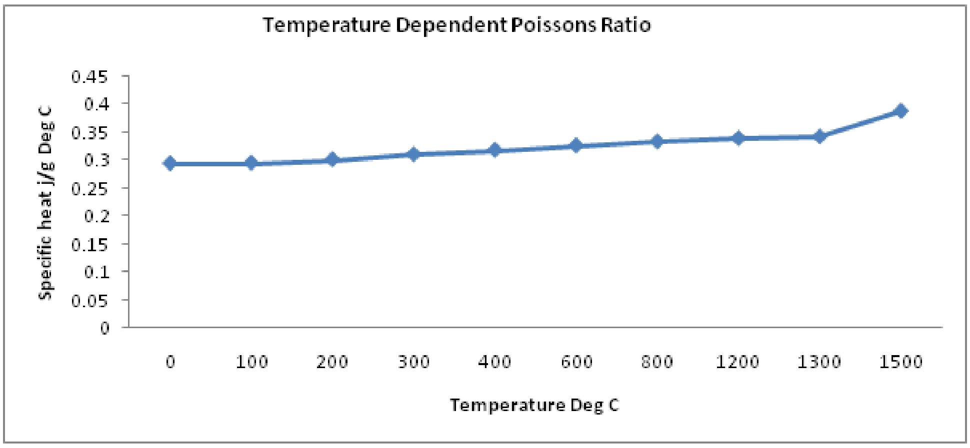

Figure 8. . Temperature vs Poisson's Ratio

Conclusion:

Background thermal properties of SS304, theoretical model for welding process and boundary conditions are discussed. Boundary conditions relevant to multipass beads are giving. The temperature field is mapped into structural analysis for residual stresses and distortion which are the final required output.

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