A NOVEL SMALL-SCALE BEND GEOMETRY CREEP TEST TO EVALUATE DEFORMATION AND CAVITATION DAMAGE IN POLYCRYSTALLINE AND BI-CRYSTAL COPPER

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Abstract
Understanding the mechanisms of creep deformation and damage (cavitation) is required for cost-effective and safe operation of high-temperature engineering components. In this study, a model material (high-purity copper) subject to constant load using small cantilever beam test specimens has allowed creep cavity nucleation and early-growth relationships to be linked to the specimen microstructure.

1. Introduction

Many metallic engineering components operate at temperatures and stresses in the creep regime. Components, such as those used for electrical power generation, are typically fabricated from ferritic and austenitic steels. Understanding the mechanisms of creep deformation and damage (cavitation) in these materials is important but, despite the significant research that has been conducted over the past 50 years, there is still a lack of understanding of the microstructural processes that influence and control the development of damage. To provide further insights into this, in the present work a novel small-scale constant load cantilever beam geometry test has been used. The materials selected for the tests were polycrystalline and bi-crystal high-purity copper. Copper provides a simple model material for exploring initiation and early growth of creep cavitation, and allows comparison with crystal-based model predictions.

2. Results

The OFHC copper bi-crystals were designed and grown at the Academy of Sciences, Prague with the grain boundary normal to the growth axis. The bi-crystals were in three groups to give soft/soft, soft/hard and hard/hard grain combinations with a certain rotation to provide a known misorientation. For example, one specimen contained two {100} grains with a 22° rotation misorientation. The polycrystalline material had a mean grain size of 129µm. The constant load tests were conducted using cantilever geometry specimens 36mm x 4mm x 2mm and tested at 285°C for 1000hr, which is about 25% of the predicted creep life. The boundary in each bi-crystal specimen was subject to a stress of 32MPa. We applied the same conditions for the polycrystalline specimen. Each test was conducted in a vacuum of 10^{-10}MPa, as shown in Figure 1a. The bi-crystal specimens were designed and loaded in specific directions to activate slip with optimum Schmid factors based on model predictions, as shown in Figure 1b. The creep tests were optimised using reference stress and finite element computer modelling.

On completion of the tests, both creep deformation and creep cavitation were measured. For the latter, a range of advanced higher spatial resolution techniques were adopted, including scanning electron microscopy, electron backscattered diffraction and focused gallium ion beam serial imaging and section milling. Creep cavity number density and size measurements were made using advanced image analysis procedures. Polycrystalline and bi-crystal results are compared, with particular attention given to the role of Schmid factor and misorientation on the initiation and early growth of the creep cavities.

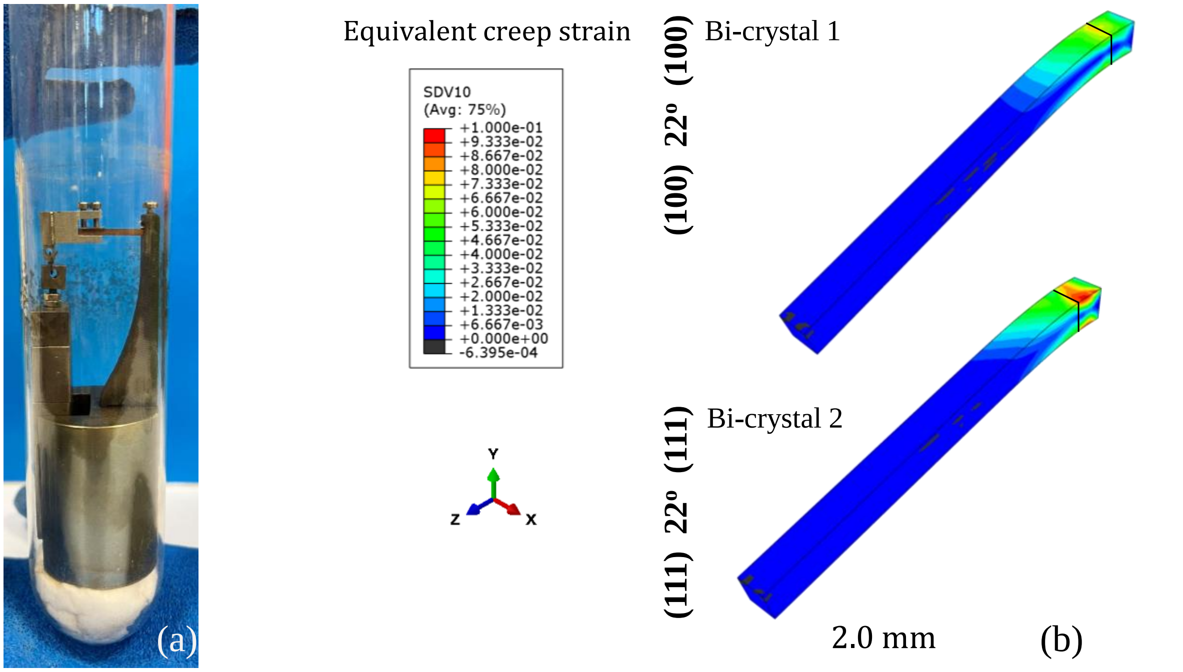

Figure 1. (a) Small cantilever beam test specimen assembly. (b) Creep strain distribution prediction by finite element analysis for bi-crystals: 1. Joint of two (100) single crystals with 22° misorientation grain boundary; 2. Joint of two (111) single crystals with 22° misorientation grain boundary.

3. **Conclusions**

The approach of this study has eliminated the influence of a wide range of parameters that add to the complexity in interpreting creep cavity initiation and early growth in engineering alloys. This then allows focus on specific, key microstructure features in a precipitate-free model material. The early stages of creep nucleation and growth are linked with key microstructural parameters and underlying mechanisms that are compared with model predictions. These data inform the development of microstructure-based models of cavitation, an essential step in providing predictive models for the complex microstructure materials selected for engineering components.

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