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Computer methods for determination of deformations in welded closed profiles

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Abstract

The work concerns the numerical prediction of deformations in welding of two rectangular profiles using TIG method. Numerical analysis of thermomechanical phenomena are carried out in the Abaqus FEA software using finite element method. Geometry of the joint is numerically recreated on the basis of the real welded joint of rectangular profiles. For this geometry a discretization of the system and numerical simulations of welding deformations are performed. The calculations are performed for the rectangular profiles made of steel X5CrNi18-10. Numerical analysis takes into account thermomechanical properties of welded elements changing with temperature. DFLUX subroutine is used in Abaqus software, allowing the modeling of moveable welding heat source. Mathematical Goldak`s description of the heat source is assumed to described the distribution of movable heat source power. Results of numerical analysis of the temperature distribution in the welded joint are presented in this study. The estimation of the shape and size of melted zone is performed as well as the prediction of stress state and welding deformations. Numerically predicted deformations are compared with results of the measurement.

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Keywords: GTAW welding; numerical analysis; displacement; stainless steel; closed profile;

1. Introduction

Different metal joining methods are currently used in the manufacturing industry [1-3]. Arc methods are still used in spite of advanced joining technologies. This results from the significantly lower costs of production and the cost of welding equipment [4, 5].

For every welding technology, an important issue is the determination of welding stress and strain generated in the weld and adjacent area [3, 5]. The prediction of strain location at an early stage of design of welded constructions allow to change process parameters in order to reduce deformations in the joint [4]. This significantly improves the quality and mechanical properties of the final product [6, 7]. Due to the high costs of conducting experimental research, more often numerical analysis is performed on the basis of finite element method [8-11].

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Numerical analysis of thermomechanical phenomena in TIG welding process of two orthogonally arranged closed rectangular profiles is performed in this paper. A three-dimensional discrete model of considered system is created in Abaqus/FEA software. The geometry of analyzed model corresponds to the geometry of a real object. Thermo-mechanical properties varying on temperature are assumed in calculations for welded profiles made of X5CrNi18-10 stainless steel [3]. Abaqus/Standard module is used in calculations where additional subroutine DFLUX is implemented. The mathematical model of moveable heat source power distribution is implemented and its location relative to connected parts. Temperature field is determined on the basis of numerical simulations of welded joints [12]. The size and shape of melted zone as well as welding deformations are numerically estimated. Values of predicted displacements are compared to measurements made on the real joint.

2. Analysis of thermomechanical phenomana in Abaqus/FEA

Numerical analysis of temperature field in electric arc welded joints (TIG) is determined on the basis of the solution of energy conservation equation with Fourier law [13]. Temperature field is expressed as follows:

$$\int_V \rho \frac{\partial U}{\partial t} \delta T \, dV + \int_V \frac{\partial \delta T}{\partial x_\alpha} \cdot \left(\lambda \frac{\partial T}{\partial x_\alpha} \right) dV = \int_V \delta T \, q_V dV + \int_S \delta T \, q_S dS \tag{1}$$

where λ is a thermal conductivity [W/m °C], $U = U(T)$ is a internal energy [J/kg], q_v is a laser beam heat source [W/m^3], $T = T(x_\alpha, t)$ is a temperature [°C], q_s is a boundary heat flux [W/m^2], δT is a variational function, ρ is a density [kg/m^3], $T = T(x_\alpha, t)$ is temperature [°C].

Equation (1) is completed by initial condition $t = 0 : T = T_o$ and boundary conditions of Dirichlet, Neumann and Newton type with the heat loss due to convection and radiation. Solid - liquid phase transformation is taken into account in the mathematical model of thermal phenomena [14, 15], assuming solidus temperature T_S=1400 [°C], liquidus T_L=1455 [°C] and latent heat of fusion H_L=260×10^3 [J/kg].

The mechanical analysis in elastic-plastic range is based on classic equilibrium equations, supplemented by constitutive relations [3, 5, 6]. Equation (1) is completed by initial and boundary conditions.

$$\nabla \circ \dot{\boldsymbol{\sigma}}(x_\alpha, t) = 0, \qquad \dot{\boldsymbol{\sigma}} = \dot{\boldsymbol{\sigma}}^T \tag{2}$$

$$\dot{\boldsymbol{\sigma}} = \mathbf{D} \circ \dot{\boldsymbol{\varepsilon}}^e + \dot{\mathbf{D}} \circ \boldsymbol{\varepsilon}^e \tag{3}$$

$$\boldsymbol{\sigma}(x_\alpha, t_0) = \boldsymbol{\sigma}(x_\alpha, T_S) = 0, \qquad \boldsymbol{\varepsilon}^e(x_\alpha, t_0) = \boldsymbol{\varepsilon}^e(x_\alpha, T_S) = 0 \tag{4}$$

where $\boldsymbol{\sigma}=\boldsymbol{\sigma}(\sigma_{ij})$ is stress tensor, x_α describes location of considered point (material particle), ($\circ$) is inner exhaustive product, $\mathbf{D}=\mathbf{D}(T)$ is a tensor of temperature dependent material properties.

The total strain is defined as a sum of elastic ε^e, plastic ε^p and thermal ε^{Th} strains:

$$\varepsilon^{total} = \varepsilon^e + \varepsilon^p + \varepsilon^{Th} \tag{5}$$

Elastic strain is modelled using an isotropic Hooke's law, whereas plastic strain is calculated using plastic flow model obeying Huber-Misses plasticity condition [6].