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FINITE ELEMENT ANALYSIS OF HEAT FLOW IN FRICTION WELDING

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In the paper a finite element method is used for solving the nonlinear transient problem of the axisymmetric friction welding. The algorithm for solving the resulting system of nonlinear equations is shown. Numerical illustrations prove the effectiveness of the approach.

1. Introduction

This article is the second in the series which discussed heat flow in welding by the finite element method. In the work [6] the temperature field in flash welding is analyzed. In this paper the heat flow in friction welding will be considered. Friction welding is a process in which the heat for welding is produced by direct conversion of mechanical energy to thermal energy at the interface of the workpieces without the application of electrical energy, or heat from other sources, to the workpieces. Friction welds are made by holding a non-rotating workpiece in contact with a rotating workpiece under constant or gradually increasing pressure until the interface reaches welding temperature, and then stopping rotation to complete the weld. The frictional heat developed at the interface rapidly raises the temperature of the workpieces, over a very short axial distance, to value approaching, but below the melting range; welding occurs under the influence of a pressure that is applied while the heated zone is in the plastic temperature range. Friction welding is classified as a solid-state welding process in which joining occurs at a temperature below the melting point of the work metal. If incipient melting does occur, there is no evidence in the finished weld because the metal is worked during the welding stage. The present paper describes a numerical method for the analysis of transient temperature distribution in the vicinity of the weld for arbitrary axisymmetric rods. The common assumption in attempting to provide an analytical solution to such a problem is the postulated temperature independence of all material properties. No such simplifications have to be done in the present approach: the finite element method used in its incremental form makes it possible to account for arbitrary variations of all material characteristics during process.

2. Finite element formation of the heat conduction problem

The variation of temperature θ, with the time t in a two-diemensional region Ω, relative to Cartesian coordinates x, y, is governed by the equation

$$\rho c \frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}\left(k_x \frac{\partial \theta}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial \theta}{\partial y}\right) + Q, \tag{2.1}$$

where k_x, k_y are temperature-dependent anisotropic conductivity coefficients, ρ and c the temperature-dependent density and heat capacity and density, and Q is the rate of heat generation. At the surface of the body the temperature may be prescribed or the flow of heat due to convection and/or radiation may be specified, or a combination of these conditions may exist.

The region Ω is divided into a number of eight noded isoparametric elements Ω^e, with quadratic shape functions h_i associated with each node i. The unknown function θ is approximated throughout the solution domain at any time t by

$$\theta = \sum_{i=1}^{n} h_i \, \theta_i(t) = \mathbf{H}\boldsymbol{\theta}, \tag{2.2}$$

where $\boldsymbol{\theta}$ is the column vector of nodal values θ_i. The substitution of the expansion (2.2) into Eq. (2.1) and the application of the Galerkin method yields the following equation:

$$\mathbf{C}\dot{\boldsymbol{\theta}} + \mathbf{K}\boldsymbol{\theta} + \mathbf{F} = \mathbf{0}. \tag{2.3}$$

The form of the matrices **C**, **K** and **F** together with a description of the temperal discretization of Eq. (2.3) and the resulting method of solution of the subsequent equations have been fully described in [6], and need not be considered further.

3. Sample solution

3.1. Friction welding of two metal rods

The two semi-infinite rods shown in Fig. 1 are subjected to friction welding. At the place of abutment the heat source is given by the following equation:

$$\dot{Q} = \int_A \sigma \cdot \mu \cdot \omega \cdot r dA,$$

where σ is a stress at the place of contact, μ is the coefficient of friction, ω is the angular speed, r is the radius, and A is the surface upon which the heat rate acts. Steel rods of the diameter ⌀ 12 mm and density 7800 kg/m^3 are considered. In our analysis $\sigma \cdot \mu \cdot \omega$ is assumed to be equal to 3×10^9 W/m^3. The material properties are given in Table 1. The surface film conductance is taken as 0.25 W/m^2. Two kinds of discretization are used for analysis, (Fig. 2). The results obtained for these discretizations were almost coincident. The results given in Fig. 3 refer to the time instants of $t = 1, 2, 3$s.

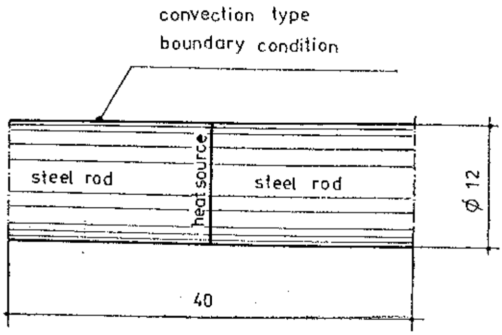

FIG. 1. Heat boundary conditions in friction welding of two rods.

Table 1

Temperature [°C]	0	500	800	900	1100
Thermal conductivity $\left[\frac{J}{mKs}\right]$	50	50	50	50	50
Specific heat $\left[\frac{J}{kgK}\right]$	510	1030	1300	680	680

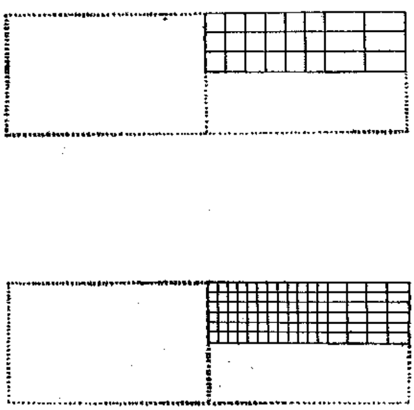

FIG. 2. Types of discretization.

3.2. *Friction welding of two rods of different diameters*

The second example concerns the friction welding problem of two different steel rods with the same material properties as before, Fig. 4. The finite element mesh used is shown in Fig. 5. The temperature distribution for the same conditions as in Sect. 3.1 is given in Fig. 6.

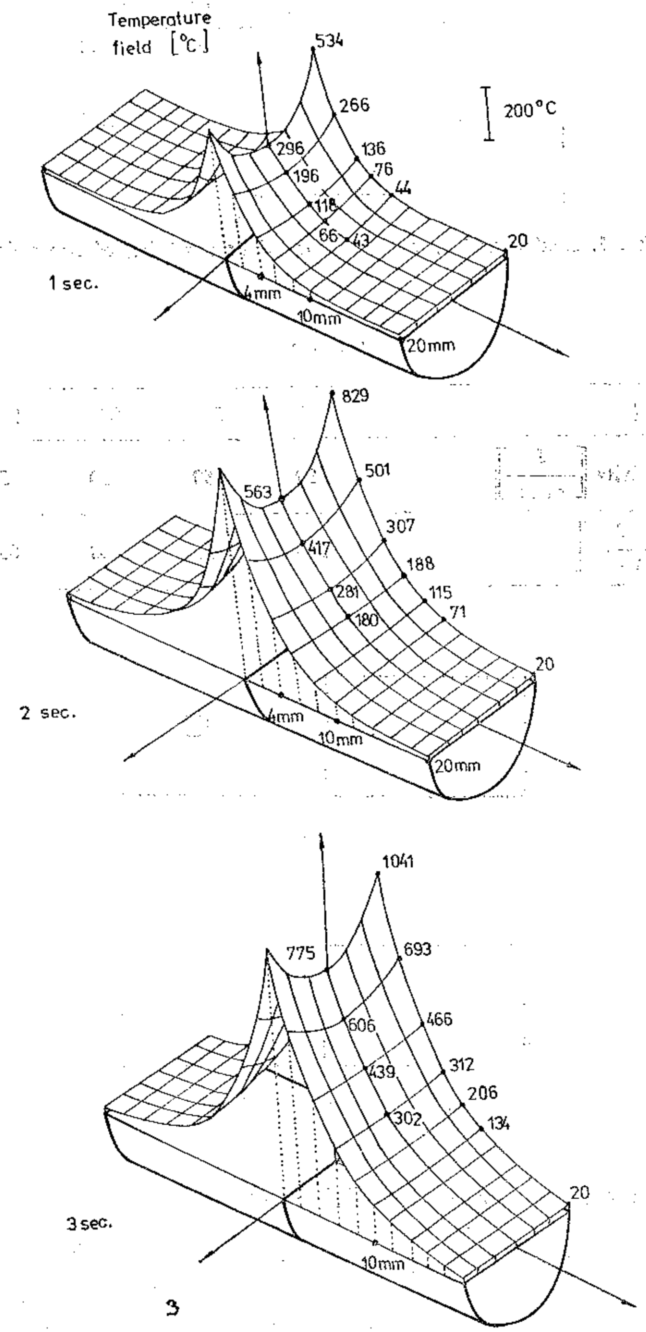

FIG. 3. Temperature distribution in friction welding.

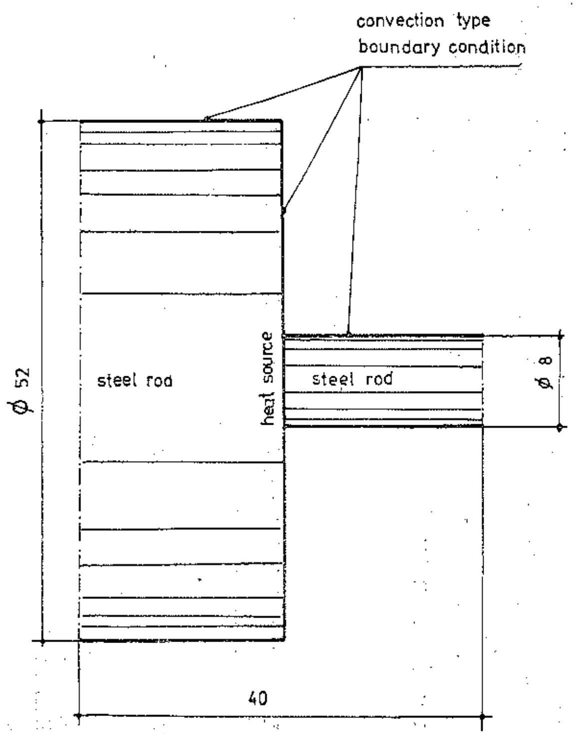

FIG. 4. Heat boundary conditions in friction welding of two different rods.

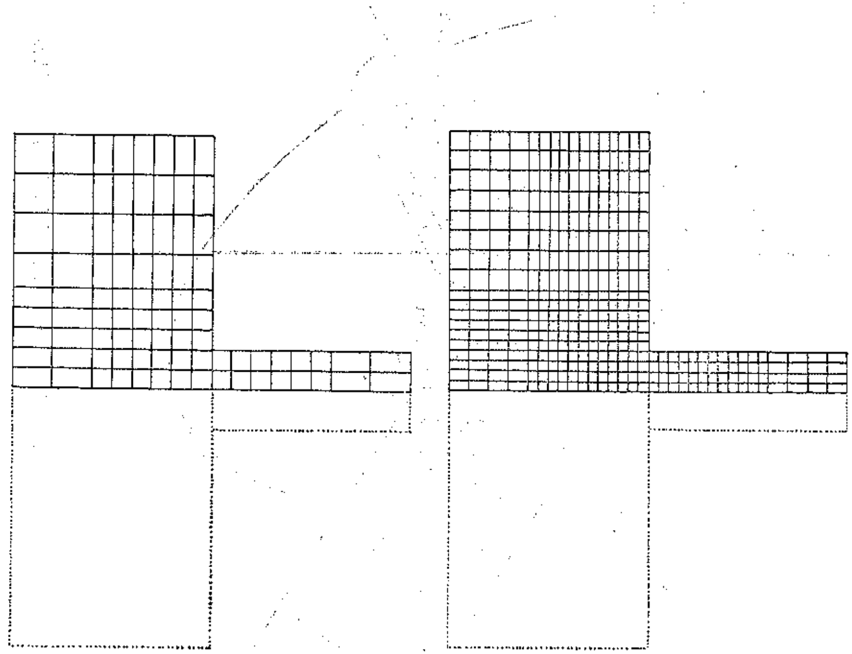

FIG. 5. Finite element meshes.

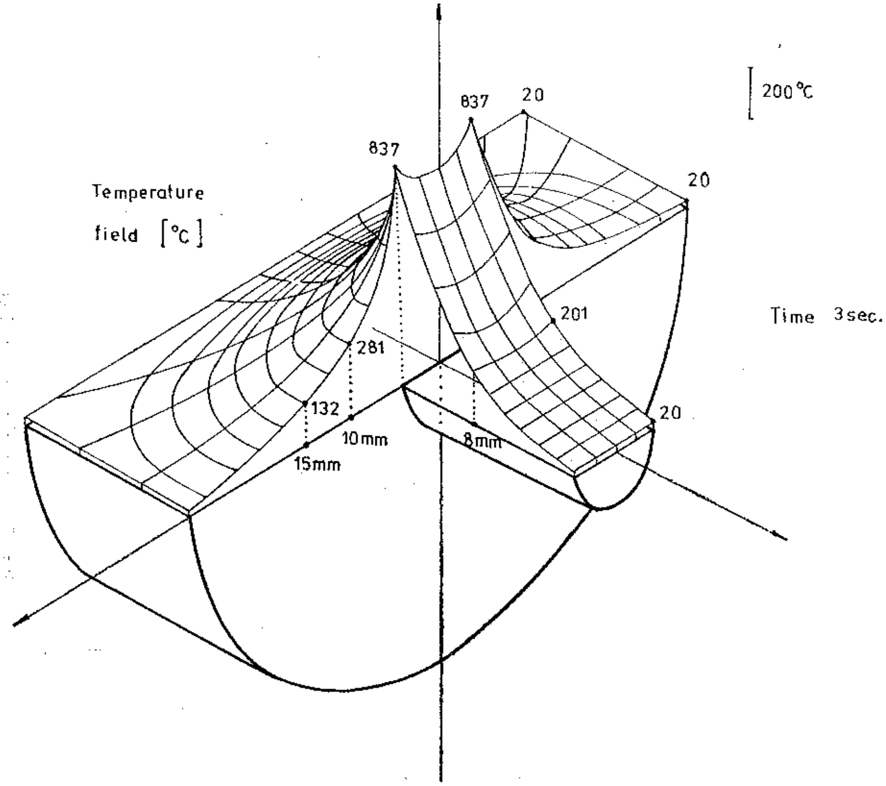

FIG. 6. Temperature field in friction welding.

CONCLUSIONS

The calculations performed confirm the known experimental results concerning the temperature distribution in rods subjected to friction welding [1–2]. As expected, the cross-sectional temperature variation is significant. The method used makes it possible to analyze effectively more complex problems of welding. Such analysis will be undertaken by the authors in subsequent publications.

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Streszczenie

ANALIZA PRZEPŁYWU CIEPŁA PRZY ZGRZEWANIU TARCIOWYM METODĄ ELEMENTÓW SKOŃCZONYCH

Artykuł opisuje zastosowanie metody elementów skończonych dla rozwiązania problemu nieliniowego przepływu ciepła przy zgrzewaniu tarciowym elementów osiowosymetrycznych. W pracy analizowano algorytm dla rozwiązania problemu przepływu ciepła. Na zakończenie podano przykłady ilustrujące rozpatrywany proces.

Резюме

ЧИСЛЕННЫЙ АНАЛИЗ МЕТОДОМ КОНЕЧНЫХ ЭЛЕМЕНТОВ РАСПРОСТРАНЕНИЯ ТЕПЛА ПРИ СВАРКЕ ТРЕНИЕМ

Статья представляет применение метода конечных элементов для решения проблемы нелинейного распространения тепла при сварке трением осесимметричных элементов. В работе дается алгоритм для ее решения. В заключении статьи даются примеры иллюстрирующие рассматриваемый процесс.

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