Thermoelastic Boundary Element Modeling of heat affected zone of a low carbon steel in laser welding

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ABSTRACT

Laser welding is a frequently used joining process in manufacturing in which a high volumetric heat generation is induced within the material, resulting in a heat affected zone. Determination of the heat affected zone is important in two ways: firstly, the material properties (especially the properties of low carbon steels) may become different from those out of the zone, and secondly, heat-induced strains (and displacements) may result in unexpected tolerance changes and residual stresses [1].

In this study, a thermoelastic model is developed for modeling heat affected zones in low carbon steels. For this, we assume a rigid block of material on which the laser weld operates (Figure-1).

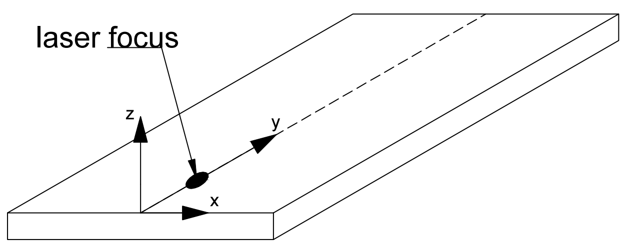

Figure 1: A representation of laser welding

The laser tip moves in $y-$direction with a pre-determined velocity V. The viscous effects and the induced accelerations in the model will be disregarded and the strain-rate induced coupling in energy equation is neglected. In such case, the equations of thermoelasticity, in Fourier Transform Space, is given by:

$$\mu u_{i,kk} + (\lambda + \mu) u_{k,ik} - \eta_i = 0 \tag{1}$$

which will be named as the *mechanical equations*, and

$$C_v i\omega\theta = r + k\theta_{,kk} \tag{2}$$

which will be called as the *energy equation* [2]. In these equations, the field variables are the components of the displacement vector, u_i, and the temperature difference from reference temperature, θ. The material properties, μ and λ are the shear and Lame modulus and C_v and k are the heat capacity under constant volume and heat conduction coefficient respectively. The coupling term, η_i is defined as

$$\eta_i = (3\lambda + 2\mu)\alpha\theta_{,i} \tag{3}$$

where α is the isotropic thermal expansion coefficient. The volumetric heat generation, in this problem, is the volumetric heat induced by the laser tip, which will be represented using a double ellipsoidal power density distribution as

$$r(x, y, z, t) = r_f(x, y, z, t) + r_r(x, y, z, t) \tag{4}$$

where the frontal component, r_f and rear component r_r are given by [3]

$$r_f = C_0 \frac{f_f Q_t}{a b_r c} \exp\left[-3\left(\frac{x}{a}\right)^2\right] \exp\left[-3\left(\frac{y - Vt}{b_f}\right)^2\right] \exp\left[-3\left(\frac{z}{c}\right)^2\right] \tag{5}$$

and

$$r_r = C_0 \frac{f_r Q_t}{a b_r c} \exp\left[-3\left(\frac{x}{a}\right)^2\right] \exp\left[-3\left(\frac{y - Vt}{b_r}\right)^2\right] \exp\left[-3\left(\frac{z}{c}\right)^2\right] \tag{6}$$

As stated before, in these equations, V represents the velocity of the laser tip in $y-$direction. Other parameters in these equations are, the total power of the heat source, Q_t, the fraction coefficients, f_f and f_r, for frontal and rear components, the geometry adjusting parameters, a, b_r, b_f and c and a general analytical constant, $C_0 = \dfrac{6\sqrt{3}}{\pi\sqrt{\pi}}$.

In this study, a boundary element formulation is presented for the solution of laser welding problems presented above. The analysis is performed in Fourier Transform Space, provided that under given velocity and parameters, Equation 4 is transformed into Fourier Transform Space using FFT algorithm. The energy equation is solved by a Helmholz solution Boundary Element Method with the volumetric heat generation being modeled using Dual Reciprocity.

After the Fourier Transform solution is obtained for the energy equation, this solution, at all frequencies, is used to augment the mechanical equations through the thermal coupling term, η_i. For this, elastostatic solution using Boundary element method is utilized, in which the coupling term is dealed using Dual Reciprocity.

With the derived formulation and implemented code, several problems are solved and compared with literature, when possible.

REFERENCES

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