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Micromechanical simulations of biaxial yield, hardening and plastic flow in short glass fiber reinforced polyamide

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ABSTRACT

Mean-field homogenization (MFH) is used to predict the biaxial yield behavior, hardening and plastic flow of composite materials made of an elasto-plastic matrix reinforced with misaligned short fibers. The procedure is applied to short glass fiber reinforced polyamide, which represents an important industrial application of those composites. First, MFH is verified against full-field accurate finite element simulations of representative volume elements with multiple fibers. Next, a parametric study is carried out with MFH in order to predict the biaxial plastic behavior of numerous microstructures corresponding to various values of volume fraction, aspect ratio and second-rank orientation tensor components of the glass fibers. Results demonstrate the loss of both isotropic hardening and plastic flow normality, except for 2D random orientation. For illustration, a fit of Hill's orthotropic plasticity criterion is conducted for several orientation tensors.

1. Introduction

The mechanical properties of polyamide containing short glass fibres have been the subject of much attention. These composite materials are known for their stiffness, toughness, resistance to dynamic fatigue, ease of manufacturing, light weight and economy. These properties are the result of a combination of the fibre and the matrix properties and the ability to transfer stresses across the fibre/matrix interface. These composites compete with metals in many engineering applications such as stressed functional automotive parts (fuel injection rails, steering column switches) and safety parts in sports and leisure (snowboard bindings). Fibre reinforced polyamides may be processed by conventional methods, such as injection moulding. Injection conditions such as screw and barrel parameters, mould temperature and design play an important role in the improvement of glass fibre/polyamide mechanical properties [1–4].

The current range of short-fibre compounds on the market is limited in their Glass content, which is usually near 15% volume fraction [1]. Injection-moulded thermoplastic composites contain a wide range of fibre lengths covering at least two orders of magnitude [5–8]. The distribution of fibre diameters is usually fixed for a specific product and will not be further affected by processing in the way that length is reduced. The influence of diameter distribution in glass-fibre composites is not much studied. Since composite properties are actually influenced by aspect ratio, and not simply length, there exist various aspect ratios in injection-moulded composites. The full effect of this disparity of aspect ratios on the balance of composite properties is far from being fully understood at this time [1]. Another factor which is experimentally studied is fibre-orientation distribution [1,2,9,10]. Injection-moulded composites exhibit a complex distribution of fibre orientations caused by a complex interaction between melt properties and moulding conditions. As the melt fills the mould there is fountain flow which initially orients the fibres and polymer molecular chains [11–13].

It is of significant design interest to characterize, both quantitatively and qualitatively, the effect of multiaxial stress on the mechanical behavior of engineering materials. Theoretical methods and experimental investigations on the yield behavior of fiber reinforced composites are available in the literature. Most of them are devoted to the study of the initial yield behavior of unidirectional continuous fiber composites and particle reinforced composites [14–17].

Kregers et al. [14] obtained the biaxial initial yield "surface", for a unidirectional and continuous fiber reinforced material, using the local strain theory. Ellyin et al. [15] carried out experimental studies

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