ELASTOPLASTIC MODEL APPLIED TO THE EVALUATION OF RESIDUAL STRESSES IN METAL MATRIX COMPOSITES.

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Modern technologies require materials with an unusual combination of properties which cannot be achieved in conventional alloys, ceramics or polymeric materials. To expand on the range of conventional properties, a variety of composite materials have been developed that possess properties superior to each of the component phases; they are elaborated by introducing a reinforcement, usually a ceramic one, into a metal or an alloy. An increasingly important application for Metal Matrix Composites (MMCs) is as reinforcements in structural components that can be used at medium and high temperatures. However, when MMCs are fabricated at high temperatures and subsequently cooled to room temperature, residual stresses are induced in the composite due to the mismatch of the thermal expansion coefficients between the matrix and the reinforcement. These internal stresses can have several consequences for the mechanical behaviour of the component and thus their evaluation is of fundamental interest.

In the present work, the experimental evolution of residual stresses induced by thermal treatment followed by different types of elastoplastic deformation in an aluminium alloy (Al 2124) matrix reinforced with silicon carbide has been studied. To this end the neutron diffraction method (particularly convenient for the study of multi-phase or composite materials, because it allows the strains to be measured in depth independently in each phase of the material) was applied and data analysed using a self-consistent elastoplastic model, facilitating the identification of different types of stresses. In a mean-field approximation, the behaviour of a crystallite embedded in a homogeneous matrix with mean elastoplastic properties can be modelled. Using a self-consistent model (described below), the strains measured by diffraction can easily be predicted as the average for the volume of crystallites for which the Bragg relation is fulfilled.

Two bars were machined from the quenched plate. One bar was then plastically deformed using the four-point bending technique to a maximum compressive surface strain during loading of 1.1% and a residual plastic compressive strain of 0.5%. For these samples the stresses were analysed using the neutron diffraction method and elastoplastic self-consistent model. A similar bar was prepared in order to take strain measurements using the 'in situ' bending test.

a) Self-consistent model

In this work, the calculations have been performed using the formalism proposed by Berveiller and Zaoui [1] and Lipinski and Berveiller [2]. This formalism was first applied to composite polycrystals (Al/SiC_p) by Corvasce et al. [3].

The calculations using the model are performed on the macro-scale (where the average strains and stresses determined by neutron diffraction are defined) and on the grain-scale, in which the behaviour of each crystallite under local stress is analysed. On this grain scale, plastic deformation occurs due to slips on the crystallographic planes. During plastic deformation, some physical phenomena such as multiplication of dislocations and evolution of their spatial distribution inside the grain influence the mechanical behaviour of the grain, which leads to the hardening of slip systems, generation of internal (residual) stresses by plastic incompatibilities, changes of the crystal orientation of the grain, or modification of the grain shape.

b) Validation of the model

In a simulated simple tensile test, the lattice elastic strains were calculated independently for Al and SiC phases. The average strain values in each phase, corresponding to those measured by diffraction, were determined from the elastoplastic model.

The theoretical results were compared with the strains measured in each phase by diffraction for the "in situ" bent samples (Figure 1). In modelling, the Al and SiC single crystal elastic constants were used respectively for both phases of the composite. Purely elastic properties were assumed for the SiC component, while the plastic properties of the Al matrix were varied in order to find the point of best agreement between the measured and theoretical strains (see Figure 1). The optimal model parameters of plastic deformation for Al (i.e.: τ_o - critical shear stress, H - rate of work hardening and A- hardening anisotropy) have been calculated. It should be stated that the theoretical values of τ_o and H could be affected by the residual stresses created by quenching [4]. In this case, both parameters should be treated as effective parameters defined for an equivalent material representing the Al matrix.

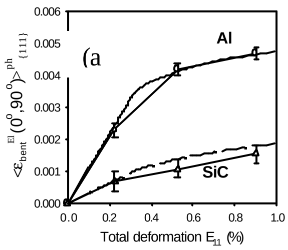

Figure 1. Elastic lattice strains measured 1 mm below the upper surface of the Al/SiC_p bar subjected to bending. The theoretical (line) and experimental (points) evolutions of phase strains in the longitudinal (a) and transversal (b) directions of the sample as functions of the total tensile strain applied are compared.

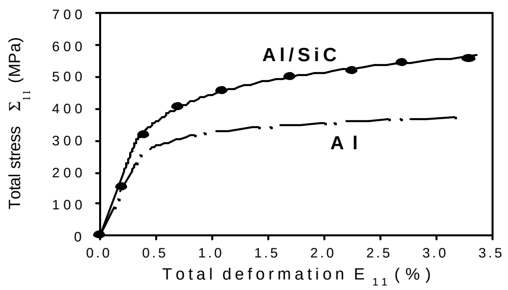

Figure 2. Mechanical test (points) compared with the model results (continuous line) for Al/SiC_p composite. Additionally, the model prediction (dashed line) for single phase Al is shown. The same model parameters as in Figure 1 were used for prediction.

Simultaneously, the calculated total stress vs total strain for the composite was compared to the results of the experimental mechanical tensile test (Figure 2). In this case the macroscopic quantities were calculated as the volume average for all the composite grains.

As shown by Figures 1 and 2, an excellent degree of consistency between the experimental data and model results was obtained for both the neutron diffraction and the simple tensile test on Al/SiC_p composite bars submitted to a plastic deformation. Such a high level of consistency was obtained simultaneously for three different thermal treatments when the plastic parameters of only one component (Al) were modified. Moreover, in the elastic range, the single crystal elastic constants were used as the input data for the model, and no free parameters were optimised.

This proves that the elastoplastic self-consistent model gives a very accurate prediction of the relation between macrostresses and the elastic strains (and stresses) measured for the two phases in the elastic and elastoplastic ranges of deformation. Additionally, the tensile test for single phase Al matrix was predicted using the model parameters (see Figure 2).

In conclusion, this work has allowed to validate the self-consistent elastoplastic model and to determine the model data input physical parameters necessary to predict the mechanical behaviour during plastic deformation of a composite. The parameters characterising the mechanical properties of the Al-metal matrix and the Al/SiC_p composite obtained by the model were found in good agreement with the literature data [5] referring to an Al alloy with the same thermal history than the composite.

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