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Fracture mechanism in a SiCw–6061 Al composite

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The dynamic fracture processes of hot-extruded SiCw–6061 Al composite were observed using scanning electron microscopy (SEM). The effect of the off-axis angle on the strength and the fracture mechanism of the composite was studied in detail. On the basis of the SEM observations, two tensile fracture models, namely the brittle fracture model and the shear fracture model, are discussed.

1. Introduction

The substantial amount of research on SiCw–Al composites in recent years demonstrates that the composite has good room temperature specific strength and modulus, as well as good thermal stability [1, 2]. It also exhibits, however, poor ductility and low fracture toughness for reasons which are not well understood [2], therefore, research on the mechanism of microcrack initiation, propagation, and joining of cracks in SiCw–Al composites has become a prerequisite for revealing the properties of the composite.

This paper aims to investigate the fracture processes in SiCw–6061Al composite, and on this basis, to analyse the mechanism of microcrack initiation and propagation in the composite.

2. Experimental procedures

The material used in this study is as-extruded (1:11) 22 vol. % SiCw–6061 Al composite. The tensile testing specimens were prepared by electrical discharged machining, then mechanical polishing. Dynamic tensile tests on the specimens with 0, 20, 45, 60, 70, and 90° off-axis angles were carried out respectively using a S-570 scanning electron microscope (SEM) equipped with a tensile stand. The microprocesses of fracture were observed continuously.

3. Results and discussion

3.1. Tensile stress–displacement curves

Fig. 1 shows the tensile stress–displacement curves for specimens with various off-axis angles, which indicate that the off-axis angle can greatly affect the tensile behaviour of SiCw–6061 Al composite. The strength of the SiCw–6061 Al composite decreases as the off-axis angle increases (Fig. 2), however, the strength values calculated by the maximum strain energy theory [3] are much lower than those obtained from the experiments. The possible reasons for this phenomenon may be as follows: either the maximum strain energy theory is unsuitable for short fibre reinforced composites or the whiskers are not parallel to the extrusion direction.

3.2. Observation of fracture processes

3.2.1. *Initiation of microcrack*

In extruded the SiCw–6061 Al composite, the whiskers were generally parallel to the extrusion direction (Fig. 3). In specimens with small off-axis angles microcracks initiated preferentially at the whisker ends (Fig. 4). With increasing off-axis angle the pattern of microcrack initiation changed from initiation at the whisker ends to initiation by debonding of the interface between whisker and matrix (Fig. 5). In the case of specimens with an off-axis angle of about 50°, there are two patterns of microcrack initiation: (1) debonding at the whisker–matrix interface (Fig. 7) and (2) void initiation at the whisker ends (Fig. 6).

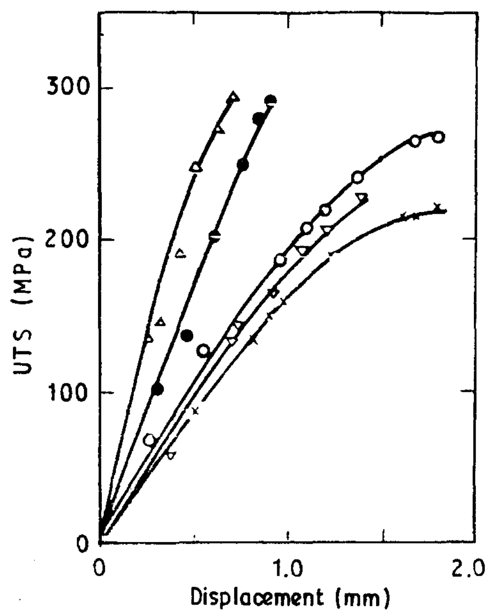

Figure 1 Tensile stress–displacement curves for hot-extruded SiCw–6061 Al composite with various off-axis angles. (△ 0°, ● 20°, ○ 45°, ▽ 60°, × 90°).

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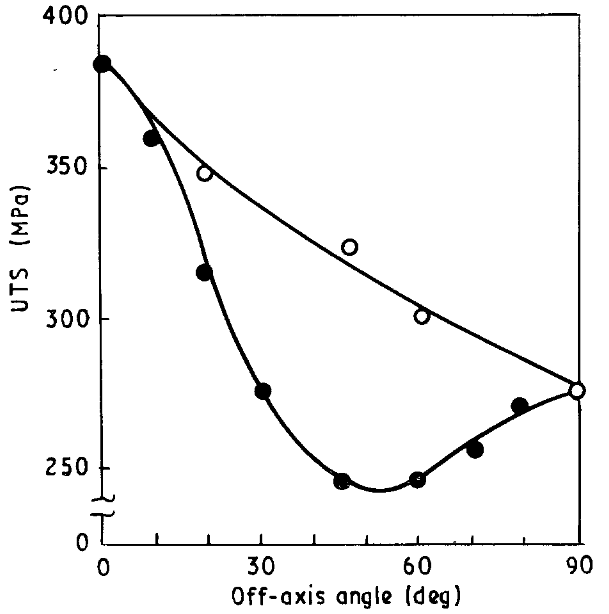

Figure 2 Relationship between tensile strength and off-axis angle for SiCw–6061 Al composites. (○ experimental; ● calculated).

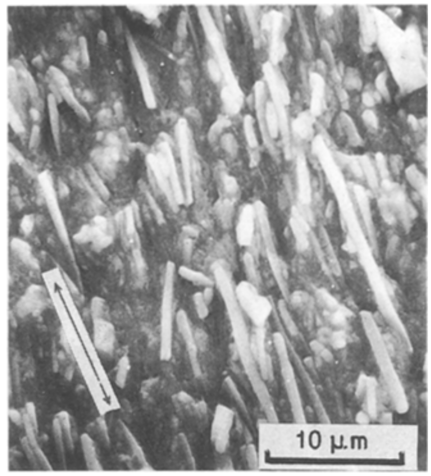

Figure 3 The orientation of whiskers in extruded SiCw–6061 Al composites. The arrow shows the extrusion direction.

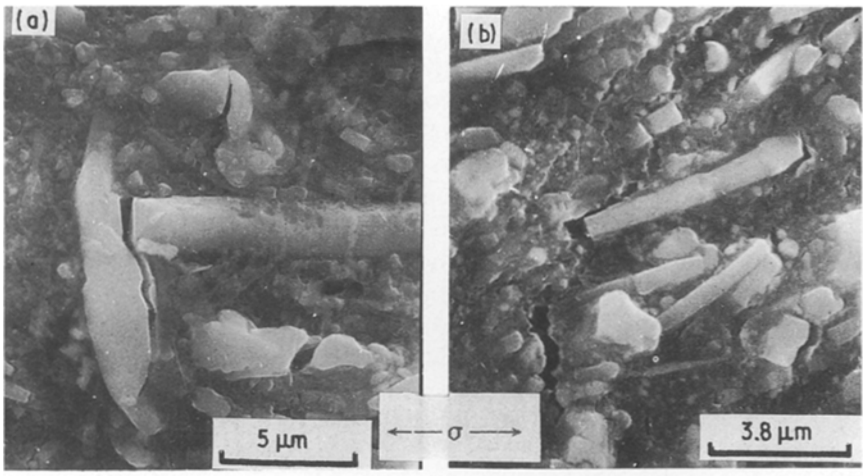

Figure 4 Initiation of microcracks at the whisker ends with small off-axis angles: (a) 0°; (b) 20°.

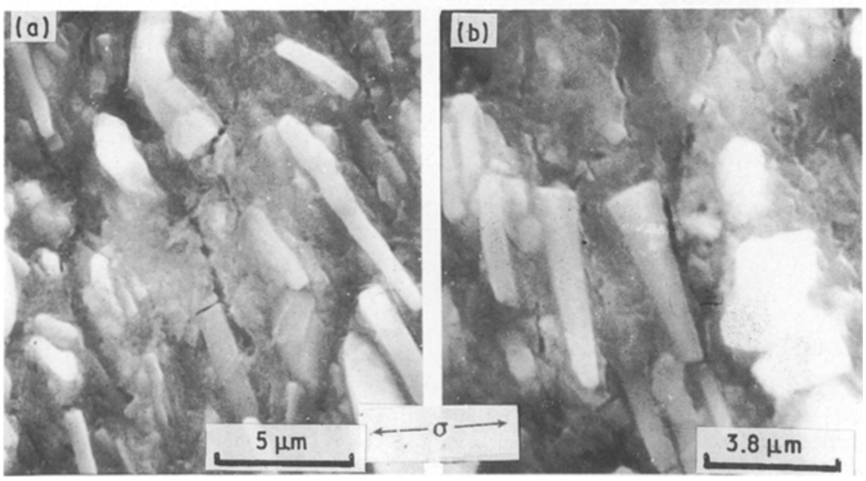

Figure 5 Initiation of microcracks at the whisker–matrix interface with large off-axis angles: (a) 70°; (b) 75°.

3.2.2. Propagation and joining of cracks

In the SiCw–6061 Al composite, microcracks propagated in the matrix, or along the whisker–matrix interface, or were propagated by the coalescence of microcracks. Due to the presence of the whiskers, cracks stopped propagating at the border of the whiskers (Fig. 8), or changed the propagation direction to bypass them (Fig. 9), or they continued to propagate after the whiskers were pulled out (Fig. 10). For specimens with small off-axis angles, cracks generally

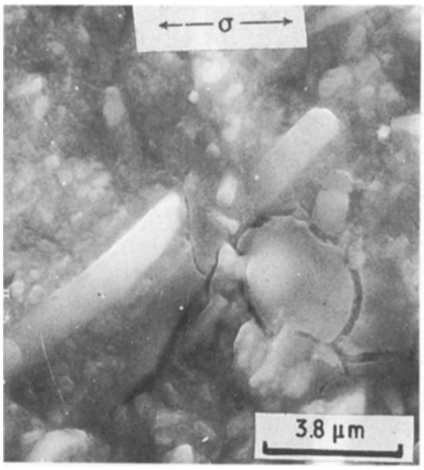

Figure 6 Initiation of microcracks at whisker ends with 45° off-axis angle.

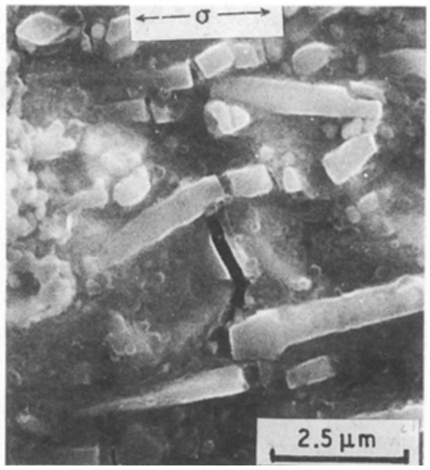

Figure 8 Microcracks stopped by whiskers.

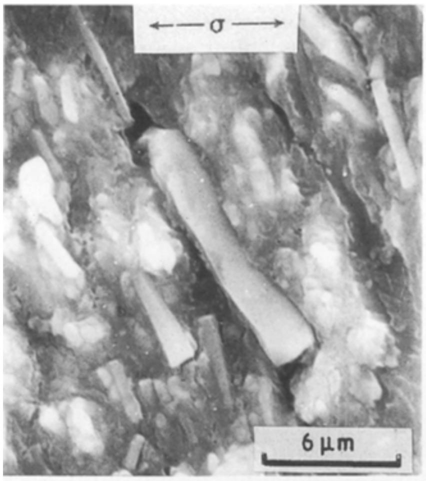

Figure 7 Initiation of microcracks at whisker ends and at whisker–matrix interface for the whisker with 55° off-axis angle.

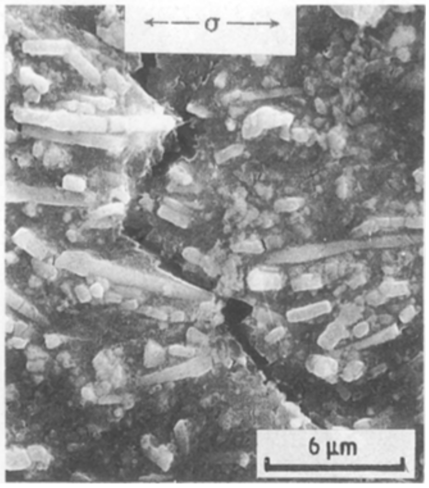

Figure 9 Microcracks bypassing whiskers.

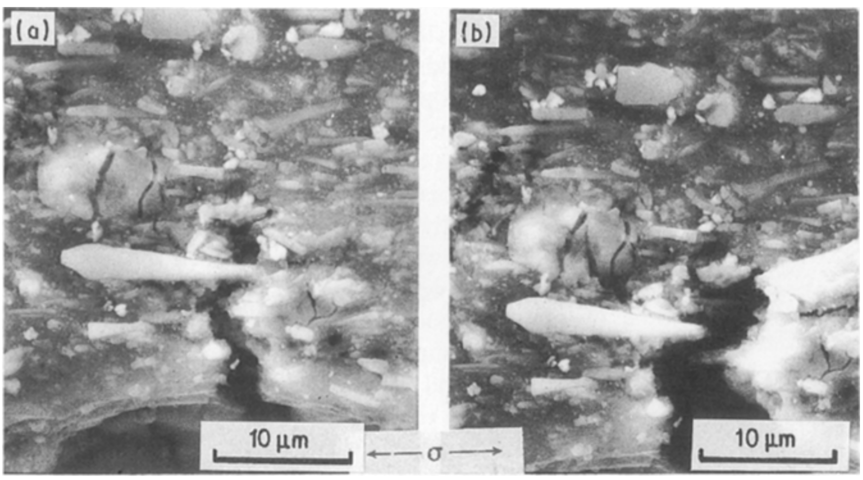

Figure 10 Pulling-out of whiskers.

propagated in the direction perpendicular to the tension direction, and there were two patterns of crack propagation: (1) bypassing the whiskers (Fig. 9); (2) pulling-out of the whiskers (Fig. 10). For specimens with large off-axis angles, cracks generally propagated in the direction parallel to whiskers by debonding at the whisker–matrix interface (Fig. 11), and the macrocrack path in the fractured specimens was approximately parallel to the whisker orientation in this situation (Fig. 12). In the case of specimens with an off-

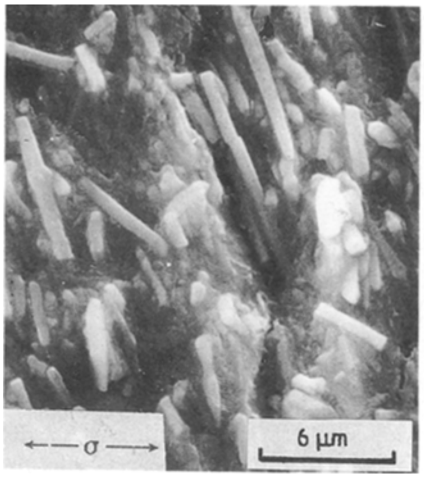

Figure 11 Propagation of crack along whisker–matrix interface.

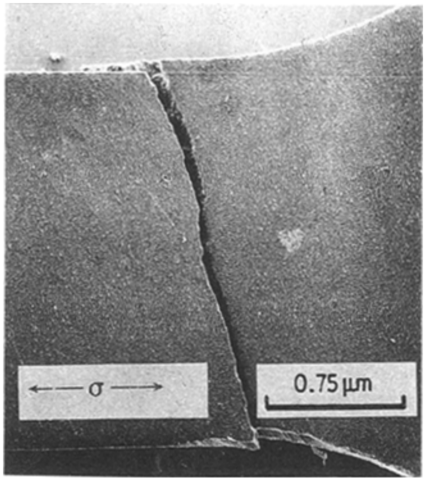

Figure 12 SEM photograph of fractured specimen with 70° off-axis angle.

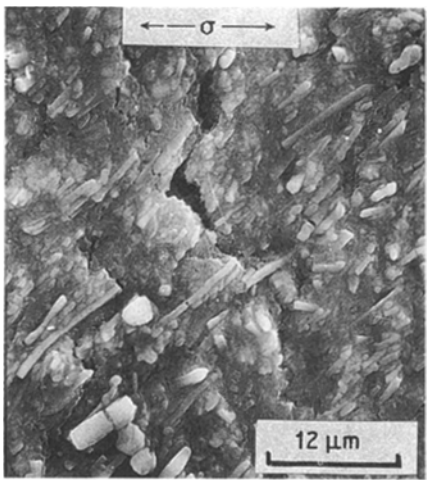

Figure 13 Crack propagating path in 45° off-axis angle specimen.

axis angle of about 50°, the cracks, which propagated in a direction perpendicular to the tension direction, often changed direction to propagate in the whisker direction by debonding at the interface or to propagate in the direction perpendicular to the whisker length direction by bypassing or pulling-out the whis-

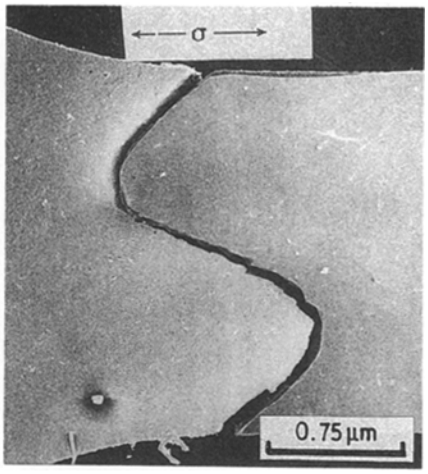

Figure 14 Fractured specimen with 45° off-axis angle.

kers (Fig. 13). The crack path was not constantly perpendicular to the applied load, but assumed a zigzag pattern. From the fractured specimen macrography (Fig. 14), it could be seen that the macrocrack path also assumed a zigzag pattern. This indicated that the probability of crack initiation and the resistance of crack propagation along the direction both parallel and perpendicular to the whisker length direction are similar at this off-axis angle.

3.2.3. Fracture models of the SiCw–6061 Al composite

As the aspect ratio of the whiskers in the extruded SiCw–6061 Al composite was greatly reduced, the probability of crack initiation by fracturing the whiskers, which is a general fracture pattern in the continuous fibre-reinforced composites, was much smaller. In SiCw–Al composites with small off-axis angles, due to the stress concentration effect, the stress at the whisker end was several times larger than that in the matrix [4]. Even at relatively low macroscopic stress levels, therefore, the stress concentration on the corners of the whisker ends was large enough for the matrix to yield and form plastic zones around the whisker ends which led to the nucleation of voids and the initiation of a microcrack at the whisker ends. Stress concentration at the whisker ends was related to the off-axis angle. When the angle was 45°, the effect of stress concentration was greatest; and when the angle was 90°, the affect was least [4]. The stress distribution in the matrix adjacent to the whiskers was, therefore, much more complicated than that for continuous fibre composites, and was a function of off-axis angle. In addition to the tensile stress and shear stress caused by the applied load, the effect of stress concentration at the whisker ends must also be considered. The initiation and propagation of microcracks in the SiCw–6061 Al composite during tension were thus related to interfacial bonding, off-axis angle, and stress concentration around the whiskers. The off-axis angle, as well as the stress concentration around the whisker ends, had a great effect on the initiation and propagation of microcracks and strength of the composite.

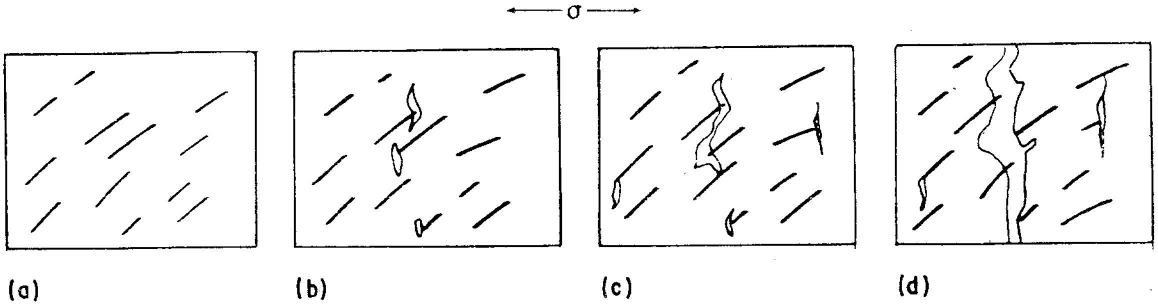

Figure 15 The brittle fracture model for SiCw–6061 Al composite (a) unload (b) initiation of microcracks at the whisker ends (c) propagation of microcracks (d) the specimen ruptured.

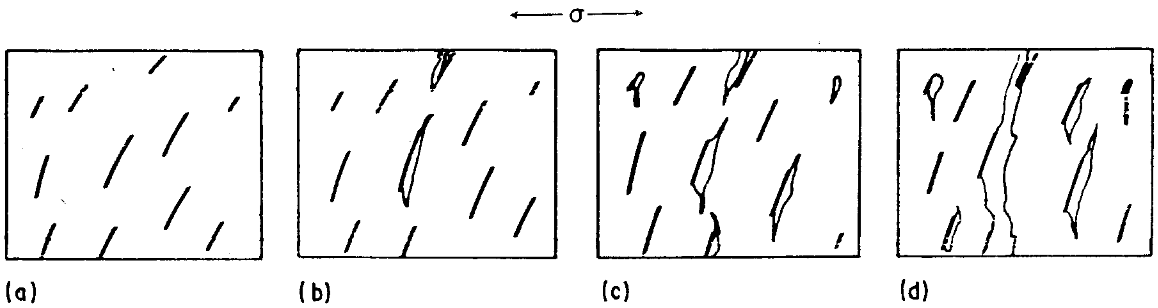

Figure 16 The shear fracture model for SiCw–6061 Al composite (a) unload (b) debonding at the whisker–matrix interface (c) propagation of microcracks along the whisker–matrix interface (d) the specimen ruptured.

On the basis of the above analysis, two fracture models of the SiCw–Al composite were put forward. First, according to the brittle fracture model, which operates at small off-axis angles (Fig. 15), the fracture process is as follows.

(1) Initiation of microcracks at the whisker ends.

(2) Propagation of microcracks in the direction with the smallest resistance which bypassed or pulled out whiskers or joined microcracks.

(3) Joining of cracks in the easiest way leading to the fracture of the composite.

Second, according to the shear fracture model, which operates at large off-axis angles (Fig. 16), the fracture process is as follows.

(1) Initiation of microcracks by debonding at the interface.

(2) Propagation of microcracks along the whisker length direction by debonding of interface or shear fracture of the matrix.

(3) Joining of cracks in the easiest way leading to the fracture of the composite.

In continuous fibre-reinforced composites, the values of tensile stress and shear stress acting on fibres are dependent on the off-axis angle. At the most favourable off-axis angle, the optimum off-axis angle (θ_0), the fracture model changed from the brittle fracture model, which is caused by the fracture of fibres, to the shear fracture model, which is caused by debonding of interface or cleavage cracking of fibres. The θ_0 can be expressed as [5].

$$\theta_0 = \tan^{-1}(\sigma_t/\sigma_l)^{1/2} \qquad (1)$$

where σ_t is the transverse tensile strength and σ_l the longitudinal tensile strength. From the values of σ_l and σ_t obtained from this research, θ_0 for SiCw–6061 Al composites with 22% V, SiCw can be calculated to be about 40°.

It was, however, found that the observed θ_0 was about 50°, which was larger than the calculated one. This might possibly be caused by the following factors: (1) Equation 1 might be unsuitable for short fibre composites; (2) stress concentration around the whisker ends, which might raise the value of θ_0, was not taken into account in Equation 1; (3) whiskers in the extruded SiCw–6061 Al composite were not perfectly oriented in the extrusion direction.

4. Conclusions

The processes of tensile fracture in SiCw–6061 Al composite were observed dynamically by using scanning electron microscope. The main results obtained are as follows.

(1) The off-axis angle has a great effect on the tensile strength of the composite. For SiCw–6061 Al composite, the strength decreases as the off-axis angle increases.

(2) The low ductility fracture in SiCw–6061 Al composite may be caused by initiation, propagation, and joining of a great number of microcracks in the matrix.

(3) There are two patterns of microcrack initiation: namely, the void initiation around the whisker ends for smaller off-axis angles, and debonding at the whisker–matrix interface for larger off-axis angles.

(4) There are four patterns of microcrack propagation: (a) bypassing whiskers; (b) debonding at the interface; (c) pulling-out of whiskers; (d) joining of microcracks.

(5) The two fracture models in the SiCw–6061 Al composite, the brittle fracture model and the shear

fracture model, are put forward on the basis of the SEM observation.

References

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