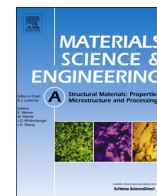




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Grain boundary sliding in copper and its relation to cavity formation during creep

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ABSTRACT

The nucleation of creep cavities, which control the creep ductility is assumed to take place by grain boundary sliding. To determine the grain boundary sliding rate at longer testing times than previously available in the literature, two creep tests have been performed at constant loading rate at 125 °C for oxygen free copper with phosphorus (Cu-OFP). The tests were interrupted after certain strains and the amount of grain boundary sliding (GBS) was measured on flat polished surfaces. The observed amount of GBS per unit strain was 20 to 65 μm. This is of the same order of magnitude as for published tensile tests (Pettersson, 150 and 200 °C) and short time creep tests (Ayensu and Langdon, 400–600 °C). The amount of GBS was modelled based on previously performed FEM investigations. For conditions corresponding to the experiments a value of 52 μm was obtained.

A model by Lim for cavity nucleation at junctions between cell and grain boundaries has been adapted to oxygen free pure copper Cu-OF and Cu-OFP. The results show that the gain in free energy at cavity nucleation is much larger for Cu-OF than for Cu-OFP implying that Cu-OF is much more prone to cavity formation. The modelled difference in free energy gain is sufficient to quantitatively explain the much higher creep ductility in Cu-OFP than in Cu-OF.

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1. Introduction

In Sweden the spent nuclear fuel is planned to be disposed underground by encapsulating in cast iron inserts enclosed by copper canisters [1]. The copper canisters will be made of phosphorus alloyed oxygen-free copper (Cu-OFP). The canisters will experience temperatures of up to 100 °C and an external hydrostatic pressure of about 15 MPa [2,3]. The hydrostatic pressure will give rise to creep deformation in the copper.

During creep, shear stresses will force the grains to slide against each other, so-called grain boundary sliding (GBS). GBS occurs along the grain boundaries as a bulk movement of two grains. GBS is one of the deformation mechanisms of materials at elevated temperature and low strain rate. GBS can give a significant contribution to the overall creep strain. The main mechanism of GBS is the combined motion of dislocations in and around the grain boundaries by glide and climb [4]. GBS takes place discontinuously with time and the amount of shear displacement is not uniform along the grain boundary.

An important effect of GBS is in the process of creep failure in terms of cavity initiation eventually leading to final rupture. Cavities are developed by GBS on the grain boundaries of pure copper specimens [5]. Langdon found that cavities are especially prevalent in pure copper at elevated temperatures and cavity nucleation is inhomogeneous [6]. However, there are many boundaries where no cavities are detected at all. It has been suggested that low angle and twin boundaries are creep cavitation resistant [7].

Observations and measurements on the creep strain attributable to GBS have frequently been performed on the specimen surface using scribe lines or micro-grid (see for example [8]) and more recently also using focused ion beam [9,10]. Using scribe lines on a polished and etched surface, the shear offset under application of stress σ can be observed and measured where the line crosses the grain boundary. Pettersson [11] used this technique to evaluate GBS in oxygen-free copper (Cu-OF) and Cu-OFP in tensile tests at temperatures up to 200 °C. The larger the plastic deformation, the larger was the mean sliding distance. The longest testing times in Pettersson's work for GBS measurements were 3 h. GBS measurements after creep tests for Cu-OF have also been performed by Ayensu and Langdon at 400–600 °C [12]. In this case the longest testing time was 5 h. There is obviously a need to measure grain boundary sliding during longer and more realistic creep times.

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