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An analytical approach to the plastic flow of a bimetallic mono-filamentary wire through a conical die

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Abstract

Cold drawing of bimetallic wires is an efficient technology for fabrication of filamentary composite materials. In the present paper an analytical approach to the plastic flow of a two-component mono-filamentary wire through a converging conical die is proposed. Developed solution is based on a number of simplified assumptions concerning the radial flow pattern, the perfectly plastic materials' behavior, and the perfect bonding conditions between the components. The stress and the strain-rate fields are determined. Obtained results for the drawing stress show a good agreement with available experimental data. Examination of the interfacial stresses localized at the boundary between the components allows to identify the range of the input parameters in which the pure radial flow can exist.
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1. Introduction

Plastic drawing and extrusion as metal forming processes have a long industrial history dating back to 1797, when Joseph Bramah used the underlying principle of extrusion to produce pipes of lead and other ductile metals. The idea consists in pulling/pushing an input billet through open converging channels (so called die and chamber) so that to change its cross section area and shape. This gives a possibility to manipulate metals similar to the molding of pottery and to fabricate a huge variety of products of different shapes. What is even more important is that drawing and extrusion drastically change properties of the material. The plastic deformation through the cross section is non-uniform due to the redundant shear at die-billet interface, which results in the anisotropy of the final products. The outer region of the billet undergoes

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the dramatic change of the microstructure related to the spectacular formation of the new surface. Eventually, the accumulation of large plastic strains significantly increases the yield strength and, therefore, the bearing capacity of the metals.

Despite the knowledge of the structural changes of the materials during drawing/extrusion is still incomplete, the problem of the mechanical simulation of these processes has been receiving considerable attention of many authors since the pioneering studies of Sokolovskii (1950) and Shield (1955). Among the most widely known approaches we can note the slab method of analysis (Hoffman and Sachs, 1953), the upper and lower bound techniques (Avitzur, 1968), the slip-line field approach (Johnson and Kudo, 1962), the viscoplasticity technique (Thomsen et al., 1965) and a large variety of their later modifications. Applications of the finite-element procedure allowed to study complicated flow patterns and to go on to the simulation of non-sound modes of the flow (Chevalier, 1992; Dixit and Dixit, 1995). Recent contributions in the field are related to the analysis of the influence of different yield criteria (Alexandrov and Barlat, 1999), study of non-steady plastic flows (Richmond and Alexandrov, 2000), taking into account variations of the die shape and finding the optimal geometry of the die (Chitkara and Aleem, 2001a; Lo and Lu, 2002). The void growth leading to the development of central bursting was considered by Dawson et al. (1992) and Saleh et al. (2005).

In the last years the growing interest in drawing/extrusion of bimetallic combinations can be observed. Bimetallic composite rods, wires and tubes are increasingly present in a lot of different industrial applications; the proper selection of components allows to obtain products possessing a number of worth properties: high strength can be combined with low weight, high electrical conductivity, corrosion and wear resistance, etc. An application of the drawing process to assemblies of bimetallic wires gives a possibility to develop a new production technology for filamentary and multi-filamentary composite materials. As an illustrative example we refer to the micrographs of copper–graphite composite wires we have fabricated by cold drawing (see Fig. 1 in Andrianov et al. (2005)); with the external diameter 5.2 mm they contain 48 (one level of heterogeneity) and 48^2 (two levels of heterogeneity) filaments of graphite.

The theoretical description of the plastic flow of bimetallic combinations is not comprehensively developed up to now. Following the Shield analysis, Durban (1984) proposed an analytical solution for drawing and extrusion of multilayered composites assuming the die angle and frictional stresses to be small. Some of more recent studies can be found in papers of Alcaraz et al. (1996), Sliwa and Mishuris (1999), Alexandrov et al. (2000), Mishuris et al. (2000), Chitkara and Aleem (2001b,c). The basic discrepancy from the homogeneous case consists in the interactions between the different components, which induce the concentration of local stresses at the components' interface. Therefore, the interface's response becomes one of the main crucial factors determining the flow pattern and the distributions of stresses and strain-rates. This phenomenon may not be predicted by the solutions, which are based on the upper bound method and thus are not focused on the evaluation of the local stress field. Alcaraz et al. (1996) presented a stress analysis of the extrusion of bimetallic tubes. However, they did not take into account the velocity discontinuities arising at the die entrance and exit, so the influence of the redundant work caused by the plastic distortion of the materials was neglected. The effect of imperfect bonding between the components was considered by Alexandrov et al. (2000) and Mishuris et al. (2000). They simulated a jump in the velocity field across the interface by the introduction at the interface of the constant frictional low. A disadvantage of their solution is that in the limit case of the perfect bonding the interfacial shear stress was assumed to reach the value of the yield stress of the softer component, which may not be always true.

We propose an analytical approach to the plastic flow of a bimetallic mono-filamentary wire through a conical die. In Section 2 the input boundary value problem is formulated basing on a number of simplified assumptions concerning the radial flow pattern, the perfectly plastic materials' behaviour, and the perfect bonding conditions between the components. Section 3 describes the general way of solution. Some intermediate evaluations are performed by means of the asymptotic expansion procedure and Padé approximants in Section 4. Section 5 is devoted to the discussion of numerical results. In particular, examination of the interfacial stresses localized at the boundary between the components allows to identify the range of the input parameters in which the pure radial flow can exist. Brief concluding remarks are given in Section 6.

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