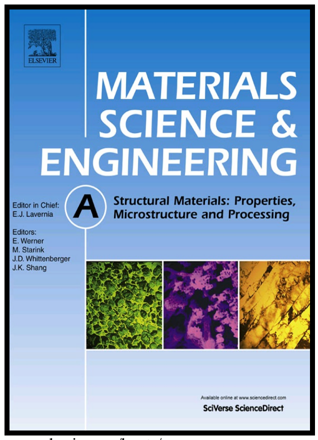

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Fracture in Annealed and Severely Deformed Tungsten

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Abstract

Bulk tungsten normally undergoes brittle fracture at ambient temperatures and has a brittle-to-ductile transition in the range 200-300^{o}C. This limits the use of tungsten for a host of applications. In general, the fracture mode of tungsten at ambient temperature is intergranular whereas at high temperatures it undergoes transgranular fracture. In this work the focus is on the influences of microstructure and temperature on three-point bend fracture of polycrystalline pure tungsten. The samples were processed by equal channel angular extrusion (ECAE) through a 90^{o} die angle via route A in order to produce an elongated microstructure. The mechanical behavior of both unprocessed and processed materials were then characterized by three-point bending at temperatures ranging from -45^{o}C to 425^{o}C. The results show that a single ECAE extrusion (strain ~1.15) reduces the flexural toughness of the material and increases the brittle-to-ductile transition temperature, while two and four extrusions dramatically increase the flexural toughness with little effect on the transition temperature compared to that of the unprocessed material. The flexural toughness of the material subjected to four extrusions (strains exceeding 4.5) is more than 50 times greater than that of the unprocessed material at ambient temperature. This is mainly due to microstructural changes that increases the resistance to intergranular fracture, enhances plastic dissipation, and activates relatively high fracture toughness crack systems for transgranular fracture. The results show that substantial elongation of grains by deformation processing at a temperature near the brittle-to-ductile transition temperature is an effective method for improving the ambient temperature ductility and toughness of bulk polycrystalline tungsten.

Keywords: Brittle-to-ductile transition; Failure Analysis; Fracture; Tungsten; Equal channel angular extrusion; ECAP.

1. Introduction

At ambient temperatures tungsten undergoes brittle fracture with no appreciable ductility. This brittle nature poses a significant hurdle for many applications which would benefit from its other attractive properties such as, high density (~19.3 g/cm^3), high melting temperature (~3422^{o}C), and high strength (~3GPa). The unfortunate poor ductility of tungsten is due to two factors: a low intergranular fracture energy [1, 2], and a relatively high ductile-to-brittle (with decreasing temperature) or brittle-to-ductile (with increasing temperature) transition temperature, generally accepted to be in the range of 200-300^{o}C. The brittle-to-ductile transition temperature of tungsten is affected by impurities, strain rate, surface finish, and microstructural features including dislocation density, grain morphology, and texture [3].