SILICIDE-FIBRES/REFRACTORY-MATRIX COMPOSITES: FABRICATION AND MECHANICAL PROPERTIES

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ABSTRACT

Until recently, molybdenum silicides have been used in molybdenum alloys either in the form of coatings that protect the body of an alloy from oxidation or as particles to enhance strength and creep resistance of the alloy. In the present work, silicides are introduced into molybdenum and molybdenum-niobium matrix in the shape of a fibre by using the internal crystallization method. The primary goal is to enhance fracture toughness of silicide/refractory-metal materials. The microstructure and mechanical properties of the composites are discussed in the present paper.

Keywords: Fibrous composites, molybdenum matrix, silicide fibres, microstructure, creep, strength, notch sensitivity.

INTRODUCTION

Molybdenum alloys with the use temperature up to 1300°C have been developing to replace nickel superalloys in gas turbine hot elements since the superalloys have the maximum use temperature of about 1100°C and this limits thermal efficiency of gas turbines. Sufficient gas corrosion resistance of the Mo-Si-B system is now a well established property (Majumdar). Creep resistance of such alloys is also sufficiently high at temperatures up to 1300°C (Jain), however fracture toughness of the alloys has not reached values acceptable for their usage in heavily loaded structural elements (Lemberg).

Metal matrix fibrous composition (MMCs) differ from metal alloy primarily by a fracture mechanisms that can yield simultaneous increase in strength (creep strength) and fracture toughness (Mileiko, 1997; Mileiko, 2015). This characteristic feature of MMCs makes attractive developing molybdenum-matrix composites as an alternative to heat resistance molybdenum alloys. Silicide fibres seem to be an appropriate choice. An existence of such fibres can be real if the internal crystallization method developed some decades ago for crystallization of oxide fibres in the channels in a molybdenum matrix (Mileiko, 1992) can be used to crystallize silicides. Recent experiments (Mileiko, 2014) have shown such a possibility. In what follows, some details of fabrication process, the composite microstructure and mechanical properties of silicide-fibre/refractory-matrix composites are presented.

RESULTS AND DISCUSSION

Three types of the composites were obtained by using the internal crystallization method. Combinations of matrix (foil and wire) and materials are shown in Table 1. Raw materials for
fibres were prepared by self-propagating synthesis. Powders obtained in such a way were melted, the melts were infiltrated into the matrix and crystallised to form the fibre. Obviously the melts interacted with the molybdenum matrix and the final composition of the fibres and matrices differs from that of raw materials. X-ray spectra taken from cross-sections of the specimens are presented in Figs. 1 to 3. Resulting fibre and matrix compositions are also shown in Table 1.

Table 1 - Characterization of composite specimens.

<table>
<thead>
<tr>
<th>Composite type</th>
<th>Fibre raw material</th>
<th>Fibre composition</th>
<th>Matrix</th>
<th>Pulling rate mm/min</th>
<th>Illustrations</th>
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<tbody>
<tr>
<td>1</td>
<td>Mo$_5$Si$_3$+MoSi$_2$</td>
<td>Mo$_3$Si</td>
<td>Mo</td>
<td>250</td>
<td>Fig. 1</td>
</tr>
<tr>
<td>2</td>
<td>NbSi$_2$</td>
<td>Nb$_2$Si$_3$+Nb$_2$Si</td>
<td>Mo+Nb</td>
<td>30 – 250</td>
<td>Fig. 2</td>
</tr>
<tr>
<td>3</td>
<td>Nb$_3$Si$_5$</td>
<td>Nb$_3$Si+MoSi$_2$+Nb$_2$C</td>
<td>Mo</td>
<td>50</td>
<td>Fig. 3</td>
</tr>
</tbody>
</table>

Fig. 1 - X-Ray spectrum obtained from a cross-section of a specimen of composite of type 1. The presence of SiC and Si is a result of impurities in the raw material.

Fig. 2 - X-Ray spectrum obtained from a cross-section of a specimen of composite of type 2.
Proceedings of the 5th International Conference on Integrity-Reliability-Failure

Strength of the composite specimens was measured in 3-point bending from room temperature up to 1400°C (Fig. 4). Composites of type 1 look stronger than others. It is important to note that high temperature strength of composites of type 1 at 1400°C reaches ~400 MPa that is about 2/3 of the RT strength value. Note also that the tensile strength value of molybdenum matrix recrystallised during fabrication process performed at a temperature of ~2000°C is just ~60 MPa (Mileiko, 1997).

An important mechanical property of molybdenum-based material is fracture toughness or notch sensitivity. The value of critical stress intensity factor for fibrous composites is not defined sufficiently strictly as fracture zone at the crack tip in composites can be much larger than the Orowan plastic zone in metal alloys (Mileiko, 2015). Hence, more reliable assessment of the crack resistance for composites is ratio of the values of strength of specimens with and without the notch. Such assessments are actually used by some author, see i.e. (Volkmann).

In the preliminary experiments, composite specimens of a length of about 65 mm with numbers COXXX were cut into two parts, one part (numbers COXXX1) was tested in 3-point bending without the notch, the second part (numbers COXXX2) were notched by EDM and tested also. A typical load/displacement curve for a notched specimen is shown in Fig. 5. The non-brittle behavior of the composite is obvious. The results of these tests are presented in Table 2.

Fig. 3 - X-Ray spectrum obtained from a cross-section of a specimen of composite of type 3. The presence of SiC and Nb2C is a result of impurities in the raw material.

Fig. 4 - Strength of composites versus testing temperature. Fibre volume fraction is 35 – 40%

Fig. 5 - Typical force/displacement curve at 3-point bending of a specimen with the notch
Table 2 - Results of testing of the unnotched specimens and those with the notch.

<table>
<thead>
<tr>
<th>Specimen number</th>
<th>Strength $\sigma_N$ of specimens with the notch (MPa)</th>
<th>Strength $\sigma_0$ of unnotched specimens (MPa)</th>
<th>Composite type</th>
<th>Crystallisation rate (mm/min)</th>
<th>Ratio of the notch length to specimen height</th>
<th>$\sigma_N/\sigma_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>C0162</td>
<td>181</td>
<td>265</td>
<td>3</td>
<td>50</td>
<td>0.41</td>
<td>0.68</td>
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<tr>
<td>C0171</td>
<td>234</td>
<td>368</td>
<td>1</td>
<td>250</td>
<td>0.5</td>
<td>0.64</td>
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<td>C0179</td>
<td>373</td>
<td>337</td>
<td>2</td>
<td>250</td>
<td>0.49</td>
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<td>C0183</td>
<td>365</td>
<td>489</td>
<td>2</td>
<td>250</td>
<td>0.5</td>
<td>0.75</td>
</tr>
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</table>

ACKNOWLEDGEMENTS

Financial support of Russian Foundation for Basic Research (Project 14-08-01254) is gratefully acknowledged.

REFERENCES