NUMERICAL MODELING OF THE FSW JOINT USING AN ELASTO-PLASTIC MATERIAL MODEL

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Present work deals with numerical modeling of the material which contain the joint made by using the friction stir welding (FSW) technology. The consider material has a heterogeneous microstructure which determined its global response to the applied load. The thermodynamically consistent elastic-plastic-damage model was introduced, additionally took the approach that assuming the construction of the joint as a composite material. Local mechanical properties were estimated based on numerical simulation determining the size of grains in the material, which are dependent on the temperature field accompanying the FSW process. The simulation results were then verified by comparing the results obtained experimentally.

1. Introduction

The FSW joint is characterized by a specific heterogeneous microstructure that affects directly on the mechanical properties of the weld [9]. Knowledge of the local constitutive relationships of individual weld zones allows to predicting its global response during loading based on the implementation of the appropriate numerical model for the MES software [3]. The omission of information about inhomogeneity of mechanical properties may be the cause of large discrepancies in numerical and experimental results [8]. However, the global behaviour of the material is not only determined by the mechanical properties of the weakest zone in the joint but also a combination of interactions of individual zones, their size, properties and geometry [9]. In order to understand these relationships, numerous simulations of the temperature distribution in the welding area and simulations of material flow around the tool are carried out, then these data are verified by experimental tests [9].

2. Experiments

Detailed results of the tensile tests of solid samples and a sample with an FSW joint were presented in the paper [5]. The base material was copper Cu-ETP in the state of R220 in the form of a sheet with a thickness of 5 mm. Based on the received tensile curves (Fig. 1) it can be concluded that the sample with FSW joint is characterized by a lower yield strength σ_{y} by approximately 60% and lower maximal strength σ_{m} by approximately 15% in compare to the base material.

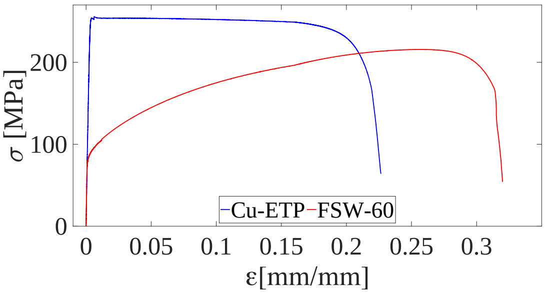

Fig. 1 Comparison of the tensile curves of a base material and a sample with an FSW joint [5].

3. Basic assumptions and equations

In this paper, in order to identify the local constitutive behaviour of individual joint zones, a 2-D simulation of the temperature distribution in the material which accompanies the process of FSW was carry out. This simulation, however, does not take into account plastic deformation, which is the second component of total thermal energy that is generated during the process [4]. The numerical model uses a non-stationary Fourier equation

$$\lambda\left(\theta_{,rr}+\theta_{,r}/r+\theta_{,zz}\right)+\dot{q}_{\mathrm{v}}=\rho c_{\mathrm{v}}\dot{\theta} \tag{1}$$

To determine the dependence of the yield strength on the grain size in the material, the description proposed by Hall and Petch is often used. However, in the case of nanostructures, this description is not very precise, the real values of σ_y are lower than it results from the H-P relationship. Therefore, another description was used to the limit of the beginning of plasticity, which was presented in the paper [2]. However, it does not have a physical explanation

$$\sigma_\mathrm{y} = 104.9 + 111.8\exp\left(-d/10.3\right) + 54.9\exp\left(-d/135.6\right) + 235.6\exp\left(-d/0.13\right) \tag{2}$$

The constitutive model used in the paper was presented by Ottosen and Ristinmaa [6] and is based on the following assumptions: (1) elastic-plastic-damage material is considered, (2) small strains are assumed.

4. Numerical results

First simulation concern on the temperature distribution in the workpiece. Because this physical magnitude directly affects the value of the yield strength, it is also possible to observe its gradient within the welding area. Also when considering individual zones of joints, we must remember about their inhomogeneities (Fig. 2). The overall stress of the entire system was presented as the sum of stresses from individual joint zones using the composite material approach. The Reuss method was adopted as the mixing rule. In order to implement a constitutive model taking into account the local impact of individual joint zones on the global behaviour of the sample. A numerical predictor-corrector algorithm was adopted using the "return mapping" procedure [1]. Integration of the Euler backward type and the tangential matrix method called the Newton-Raphson method was used in this algorithm [7].

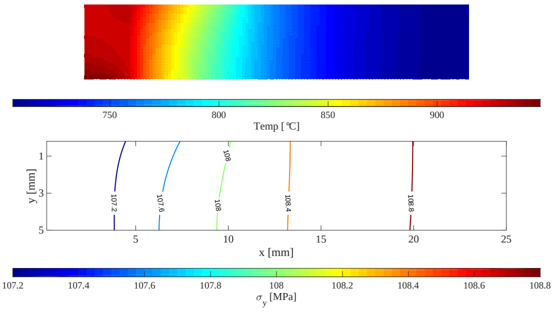

Fig. 2 The temperature field accompanying the FSW process on the cross section of the joint (1/2 of the sample) and its effect on yield strength of the copper.

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