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Plastic size effect analysis of lamellar composites using a discrete dislocation plasticity approach

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ABSTRACT

Plastic size effect analysis of lamellar composites consisting of elastic and elastic–plastic layers is performed using a discrete dislocation plasticity approach, which is based on applying periodic homogenization to the superposition method for discrete dislocation plasticity. In this approach, the decomposition of displacements into macro and perturbed components circumvents the calculation of superposing displacement fields induced by dislocations in an infinitely homogeneous medium, resulting in two periodic boundary value problems specialized for the analysis of representative volume elements. The present approach is verified by analyzing a model lamellar composite that includes edge dislocations fixed at interfaces. The plastic size effects due to dislocation pile-ups at interfaces are also analyzed. The analysis shows that, strain hardening in elastic–plastic layers arises depending on two factors, namely the thickness and stiffness of elastic layers; and the gap between slip planes in adjacent elastic–plastic layers. In the case where the thickness of elastic layers is several dozen nm, strain hardening in elastic–plastic layers is restrained as the gap of the slip planes decreases. This particular effect is attributed to the long range stress due to pile-ups in adjacent elastic–plastic layers.

1. Introduction

Plastic size effects observed in polycrystals and metallic composites with submicron structures are attributed to dislocation pile-ups at interfaces (Hirth and Lothe, 1982). The pile-ups contribute to increasing dislocation densities near interfaces and to generating elastic long range stresses. The long range stresses are considered not only to work as back stresses in the domain including the pile-ups but also to affect adjacent domains through interfaces. When lamellar composites consist of elastic and elastic–plastic layers, the plastic deformation is apt to induce the pile-ups of oppositely signed dislocations at the interfaces of both sides of the elastic layer (see Fig. 1). The long range effects due to signed and oppositely signed dislocations act to weaken each other as the thickness of the elastic layer decreases. Consequently, the plastic size effects of lamellar composites appear to arise, depending to a large degree, on the thickness of the elastic layer. Discrete dislocation plasticity simulations are considered to have the ability to predict the above plastic size effects since the long range interactions of dislocations are directly implemented as their elastic fields into the framework.

Discrete dislocation dynamics was first used for single crystals subjected to uniform external stresses (Gulluoglu et al., 1989; Devincre and Kubin, 1994; Zbib et al., 1998), and then began being applied to heterogeneous materials with advances in theoretical approaches. A superposition method (Van der Giessen and Needleman, 1995) was based on superposing the

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