Temperature Distribution on Continuous-Drive Friction Welding Involving Plastic Deformation

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INTRODUCTION

Friction welding is a widely used solid-state joining process. The friction welding processes can be divided for following kinds: continuous-drive friction welding (CDFW), inertia friction welding, linear friction welding, orbital friction welding and friction stir welding. One of the most effective numerical method for structural and thermal problems is the finite element (FE) method. Several studies have so far been made to investigate the thermal problem of friction welding [1]. In this paper axisymmetric FE model of the CDFW has been developed to analyse a temperature field.

PROBLEM STATEMENT

A friction stage of CDFW process is considered (Fig. 1). Assembly of two cylindrical parts by rotational friction when applying a compression, constant pressure p_0 generates heat at the contact zone. One part is stationary while the second is rotating with constant value ω_0 in predetermined time t_s. After this stage the rotation is stopped and final forging pressure is applied to make the weld.

It is assumed that the properties of materials: thermal conductivity K, specific heat c, density ρ and coefficient of friction f as well as yield point in the tension σ_y are temperature-dependent:

$$K(T) = K_0 K^*(T),\ c\ (T) = c_0 c^*(T),\ \rho\ (T) = \rho_0 \rho^*(T),$$

$$f\ (T) = f_0\, f^*(T)\ ,\ \sigma_y(T) = \sigma_{y0}\sigma_y^*(T), \tag{1}$$

$$K_0 = K\ (T_0),\ c_0 = c\ (T_0),\ \rho_0 = \rho\ (T_0)\ ,\ \ f_0 = f(T_0)\ ,\ \sigma_{y0} = \sigma_y(T_0) \tag{2}$$

In equations (1) and (2) $K^*(T), c^*(T), \rho^*(T)$, $f^*(T)$ and $\sigma_y^*(T)$ are dimensionless functions of temperature (Fig. 2), T_0 is initial temperature.

Axisymmetric transient temperature field $T(r,z,t)$ will be obtained from the solution of the boundary-value problem of heat conduction in the cylindrical coordinate system [2].

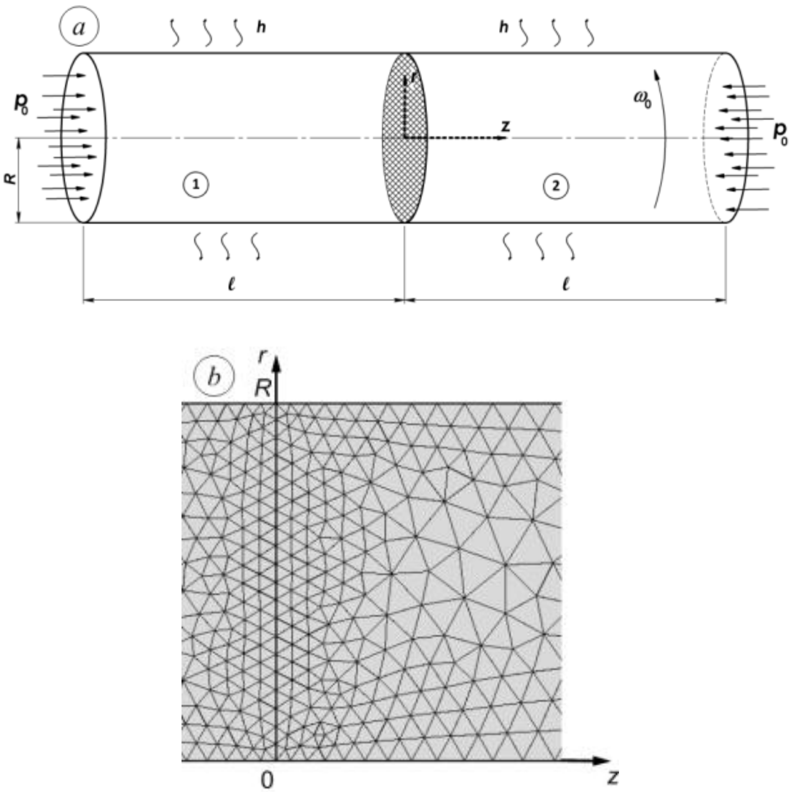

Fig. 1 Scheme of specimen contact in rotary friction welding (a); the finite element mesh near of the contact surface (b).

The capacity of heat power at the interface of two specimens is sum of friction and plastic deformation part, as following:

$$q(r,t) = (1-\delta)q_{\mathrm{f}}(r,t) + \delta\, q_{\mathrm{p}}(r,t),\ 0 \le \delta \le 1\,, \tag{3}$$

$$q_{\mathrm{f}}(r,t) = f_0 p_0 \omega_0 r f^*[T(r,0,t)], \quad q_{\mathrm{p}}(r,t) = \sigma_{\mathrm{y}0}\omega_0 r \sigma_{\mathrm{y}}^*[T(r,0,t)]/\sqrt{3}. \tag{4}$$

where: δ is state parameter (weighting function) denotes the share part of sliding and sticking mechanism in total heat generation [3]. If $\delta = 0$ entire heat is produced by frictional dissipation, whereas heat is generated only by plastic deformations $\delta = 1$. In this approach it was assumed that δ parameter takes constant values in friction stage of CDFW process.

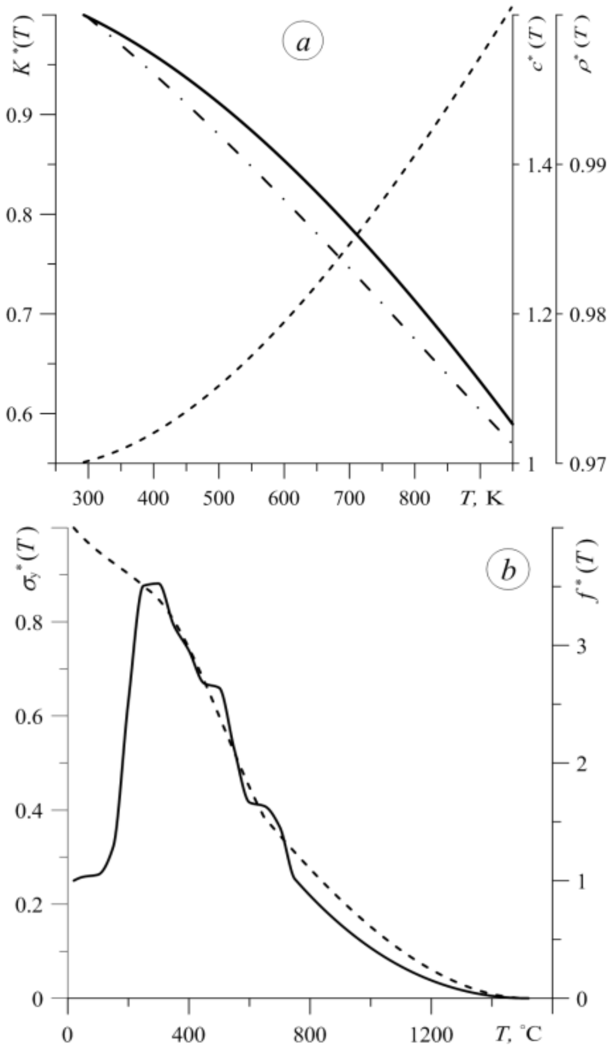

Fig. 2 Dimensionless functions $K^*(T)$ (solid line), $c^*(T)$ (dashed line) and $\rho^*(T)$ (dash-dot line) [5] (*a*); $f^*(T)$ (solid line) [4], $\sigma_y^*(T)$ (dashed line) (*b*) for friction couple AISI 1040 – AISI 1040.

NUMERICAL ANALYSIS AND RESULTS

Simulation of heating in a couple during a friction process with parameters: f_0=0.158, p_0 =75 MPa, ω_0 =146.6 rad/s, t_s=7.45 s [4], h=40 W/(m^{2}K), $T_0 = 20$℃, $\sigma_{y0} = 372$ MPa using FE based software (COMSOL Multiphysics v. 5.2a) was carried out. The calculations were performed for two specimens of radius R=6 mm and length l =30 mm each, made of steel AISI 1040 (K_0=52 W/(mK), c_0=479 J/(kgK), ρ_0=7860 kg/m^3 [5]).

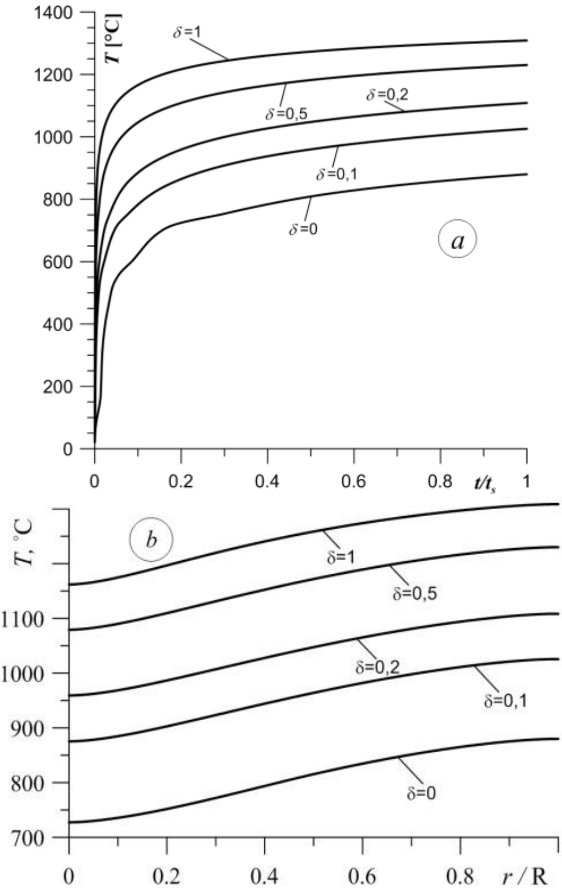

Fig. 3 Change of the temperature T for different values of the parameter δ depending on: friction time t for $r = R$, $z = 0$ (a); radial direction r for $z = 0$, $t = t_s$ (b) [6].

The effect of plastic deformation on temperature was considered. It was found that an increase in the parameter δ leads to an increase in the temperature of the contact surface $z = 0$ during the entire welding process (Fig. 3a). The temperature most increases on the side surface of the sample $r = R$ for $t = t_s$ (Fig. 3b) [6].

To achieve the value of forging temperature of steel $T_f = 950°\text{C}$, necessary to the creation of the proper welding join, on the whole contact surface enough to share the heat from the plastic deformation amounted to 20% ($\delta = 0{,}2$) of the total generated heat in process (Fig. 3b). For this value of parameter δ there were obtained: $T(0{,}0{,}t_s) = 959{,}2°\text{C}$, and $T(\text{R}{,}0{,}t_s) = 1108{,}5°\text{C}$ [6].

Conclusion

A mathematical model is proposed for investigating the temperature field caused by the friction welding of metals. For this purpose, an axisymmetric nonlinear boundary value problem of heat conduction is formulated with allowance for the frictional heating of two cylindrical samples of finite length made of AISI 1040 steel. The thermophysical properties of this steel, its yield strength, and the coefficient of friction changes with increasing temperature. The numerical solution of the problem is obtained by the finite element method. The influence of two mechanisms of heat generation on the temperature field of samples has been considered: due to friction on the contact surface and plastic deformation. For friction pair AISI 1040 – AISI 1040 value of state parameter $\delta = 0{,}2$ is the most suitable to obtain the correct temperature over the entire contact surface.

References

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