Effect of particle size, forging and ageing on the mechanical fatigue characteristics of Al6082/SiC$_p$ metal matrix composites

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Abstract Addition of inexpensive silicon carbide particulates (SiC$_p$) in the aluminium alloy matrix results in materials with properties non-obtainable in monolithic materials. The forging process results in improved properties as well as forms a shape of the final product. The age-hardening processes accelerate the coarse hardening process of the composites and improve strength and ductility. The size, morphology and volume fraction are the key controlling factors that control the plasticity and the thermal residual stresses in the matrix and thereby its mechanical and fatigue properties. This research paper focuses on the effect of particle size, forging and ageing on the mechanical and fatigue properties of the cast, forged and age-hardened aluminium 6082 (Al6082) reinforced with SiC$_p$. Al6082 reinforced with three different particle sizes of SiC$_p$ (average particles size of 22, 12 and 3 µm) in the forged and ageing conditions were studied. The samples were characterised by optical microscopy, hardness, tensile and fatigue tests. The forged microstructure shows a more uniform distribution of SiC$_p$ in the aluminium matrix. The addition of SiC$_p$ results in improved tensile strength, yield strength and elastic constants of the composites with reduction in ductility. It also increases the fatigue strength of the composites by increasing the number of cycles required for fatigue failure of the composites for the given value of stress. The results also show considerable improvements in mechanical fatigue properties due to forging and ageing heat treatment of the metal matrix composites.

Keywords Metal matrix composites · Particle size · Forging · Ageing tensile and fatigue behaviour

1 Introduction

The great potential of application of metal matrix composites (MMCs) in automotive, aerospace and other industries have started reaching its widespread importance. The addition of relatively inexpensive silicon carbide particulates (SiC$_p$) results in material having a very low coefficient of thermal expansion and high specific strengths, wear resistance and heat resistance than conventional Al alloys.

Varieties of techniques are used to manufacture MMCs to the useful engineering shapes [1] such as (1) liquid phase techniques (solidification processing), (2) semi-solid phase techniques and (3) solid phase techniques. Most of the methods are expensive and require skilled, complicated operations [2]. The liquid phase routes are more similar to conventional casting and are economical for the manufacture of MMCs. Solidification processing as in conventional casting leads to casting defects that include porosity and inclusions [3–5]. The characteristics of composites are greatly influenced by these defects.

The improvements in strength and ductility are observed with the application of plastic-forming processes like forging, extrusion etc. [6]. These alterations in properties are attributed to the factors which control the mechanical properties of these materials. Forming process alters structural parameters, which influence the characteristics, as they are sensitive to the reinforcement, production and
fabrication methods [4]. Recent widespread publicity on the increasing use of light metals in the transport sector replacing steel has possibly overlooked the tried and proven technology of forging aluminium in a wide range of applications. So, it becomes important to establish a relationship between the factors that affect the properties of the materials. Great improvements in mechanical properties of Al alloys can be achieved by suitable solution treatment and ageing conditions [6–9]. A lot of works have been carried out to study the effect of ageing on the mechanical properties of the composites, but there is little work on the effect of forged metal matrix composites with ageing and their relationship.

A study has been made to understand the effect of particle size, forging and ageing on the mechanical and fatigue properties of Aluminium 6082 (Al6082) reinforced with three different sizes of SiCp. Porosity, hardness, tensile and fatigue tests are conducted on the cast, forged and age-hardened specimen to characterise the mechanical and fatigue properties of the composites.

2 Experimental details

Stir-cast metal matrix composites Al6082/ SiCp were used for the study. The matrix material used in this work was Al6082 containing 1.0%Si, 0.5%Fe, 0.1%Cu, 0.8%Mn, 1.0%Mg, 0.2%Zn, 0.1% Ti and remainder Al. The density of the aluminium alloy is 2.70 g/cm$^3$. The alloy is reinforced with SiC particles of abrasive grade. The metal matrix composites of aluminium 6082 reinforced with SiCp are prepared in a crucible furnace. Three different sizes of SiCp with average particle size of 22, 12 and 3-μm sizes were fabricated. The composites were henceforth called as Almmc22, Al mmc12 and Al mmc3, respectively. The composites were fabricated by adding pre-oxidised (at 650°C for 2 h) SiCp into the liquid matrix alloy at constant rate and at constant stirring. The SiC particles were added to 10% weight fraction of Al6082. The stirred melt is then poured into the permanent iron die mould to obtain composites of size 17-mm diameter and 230-mm length. Magnesium is added to increase the wettability of the particulates. No evidence of macro-casting defects was seen. The matrix metal was also cast in the same process to standardise the casting process.

Optical micrographs were examined to study the effect of SiCp percentage on the microstructure and its distribution. The cast MMCs are then forged in a closed die forging at a temperature of 500°C. The porosity, hardness and tensile tests were carried out on the as-cast and forged specimens to compare the resultant effect on the MMCs. The samples were artificially aged to T6 condition by solutionising at 550°C for 1 h followed by precipitation heat treatment at 178°C for 8.5 h [27]. Hardness and tensile tests were also carried out on the aged specimens to study their characteristics.

<table>
<thead>
<tr>
<th>Material</th>
<th>Calculated density (g/cm$^3$)</th>
<th>Experimental density, as-cast (g/cm$^3$)</th>
<th>Experimental density, forged (g/cm$^3$)</th>
<th>Percentage of porosity, as-cast (%)</th>
<th>Percentage of porosity, forged (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al Matrix</td>
<td>2.7</td>
<td>2.6474</td>
<td>2.672</td>
<td>1.9481</td>
<td>1.037</td>
</tr>
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<td>Al mmc22</td>
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<td>2.66</td>
<td>2.704</td>
<td>3.2023</td>
<td>1.6011</td>
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<tr>
<td>Al mmc12</td>
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<td>2.655</td>
<td>2.6997</td>
<td>3.384</td>
<td>1.757</td>
</tr>
<tr>
<td>Al mmc3</td>
<td>2.748</td>
<td>2.6548</td>
<td>2.69</td>
<td>3.3915</td>
<td>2.110</td>
</tr>
</tbody>
</table>

Fig. 1 The microstructure of the composite Al6082/SiC/10p in the a as-cast b forged conditions

Table 1 The densities and porosity content of the matrix alloy and the composites in the as-cast and forged conditions