

Effect of SiC concentration and strain rate on the compressive deformation behaviour of 2014Al-SiCp composite

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Abstract

The compressive deformation behaviour of 2014Al-SiCp composites containing varying amount of SiCp has been studied at different strain rates (10^{-3} to 10^{-1} s⁻¹). The composite materials were prepared through stir-casting (vortex) method. The yield stress, Young's modulus, percentage elongation and fracture stress were measured from the true stress–true strain plots. The Young's modulus of the materials was found to increase with increase in SiCp content. But the yield stress and the fracture stress do not follow any definite relationship with SiC content. The composite, containing 15 vol.% SiCp, exhibits minimum stress values irrespective of strain rates. The composite, containing either less or greater than 15 vol.% SiCp, exhibited almost same yield stress as that of the alloy. The elongation, in general, decreases with increase in SiCp. It was further found that the above parameters do not follow any definite trend of variation with strain rate for any investigated materials. The strain-hardening exponent and the strain rate sensitivity were determined for each of the materials at different strain rates. It was noted that the plastic strength coefficient also follows the same trend of variation with SiCp content irrespective of strain rate; but the strain-hardening exponent increases marginally with increase in SiCp content. The strain-hardening exponent also remains invariant to strain rate. The strain rate sensitivity is noted to be very low. However, within this variation, the composite containing 15 vol.% SiC exhibits the minimum value of strain rate sensitivity. This also suggests that at room temperature, the cast alloy and/or composites are almost insensitive to strain rate.

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1. Introduction

Aluminium metal matrix composites (AMCs) are found to be potential materials because of their excellent physical, mechanical and tribological properties [1–8]. Because of good combination of thermal conductivity and dimensional stability (low thermal expansion coefficient) AMCs containing 50–60% ceramic reinforcement is found to be potential materials for electronic packaging [9–12]. Higher wear and seizure resistance, in combination with higher specific strength and stiffness, and improved high temperature strength make them suitable for automobile and aerospace components [13–17]. In recent years, attentions were also being paid for using AMCs as personal armour [18] where higher specific strength, stiffness and

greater work hardening rate are important considerations. The application of AMCs is also sought for mineral engineering applications for component (insert) in hydro-cyclone [19]. The use of AMCs in defence, aerospace and automobile also depends on how AMCs behave during elasto-plastic deformation. Several attempts were made for understanding the deformation behaviour of AMCs [20–35]. In general, it was reported that the specific strength and stiffness of the alloy increases with the addition of ceramic reinforcement especially in the form of whisker, continuous and discontinuous fibres. This is possible because of uniform distribution, sound interface between the reinforcement and matrix, and the reinforcements have critical aspect ratio and are free from any inherent flaws [20–22]. The strength and elastic modulus of the composite improve to a lesser extent in particle reinforced composite as compared to that in fibre and whisker reinforced composites. This is primarily because of the fact that the critical aspect ratio in particle is significantly less as compared to that required for effective load transfer. These values are further affected due to particle cluster-

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ing [22–25], presence of flaws [26] and weak interface bonding especially when composites are synthesized through solidification route (stir-casting technique). However, this technique has unique advantages. This include (i) this method could easily be adopted using the present set up, (ii) any types of billets could be made and (iii) composite billets could be subjected to secondary processing like forging, rolling and extrusions [27]. As a matter of this fact, many researches have been carried out in the development and characterization of aluminium alloy particle reinforced composites. The tensile and the compressive deformation behaviours of particle reinforced AMMCs have been carried out both at room temperature and elevated temperature. It was reported that the strength and the stiffness increase with decrease in particle size. But there is a greater tendency of agglomeration with decrease in particle size, which again leads to reduction in strength [23,24,28,29]. It was also reported that because of greater possibilities of flaws present in the coarser particles, the strength of particle reinforced AMCs decreases with increase in particle size [30]. Additionally, the extent of dislocation strengthening is less in the case of coarser particle reinforcement [30]. The strength and the stiffness also increase with increase in reinforcement content. However, according to Geni and Kikuchi [21], quite significant improvement in strength is noted when 5% SiC particle is added; further increase in SiC content leads to marginal improvement in strength values. This may be because of greater agglomeration of particles and higher degree of micro-porosity present in the composite at higher SiC content.

The effect of age hardening treatment on the compressive deformation behaviour has been investigated in details by several investigators. It was reported that peak aging leads to improvements in strength and hardness of composite materials like that observed in the case of alloys. The strength of particulate composite was reported to be decreased with increase in temperature. It was further mentioned that the strength of the composite is, in general, higher than that of the alloy at the elevated temperature [31,32]. This signifies that the composite has the capability to withstand higher temperature as compared to that of the alloy. A few literatures also report the deformation behaviour of particle reinforced AMCs at varying strain rate especially at elevated temperature [33–37]. It was reported that the flow stress at a higher temperature and at a given strain increased with increase in strain rate [33–36]. Chan and Tong [33] and Wang et al. [34] reported that flow stress of Al6061/20SiCw composite increased significantly with increase in strain rate (from 10^{-1} s^{-2} to 10^{-1} s^{-1}) when the tests were conducted at near solidus temperature 873 K. Chan and Tong [33] also reported that the value of strain rate sensitivity exponent of the above mentioned composite to be around 0.36 under tensile loading when the tests were conducted at 873 K. Wang et al. [34] reported that highest value of strain rate sensitivity exponent could be achieved at a temperature near solidus temperature. Han et al. [35] also reported similar observation in 2124/SiCp composite at temperature between 723 and 823 K. But, the flow stress does not follow any specific trend with the temperature at which the tests were conducted. The strain-hardening exponent of aluminium metal matrix composite has been investigated by

Martin et al. [32] on T4 heat treated Al2124/17% SiCp composite at various temperature. According to these investigators, the strain-hardening exponent of both the alloy and the composite decreased with increase in temperature. It was further reported that the strain-hardening exponent also decreased with increasing in strain. It was reported that the average strain-hardening exponent of the alloy and the composite at room temperature are 0.36 and 0.28, respectively [32]. In general, the strain-hardening exponent of the alloy was reported to be greater than that of the composite irrespective of temperature. On the other hand, according to these investigators, the plastic strength coefficient of the composite is greater than that of the alloy. The nature of the variation of strain-hardening exponent and plastic strength in the composite as compared to that in the alloy contradicts each other. So far, to the best of our knowledge, the effect of the strain rate and the volume fraction of SiC particle on the elasto-plastic compressive deformation behaviour of SiC particulate reinforced cast AMCs has not been studied systematically. Furthermore, the effect of SiC concentration and the strain rate on the strain-hardening exponent and the plastic strength coefficient of SiC particle reinforced AMCs has not yet been studied. The present study aims primarily at investigating these aforesaid aspects. In the present study, 2014Al/SiCp cast composite has been taken as the model composite material.

2. Experimental

2.1. Synthesis of composites

The alloy and the composites were synthesized using solidification route. The alloy nominally contains 4.5 wt.% Cu, 0.3 wt.% Fe, 0.7 wt.% Mg, and balanced Al. The SiC particles used in the present study as the reinforcing phase and these were incorporated in the alloy matrix through mechanical stirring while the alloy was melted. After thorough mixing, the composite mixture was poured into the permanent cast iron mould to get casting in the form of cylinder of 40 mm diameter and 200 mm length. The size of SiC particles was in the range of 40–80 μm with an average value of $55 \pm 5 \mu\text{m}$. The volume fraction of SiC varies in the range of 10–25 vol.%. The shape of the SiC particles used was angular and these particles contain inherent micro-flaws (Fig. 1). The size distribution of SiCp used in the present study is shown in Fig. 2.

2.2. Microstructural characterization

The alloy and the composite materials were microstructurally characterized in terms of the volume fraction of SiCp, the grain size of the matrix alloy, distribution of the particles and the interface between the particle and the matrix. The volume fraction of particles was measured using the point counting technique [38] and the grain size of the matrix alloy was measured through the random intercept method [38]. For microstructural characterization, samples were cut from the cast cylinders, and polished mechanically following the standard metallographic practices. Polished sample were etched with the Kellor's reagent. The

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