INFLUENCE OF FACTORS ON MICROMECHANISMUS OF FRACTURE Al-Al₄C₃ SYSTEM

O. Velgosová, M. Besterci, M. Varchola

Abstract
The principle of strength enhancement in dispersion strengthened materials lies in introducing high strength dispersed phase into the matrix. This phase can be introduced into the matrix from outside, or it can be formed „in-situ“ during the milling, which is called the method of mechanical alloying.

The change in fracture behaviour for the Al-12Al₄C₃ system was investigated and analysed at temperatures from 20 to 400°C and strain rates from 2.5·10⁻⁵ to 10⁻¹ s⁻¹. At room temperature during tensile testing the strain is controlled by dislocation movement and reactions. For high temperatures in the investigated region the principal mechanism keying the strain is the presence of dynamic recovery processes. Strain rate influences on fracture are analysed.

Keywords: dispersion strengthened materials, mechanical alloying, fracture mechanism, SEM analysis

INTRODUCTION
The dispersion strengthened alloys Al-Al₄C₃ prepared by mechanical alloying using powder metallurgy technology are promising structural materials enabling significant weight reductions for use first in aircraft and car industry, also at elevated temperatures [1-3]. Mechanical alloying is a solid-state reaction process, in which a mixture of powders is converted into an alloy by facilitating a series of high-energy collisions in a controlled (usually inert) atmosphere. By mechanical alloying powder particles are repeatedly deformed, fractured and cold welded [4]. This is in contrast to conventional ball milling, in which powder particles are simply mixed while particle size, shape and density change. The chemical reaction mechanisms driven by the high-energy particle collisions in the mill are currently not well understood [5]. In present work we analysed fracture at different strain rates from 2.5·10⁻⁵ s⁻¹ to 10⁻¹ s⁻¹ and temperature of 20°C.

EXPERIMENTAL MATERIAL AND TESTING METHODS
The experimental material has been prepared by mechanical alloying. The Al powder with a grain size of <50 μm was cold milled in an attritor during 90 min with an addition of 4 wt.% of graphite KS 2.5 assuming that 12 vol.% Al₄C₃ was formed. The granulate was cold pressed with 600 MPa on the cylinders. The degree of reaction during milling is very low (10%), most dispersoids are formed during the heat treatment. During subsequent heat treatment at 550°C/3 h a chemical reaction 4Al+3C → Al₄C₃ took place, the dispersoids are formed during these heat treatments. The cylinders were hot extruded at 600°C with cross-section reduction of 94% [6,7].
Fig.1. Distribution of large particles – category A, a) transverse cut, b) longitudinal cut.

The microstructure analysis of this system shows that the mean matrix grain size was 0.8 μm, the Al₄C₃ particles were distributed in lines and formed two different size categories. Besides the Al₄C₃ phase, the system also contained Al₂O₃ which was detected chemically [7]. The category A are large particles, observed by optical microscopy and SEM, with sizes of 0.4 – 5 μm, and the category B are small particles with mean size of 30 nm found in thin foils. The particles of both categories are depicted in Figs.2 and 3.

Fig.2. Distribution of small particles – category B.

Fractures were analysed at different strain rates, from 2.5·10⁻⁵ to 10⁻¹ s⁻¹, and temperatures from 20 to 400°C using SEM. For tensile testing specimens 3 mm in diameter and 15 mm gauge length were machined.

RESULTS AND DISCUSSIONS

The results of the yield strength R_p0.2 and the reduction of area Z for 12 vol.% Al₄C₃ at different test temperatures and applied strain rates are summarised in Table 1. Note
that by temperature 400°C and strain rate $\dot{\varepsilon} = 10^{-1} \text{s}^{-1}$ a rapid increase in $Z$ value occurs, but the value of yield strength does not reflect this substantial change. Corresponding results were obtained for both UTS and elongation.

Tab.1. The value of yield strength $R_{p0.2}$ and reduction of area $Z$ for 12 vol.% Al$_4$C$_3$ at different temperatures and strain rates.

<table>
<thead>
<tr>
<th>$R_{p0.2}$</th>
<th>Strain rate [s$^{-1}$]</th>
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<tbody>
<tr>
<td>Temperature [°C]</td>
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<tr>
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<table>
<thead>
<tr>
<th>$Z$</th>
<th>Strain rate [s$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature [°C]</td>
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<tr>
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<td>21.3</td>
</tr>
<tr>
<td>400</td>
<td>62.3</td>
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</table>

Figures 3 and 4 represent the fracture surface for a high strain rate of $\dot{\varepsilon} = 10^{-1} \text{s}^{-1}$ and a low strain rates of $\dot{\varepsilon} = 2.5\cdot10^{-5} \text{s}^{-1}$ at a temperature of 20°C, respectively. There are no significant differences between them. Both are ductile, transcryalline fractures with ductile dimples. The dimples are shallow with a characteristic dimension of 0.45 μm.

Fig. 3. Transcyrstalline fracture surface obtained with strain rate of $10^{-1} \text{s}^{-1}$ and temperature 20°C.

Fig. 4. Transcyrstalline fracture surface obtained with strain rate of $2.5\cdot10^{-5} \text{s}^{-1}$ and temperature 20°C.
At low strain rate, $\dot{\varepsilon} = 2.5 \times 10^{-5} \text{s}^{-1}$, and temperature of 400°C the reduction in area $Z = 8\%$. Typical microfacets of the fracture are shown in Fig.5. Prevailing, developed intercrystalline facets are present, with dimensions corresponding to the fine grain size, and with great angle disorientation. There are small parts of fracture showing crests of ductile facets. For the strain rate $\dot{\varepsilon} = 10^{-1} \text{s}^{-1}$ fracturing occurs with a reduction of area $Z = 64\%$. The fracture is ductile and transcrystalline with developed deep dimples, Fig.6. The dimple dimension characteristic is 0.65 μm.

Surfaces of fractures at a strain rate of $\dot{\varepsilon} = 2.5 \times 10^{-5} \text{s}^{-1}$ and temperature 300°C showed underdeveloped intercrystalline facets and ductile fracture for the end of the process. At a strain rate of $\dot{\varepsilon} = 10^{-1} \text{s}^{-1}$ the fracture was transcrystalline with dimples. The dimples were deeper and larger than those at 20°C. The characteristic dimple diameter is around 0.6 μm.

CONCLUSIONS
1. The microstructure analysis of Al-Al₄C₃ system shows that mean grain size was 0.8 μm, the Al₄C₃ particles were distributed in lines and formed two different size categories (A - 0.45 μm and B - 30 nm).
2. There is a marked decrease of plastic properties of Al-12Al₄C₃ system for the strain rate of $\dot{\varepsilon} = 2.5 \times 10^{-5} \text{s}^{-1}$ with an increase of temperature in the investigated region. This is explained by changes in the micromechanism of deformation and by a change of fracture mode. Fracture surface shows a transition from ductile fracture with dimples at 20°C, to intercrystalline fracture, with increase of temperature, an indication of exhausted grain boundary plasticity.

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REFERENCES