High-strain-rate superplasticity of an AL2009–SiC\textsubscript{w} composite

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Discontinuously reinforced aluminium composites are considered to be excellent candidates for aerospace and automobile industries. However, their formability and machinability needs to be understood first before they can be widely used in these industries. Therefore, a lot of research effort has been spent in the study of the superplasticity of such composites over the past decade. The superplastic capability of many discontinuously reinforced aluminium matrix composites [1–7] has been discovered. Al 2009/SiC\textsubscript{w} composite is attractive for its high strength, stiffness and thermal stability and an ideal substitute for titanium used at service temperatures between 366 and 450 K. Also this material can be used in the sporting goods industry. Up to the present day, the superplastic deformation of Al 2009–20 vol% SiC\textsubscript{w} composite has not been investigated. In the present study, the superplastic behaviour of a SiC whisker reinforced 2009 aluminium matrix composite has been investigated.

A 20 vol% SiC whisker-reinforced 2009 aluminium alloy composite sheet supplied by Advanced Composite Materials Corporation was investigated in this paper. The sheet thickness was 2.286 mm and the size of the \(\beta\)-SiC reinforcement is 0.45–0.65 \(\mu\)m in diameter and 5–80 \(\mu\)m in length. The composite was fabricated by powder metallurgy followed by extrusion and rolling. A typical scanning electron micrograph of the composite is shown in Fig. 1. The distribution of whiskers was found to be uniform and approximately aligned in the direction of the rolling direction.

The solidus temperature of the composite was determined by a Du Pont 9900 differential scanning calorimeter (DSC). The solidus temperature of the composite was found to be 812 K when the DSC test started at room temperature and ended at about 893 K with a constant heating rate of 10 K min\(^{-1}\).

Superplastic tensile samples with a gauge length of 5 mm and a width of 4 mm were machined from the sheet in the rolling direction. Superplastic tests at temperatures ranging from 723 to 813 K were conducted in an Instron test machine with a ceramic heater furnace. Prior to testing, the specimen was held in the furnace at the specified test temperature for about 20 min to establish thermal equilibrium and all testing was carried out in air at different constant crosshead velocities.

The material showed the superplastic ability under certain conditions. The relationship between the total elongation-to-failure and the initial strain rate of the composite at different test temperatures is shown in Fig. 2. A maximum elongation of 190% was obtained at a strain rate of \(6.7 \times 10^{-1}\) s\(^{-1}\) and at 773 K which is far below the solidus temperature, 812 K. A similar phenomenon was also observed for Al2009–15 vol% SiC\textsubscript{w} composite [8]. That the optimum superplastic temperature was far below the solidus temperature was anomalous because the optimum temperatures of several other superplastic aluminium composites were found to be slightly higher than their solidus temperatures [1–7]. The optimum superplastic strain rate of the superplastic composites was obviously higher than the conventional superplastic strain rate of \(10^{-3}–10^{-3}\) s [9] and this was considered to be highly beneficial in the superplastic forming of aluminium composites. The optimum superplastic temperature of several super-

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Figure 1 A typical distribution of SiC whiskers in a matrix of Al2009–SiC\textsubscript{w} composite.

Figure 2 The variation of elongation with initial strain rate of Al2009–SiC\textsubscript{w} (○ 723 K; ⊗ 743 K; △ 763 K; ■ 773 K; □ 783 K; ▲ 793 K; + 803 K).
plastic aluminium composites was near or slightly higher than their respective solidus temperatures and this was thought to be harmful to the superplastic forming and post-superplastic properties of aluminium composites because molten aluminium can react with SiC to form a brittle aluminium carbide at the interface [10]. Therefore, the fact that the optimum superplastic temperature of Al2009–SiCw composite was far below the solidus temperature was beneficial to the superplastic forming and post-superplastic properties.

The relationship between the flow stress at a true strain of 0.2 and the true strain rate for different testing temperatures is shown in Fig. 3. The results showed that the flow stresses at all test temperatures increased with increasing strain rate. In the strain rates ranging between $10^{-2}$ and $10^9$ s$^{-1}$, a strain rate sensitivity value, $m$, of about 0.37 was found which was similar to that of other superplastic aluminium composites. The value of $m$, 0.37, indicated that the grain boundary sliding and interfacial sliding played a major role in high-strain-rate superplasticity. The fractured surfaces of the tensile specimens tested at various strain rates and at 773 and 813 K are shown in Fig. 4. A lot of whiskers were found to be pulled out and this indicated that a large deformation had taken place in the vicinity of the matrix/whisker interfaces. Some filaments which were thought to be related to a liquid phase at the interfaces were observed on the fracture surface at a temperature of 813 K.

To summarize, a 20% SiC whisker-reinforced 2009 aluminium composite was found to show high-strain-rate superplasticity. A maximum elongation of 190% was obtained at an initial strain rate of $6.7 \times 10^{-1}$ s$^{-1}$ and at a temperature of 773 K, which is below the solidus temperature of the composite. The strain rate sensitivity, $m$, was 0.37 at strain rates ranging between $10^{-2}$ and $10^9$ s$^{-1}$.

![Figure 3](image3.png)

**Figure 3** The variation of flow stress with strain rate of Al2009–SiCw ($\blacklozenge$ 723 K; $\triangle$ 743 K; $\bullet$ 763 K; $\blacklozenge$ 773 K; $\bigcirc$ 783 K; $\blacktriangle$ 793 K).

![Figure 4](image4.png)

**Figure 4** Fracture surface of tensile specimens of Al2009–SiCw: (a) 773 K, $1.7 \times 10^{-2}$ s$^{-1}$; (b) 773 K, $1.7 \times 10^{-1}$ s$^{-1}$; (c) 773 K, $6.7 \times 10^{-1}$ s$^{-1}$; (d) 813 K, $1.7 \times 10^{-1}$ s$^{-1}$.