Model of heat transfer in High Frequency Welding – numerical approach and laboratory investigation

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1. Introduction

Numerical model of the process of high-frequency (HF) pipes welding was presented in this paper. The thermomechanical analysis in the 3D was carried out using FEM. The influence of the welding speed, frequency, and voltage on the quality of welded joint was investigated. The simulations performed for pipe profiles of various diameters made of S355 and S420 steel allowed to determine the heat-affected zone. Measurement of the temperature in the production line was used to verify the correctness of the model. The obtained results allowed to formulate the optimal process parameters.

1.1. Numerical model

Process of high frequency welding of closed profiles consists of the mechanical forming of a steel strip, and then joining the edges of the sheet by fast, local induction heating to the range of high plasticization, followed by pressing them with rollers (Fig.1a). The joint formed by welding has a key impact on the strength of the product. It is particularly important when round profiles are intended for friction anchors used in the construction and mining industries, which, after installation in the rock mass, are expanded with water under a pressure of approx. 300 bar.

The quality of the weld is strictly dependent on the mechanical factors, such as the geometry of the welding area, the size of the Vee angle, as well as electrical factors, including frequency, voltage and current, which determine the welding temperature. It is precisely the maintenance of the welding temperature at the level of approx. 1350°C is the main task of the manufacturing process. Too high temperature increases the range of the heat-affected zone, leads to grain growth and deterioration of the strength properties of the material. When the temperature is too low, due to insufficient plasticization of the edges, there is a risk of a significant deterioration of the durability of the resulting seam, including the appearance of the "open seam" defect. A properly made weld should have the shape of hourglass with a possible thin decarburized layer in the weld axis. Optimum fracture toughness is ensured by the microstructure of the fine acicular ferrite [1,2].

HF welding of pipes is a complex, dynamic process in which the occurring thermomechanical phenomena combine mechanical, electrical, thermal and metallurgical factors. Performed numerical analysis taking into account the coupling of the electromagnetic field with the thermal field by

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solving the Maxwell (1) and Fourier (2) equations. The general scheme of the algorithm is shown in Figure 1b. The electrical solution generates a heat source (Joule Heat) that sets the boundary condition in the thermal solution. Thermal analysis includes simulation of heat losses by radiation and convection from open surfaces of the pipe. The solution in the 3D was realized using FEM on the basis of program package ANSYS.

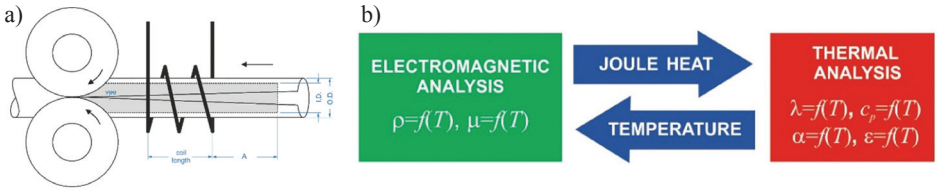

Figure 1. a) Schematic diagram of HF welding of pipes,
b) algorithm of transient coupled electromagnetic-thermal analysis.

The electromagnetic field is described by Maxwell equation in the form:

$$\nabla \times \vec{B} = \overrightarrow{\mu j} + \mu\varepsilon \frac{\partial \vec{E}}{\partial t} \tag{1}$$

where: $\vec{B}$ – magnetic field intensity, μ – magnetic permeability, j – current density, ε – electric permittivity, E – electric field intensity.

The transient thermal field is determined from the Fourier equation (2):

$$\rho C \frac{\partial T}{\partial t} + \nabla(-k\nabla T) = Q \tag{2}$$

where: k – thermal conductivity, ρ – density, C – specific heat, Q – heat source, obtained from electromagnetic field analysis.

Boundary conditions of convection and radiation applied on the outer surface of the pipe:

$$q_{conv} = h(T - T_{\text{int}}) \tag{3}$$

$$q_{rad} = \varepsilon\sigma(T - T_{\text{int}}) \tag{4}$$

where: h – heat transfer coefficient, T_{int} – external bulk temperature.

2. Results

The simulations performed for pipe profiles of various diameters made of S355 and S420. The model takes into account the process parameters: power, current frequency and material data: thermical and electrical (table I). Results of numerical simulations of HF welding are presented in Figure 2–3. the welding temperature determined from the model covered the range 1196–1353°C.

Table 1. Thermal and electrical parameters.

	Specific heat, J/kg·K	Thermal conductivity, W/m·K	Thermal expansion, K^{-1}	Electrical conductivity, S/m	Resistance, Ω·m
S355	680	44	$16.2 \cdot 10^{-6}$	$2 \cdot 10^{6}$	$10 \cdot 10^{-8}$
S420	470	41	$13.2 \cdot 10^{-6}$	$2 \cdot 10^{6}$	$10 \cdot 10^{-8}$

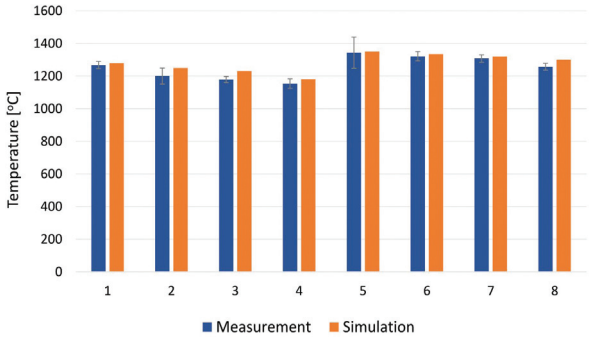

Figure 2. Comparison of calculated (orange column) and measured (blue column) temperature of weld.

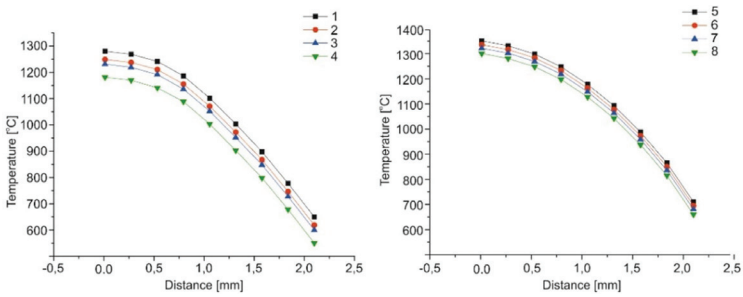

Figure 3. Calculated temperature gradient in the heat affected zone.

3. Conclusions

The model allows the determination of the temperature of the weld and temperature gradient in the heat-affected zone for variable process parameters process parameters: power, frequency, profile diameter. Measurements of temperature made in the technological line confirm the correctness of the model. As a result, the model can be used to optimize the HF welding process.

References

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