INFLUENCE OF FABRICATION ON MECHANICAL PROPERTIES OF SiC-WHISKER-REINFORCED ALUMINA

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ABSTRACT

Samples of SiC-whisker-reinforced Al₂O₃ composites obtained from three different sources have been crept in compression at 1400°C using both constant load (CL) and constant strain rate (CSR). Macroscopic results indicate some difference in behavior due to fabrication. TEM is used to support this hypothesis.

INTRODUCTION

It has been shown that the addition of silicon carbide whiskers (SiCₜ) to a polycrystalline Al₂O₃ matrix enhances its resistance to fracture [1]. Recent investigations have also shown that SiCₜ/Al₂O₃ composites are more creep resistant than pure alumina, for a variety of whisker concentrations and experimental conditions [2,3]. Degradation in oxidizing atmospheres is, however, the main limitation for the use of this composite system at high temperatures [2,4].

It is generally accepted that high temperature deformation of fine-grained Al₂O₃ is controlled by grain boundary sliding (GBS) [5]. The improved resistance of SiCₜ/Al₂O₃ to plastic deformation is considered to be due to the pinning of the grain boundaries. Detailed creep and microstructural studies performed by DeArellano-Lopez [6] have supported this hypothesis.

Nevertheless, it is well known that mechanical properties of ceramics are greatly influenced by the way they are fabricated [7]. In this study, we will compare the creep response of SiCₜ/Al₂O₃ composites obtained from several sources in order to obtain more information about the effects of fabrication on mechanical properties.

EXPERIMENTAL

Materials

Silicon carbide-whisker-reinforced alumina composites were obtained from ARCO Chemicals (ARCO), Oak Ridge National Laboratory (ORNL), and Argonne National Laboratory (ANL). All sources used the same Al₂O₃ powders, with grain size (GS) = 0.3 μm, and the same SiC whiskers (diameter = 1 μm, length = 10 μm). Samples were processed by uniaxial hot-pressing at approximately 1800°C to a relative density ≥ 99%. Table I summarizes each composite with its SiC volume fraction (Vₜ). As-fabricated GS varied between 1.5 and 2 μm.
TABLE I
Samples and whisker concentration

<table>
<thead>
<tr>
<th>Sample</th>
<th>ARCO15</th>
<th>ARCO25</th>
<th>ANL15</th>
<th>ANL30</th>
<th>ORNL20</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_w$</td>
<td>18</td>
<td>30</td>
<td>15</td>
<td>30</td>
<td>20</td>
</tr>
</tbody>
</table>

ARCO used densification additives, while ORNL and ANL did not. Furthermore, ARCO used as-received whiskers while ORNL and ANL chemically etched the whiskers to remove the thin amorphous SiO$_2$ coating the SiC$_w$.

Several microstructural studies (TEM, SEM and optical microscopy) on the as-processed composites are available in the literature [6,8].

Techniques

Compressive deformation tests, constant load (CL) and constant strain rate (CSR) were conducted at 1400°C, in inert atmosphere (argon), on 5 x 2 x 2 mm specimens. Thin foils from deformed samples were prepared with traditional techniques [6] and TEM was used to study microstructure in order to support results obtained from mechanical experiments.

RESULTS AND DISCUSSION

Results from creep tests of ANL samples are included in figure 1. Similar behavior has been observed in ARCO and ORNL composites [6]. Results have been analyzed in terms of the creep equation that relates strain rate $\dot{\varepsilon}$, to stress $\sigma$ by

$$\dot{\varepsilon} \propto \sigma^n$$

in which the value of the parameter n (stress exponent) is related to deformation mechanisms through several models developed for traditional monolithic materials [9].

The value of $\dot{\varepsilon}$ for the various composites, at constant stress, in the $n = 1$ regime, never varied by more than a factor of five. Therefore, the effects of fabrication are not readily discernable in the absolute creep rate.

For every composite, two values of stress exponent were calculated, indicating a changing mechanism, depending primarily on stress. Table II contains n values in each regime ($n_1$ and $n_2$) and the transition stress ($\sigma_C$) defined as the intersection of the extrapolation of both regimes. In all cases, the low stress regime is characterized by $n=1$, whereas the high stress regime is characterized by $n > 2$.

<table>
<thead>
<tr>
<th>Sample</th>
<th>$n_1$</th>
<th>$\sigma_C$ (MPa)</th>
<th>$n_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARCO15</td>
<td>$1.1 \pm 0.2$</td>
<td>65</td>
<td>$2.4 \pm 0.1$</td>
</tr>
<tr>
<td>ARCO25</td>
<td>$1.0 \pm 0.1$</td>
<td>75</td>
<td>$3.0 \pm 0.1$</td>
</tr>
<tr>
<td>ANL15</td>
<td>$0.8 \pm 0.1$</td>
<td>100</td>
<td>$3.4 \pm 0.2$</td>
</tr>
<tr>
<td>ANL30</td>
<td>$0.9 \pm 0.2$</td>
<td>170</td>
<td>$5.9 \pm 0.5$</td>
</tr>
<tr>
<td>ORNL20</td>
<td>$1.3 \pm 0.1$</td>
<td>157</td>
<td>$5.4 \pm 0.5$</td>
</tr>
</tbody>
</table>
The composite nature of the system under study makes microstructural observation necessary to determine the mechanism represented by each stress exponent. TEM has been performed for this purpose (figs. 2 and 3). Such analysis has led to the conclusion that the deformation mechanism is pure diffusional at low stresses and occurs by damage accumulation at high stresses [6,10].

The effect of fabrication on \( \sigma_c \) can be observed in table II. ARCO composites have \( \sigma_c \) values systematically lower than the ones obtained for ANL and ORNL. This indicates that the damage accumulation regime is reached at lower stress in the less pure composites.

The value of \( \sigma_c \) (appearance of damage at a lower stress in form of intergranular cavities and propagation of cracks) has to be related then to the amount, type, and distribution of additives used and to the whiskers treatment. All these facts will certainly affect the properties of grain boundaries and whisker/grain interfaces.

CONCLUSIONS

Additives used in the fabrication of SiCw/Al2O3 composites determine, in part, the value of \( \sigma_c \). Low values of \( \sigma_c \) means that damage occurs at lower stresses. This parameter may be an extremely useful measure of the effects of processing on mechanical properties.
Figure 2. TEM of ORNL20 deformed in the diffusional creep regime at 1400°C in argon using a stress of 45 MPa and achieving a total strain of 0.10. Notice the absence of dislocations, cavities or cracks.

Figure 3. TEM of a ORNL20 Sample deformed 0.14 at 1400°C in argon using a maximum stress of 320 MPa. Damage in the form of cavities and cracks (arrows) is visible. Cracks are deviated by the whiskers (w).
REFERENCES


