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Effective properties and micro-mechanical response of filamentary composite wires under longitudinal shear

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Abstract

We propose an asymptotic approach for evaluating effective properties and determining the micro-mechanical response of filamentary composite wires fabricated by cold drawing under longitudinal shear (torsion). Our procedure is based on the homogenization method; a cell problem is solved using the underlying principles of the boundary shape perturbation technique. As the results we derive approximate analytical solutions for the effective shear modulus and for local distributions of the stress field. Developed approach is valid for all values of the components' volume fractions and properties, in particular, it works well in cases when rapid oscillations of stresses occur on micro level (e.g., in the case of perfectly rigid nearly touching inclusions). Analysis of the local stresses allows to predict the effective initial yield limit corresponding to the beginning of plastification of the composite medium. Obtained results are in good agreement with data of other authors.

Keywords: Composite materials; Effective properties; Interfacial stresses; Asymptotic methods; Homogenization

1. Introduction

We study filamentary composite materials fabricated by cold wire drawing. 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 soft metals. 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 the 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 Fig. 1 displays micrographs of copper–graphite composite wires we have fabricated by cold drawing; with the external diameter 5.2 mm they contain 48 (one level of heterogeneity) and 48^2

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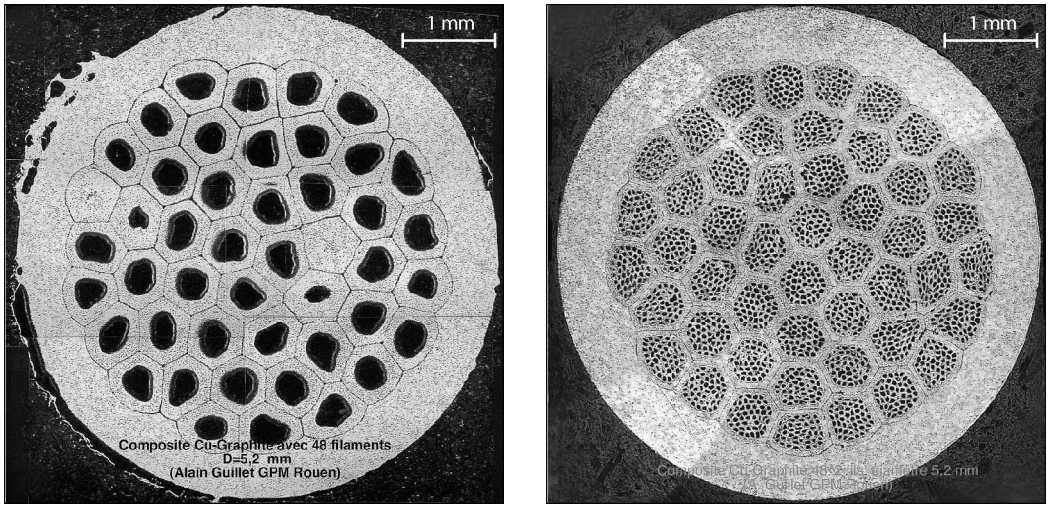

(a) (b)

Fig. 1. Copper–graphite composite wires fabricated by cold drawing; (a) one level of heterogeneity, 48 filaments; (b) two levels of heterogeneity, 48^2 filaments.

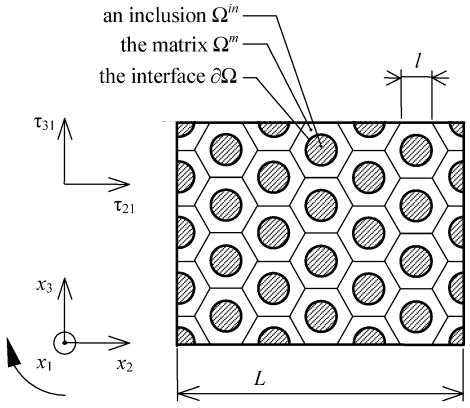

Fig. 2. Composite structure with the hexagonal array of cylindrical inclusions.

(two levels of heterogeneity) filaments of graphite. It can be observed that due to the uniform radial compression of the medium in the plastic flow through a converging conical die the filaments appear to be arranged almost perfectly regularly. Thus, the composite wire may be geometrically approximated by a two-component structure consisting of a matrix with a hexagonal array of cylindrical inclusions (Fig. 2).

Theoretical prediction of effective properties as well as the micro-mechanical simulation of composite materials are important problems in science and engineering, they receive considerable attention of many authors since the pioneering studies of Maxwell (1873) and Lord Rayleigh (1892). Here we are not able to summarize even a small fraction of previous results and refer for detailed reviews of the subject to Manevitch et al. (2002), Torquato (2000, 2002), Sahimi (2003a, 2003b), Nemat-Nasser and Hori (1999), Suquet (1997), Buryachenko (2001), Gailletaud et al. (2003), Benveniste and Milton (2003), Weber et al. (2003). However, it should be noted that many of known methods are able to provide accurate numerical results only in certain partial cases of the problem – when volume fraction of one of the components is relatively small (or large), when physical properties of the components are not too distinct, etc. As usual, the main computational difficulties arise when rapid oscillations of physical fields occur in the composite on micro level (e.g., in the case of nearly touching perfectly rigid inclusions). In the present paper we propose an asymptotic approach which allows to obtain approximate analytical solutions valid for all values of the components' volume fractions and properties.

Our procedure is based on the asymptotic homogenization method. It was originally developed by Bakhvalov (1974) and Bakhvalov and Panasenko (1989), Bensoussan et al. (1978), Sánchez-Palencia (1980), some of the recent applications can be found in the works of Kalamkarov and Kolpakov (1997), Guinovart-Díaz et al. (2001), Rodríguez-Ramos et al. (2001),