JOURNAL OF MATERIALS SCIENCE 37 (2002) 211–215

Hot rolling behaviors of whisker reinforced aluminum composites

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Aluminium matrix composites reinforced by silicon carbide and aluminium borate whiskers were hot rolled at 550°C, and the hot rolling behaviors of the composites were studied by scanning electronic microscope and X-ray diffraction (anti-pole figure). The results indicated that the whiskers in composite were reorientated, and some whiskers were broken during hot rolling process. The cracks in hot rolled composites may be related to the interface slide which is dependent on the interface strength of the composites. The tensile properties of hot rolled composites were also investigated.

1. Introduction

Hot forming is a widely used technique for the forming of discontinuous reinforced aluminum composites. Hot extrusion process had been studied extensively [1–4], including the microstructure, texture evolution, mechanical properties, and so on. The research on the hot forging process of SiC whisker reinforced aluminum (SiCw/Al) composite was also reported by the authors [5]. Although the studies on the rolling process of the composites were reported [6, 7], the research about the rolling process of the composite is limited because of brittleness of the composite.

After heavier hot deformation, the orientation of the whisker in composites can be changed greatly, which affect obviously the deformation behaviors and anisotropy properties of the composite. In the study, SiC whisker reinforced aluminum composite and aluminum borate whisker ($Al_{18}B_4O_{33}$ whisker denoted by ABOw) reinforced aluminum composite were employed to investigate the hot rolling behaviors of whisker reinforced aluminum composites. SiCw/Al composite had been well studied because of its excellent properties and technique importance. Some researchers [8–10] indicated that some orientation relationships between SiC whisker and aluminum matrix exist in the squeeze cast SiCw/Al composite. However, no certain orientation relationship between ABOw and aluminum matrix in the squeeze cast ABOw/Al composite has been observed [11]. Therefore, the effect of orientation relationship between the reinforcement and matrix on the texture evolution and deformation behaviors can be probed by the two composites. In the investigation, the rolling behaviors of SiCw/Al and ABOw/Al composite are studied, and the difference of hot rolling behavior between them was analyzed.

2. Materials and experiments

Both SiCw/Al and ABOw/Al composite was fabricated using squeeze casting method, and volume fractions of whisker were 20%. The specimen with the dimension of 5.5 mm × 40 mm × 45 mm was cut from the composite ingot. To obtain a large hot rolling ratio, the composites were packaged by aluminum alloy before rolling. The specimens with aluminum package were heated at 550°C for 30 min then rolled to final rolling ratio of 75% with 1.5 mm per path.

The microstructures of the hot rolled composites were examined by scanning electronic microscope (SEM) observation on a S570 type SEM. The transmission electronic microscope (TEM) observation of interfaces of the composites were observed in a CM-12 type TEM, and the specimens were thinned by ion milling. The textures were studied by X-ray diffraction (XRD) on a Rigaku–Dmax/r-A X-ray diffractmeter using anti-pole figure method. To obtain the anti-pole figure, the diffraction patterns from the plans perpendicular to rolling direction (RD), transverse direction (TD), and normal direction (ND) were measured using θ-2θ scanning manner with Cu K_α radiation. The Horta method [12] was employed to calculat the pole intensities in pole figures.

The tensile properties of the hot rolled composite were also test, and the tensile specimen as shown in Fig. 1 was cut alone the rolling direction.

3. Results and discussion

3.1. Microstructure

SEM micrographs of as-cast and rolled ABOw/Al composites are shown in Fig. 2. It is clear that the aluminium borate whisker in as-cast composite distribute randomly

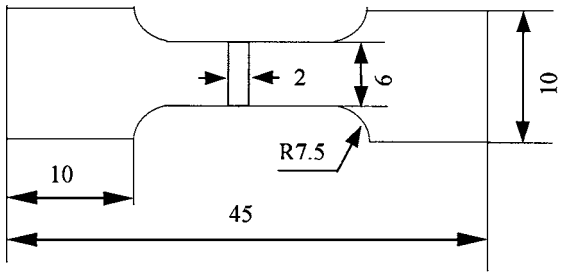

Figure 1 Tensile Specimen (in mm).

(see Fig. 2a). After hot rolling, the distribution of the whisker was changed greatly as shown in Fig. 2b. The longitudinal direction of the whisker tend to parallel to the rolling direction after hot rolling. It can also be seen that some ABO whiskers in composite were broken during hot rolling process.

SEM micrographs of as-cast and rolled SiCw/Al composites are demonstrated in Fig. 3. It can be found that the microstructures in SiCw/Al composite are similar to that in ABOw/Al composite as shown in Fig. 2. However, much more whiskers were broken in SiCw/Al composite during hot rolling compared with that in ABOw/Al composite. For SiCw/Al composite, some cracks can be seen in the plans perpendicular to the TD and ND direction, as shown in Fig. 4a and b. However, no crack can be found in hot rolled ABOw/Al composite as shown in Fig. 4c and d.

The phenomena that the whisker in whisker/Al composite is rotated during large deformation have been investigated by many researchers [1–7]. When the composites is deformed, a force moment is applied to whisker and the whisker rotation takes place during the deformation, in addition, the plastic deformation of matrix can also haul the whisker to rotation. Only when the whisker rotation and plastic deformation of matrix are concordant, the crack can be avoided. Because the rolling temperature is higher (550°C) and the matrix alloy (pure aluminium) is very soft, it can be suggested that the interface state between the whisker and aluminium matrix is a key factor to affect the formation of the crack during hot rolling. The easier the interface slide in hot rolling, the more difficult the crack formation. As the previous studies mentioned [8, 9], the interface strength between SiC whisker and aluminium in SiCw/Al composite is very high. To compare the interface state of as-cast SiCw/Al and ABOw/Al composite, the interfaces in the two composite were examined by

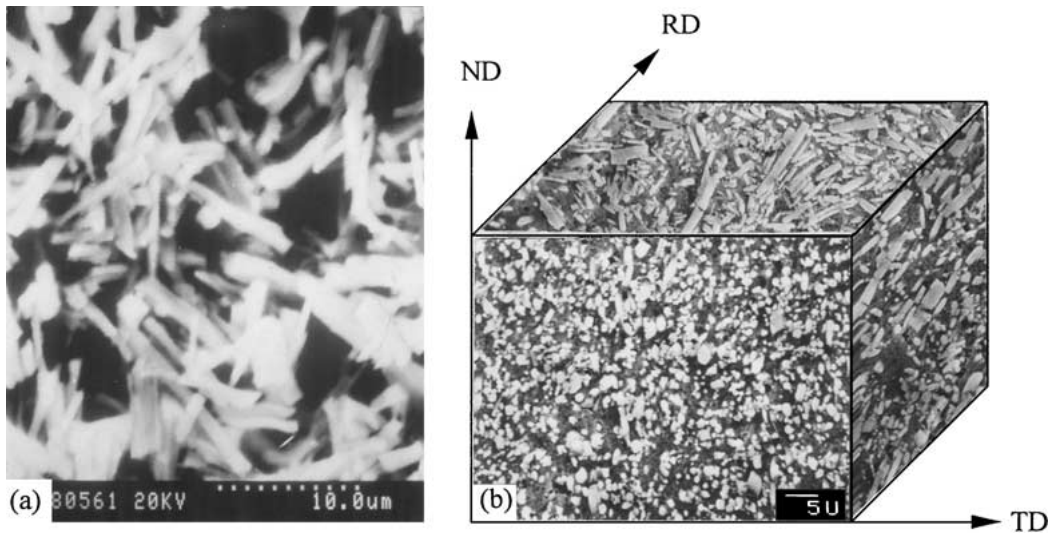

Figure 2 SEM Nicrographs of as-cast (a) and hot rolled (b) ABOw/Al comosite.

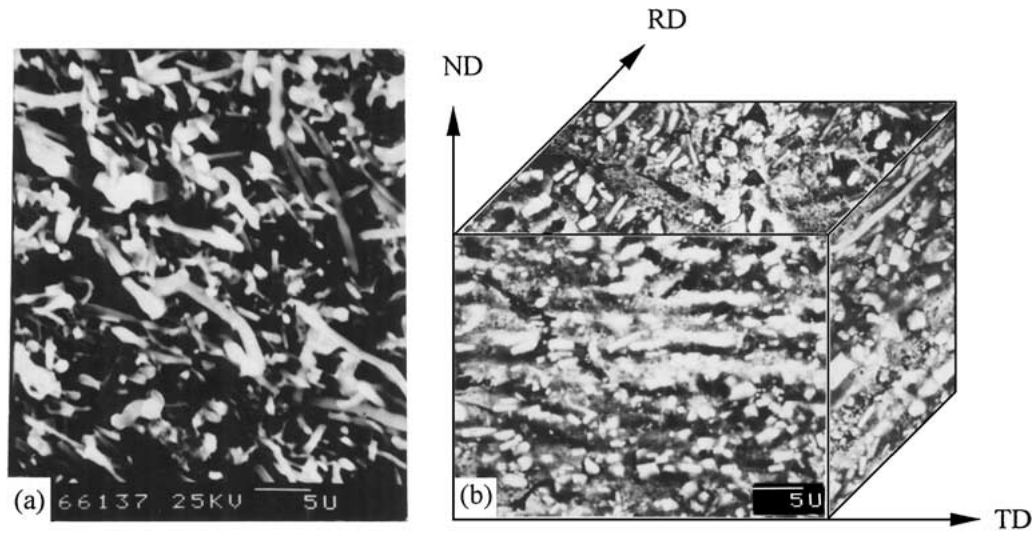

Figure 3 SEM Nicrographs of as-cast (a) and hot rolled (b) SiCw/Al comosite.

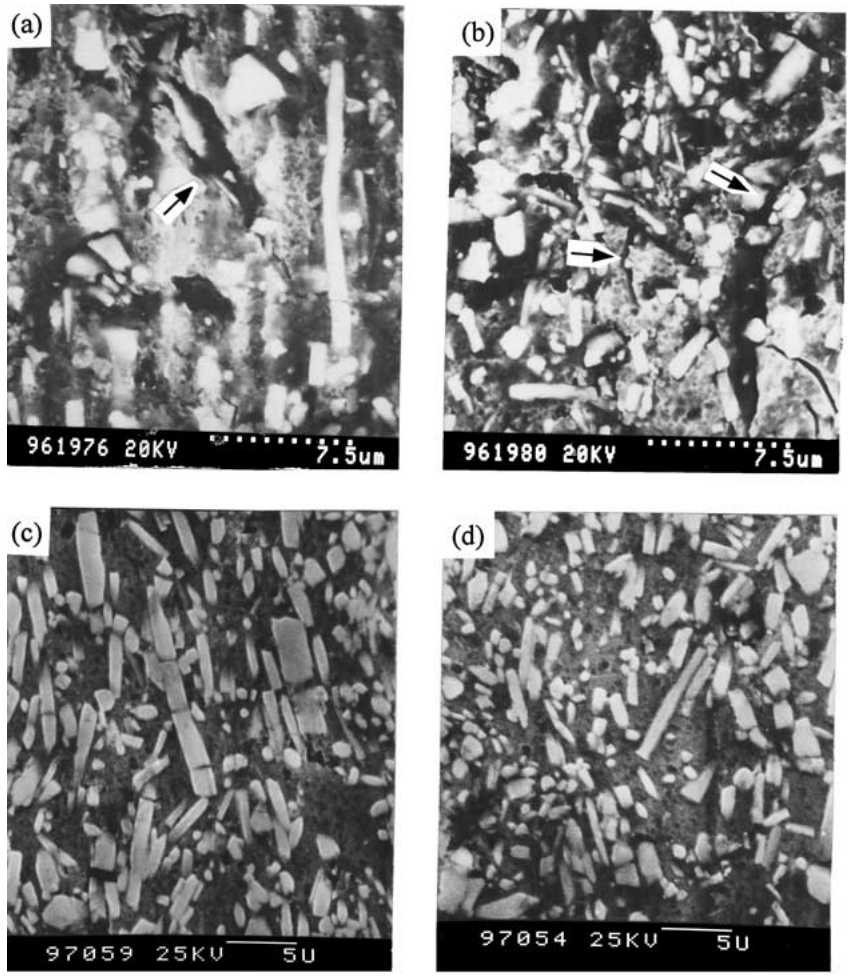

Figure 4 SEM photos of hot rolled SiCw/Al composite in the plan perpendicular to TD (a) and in the plan perpendicular to ND (b), and of hot rolled ABOw/Al composite in the plan perpendicular to TD (c) and in the plan perpendicular to ND (d).

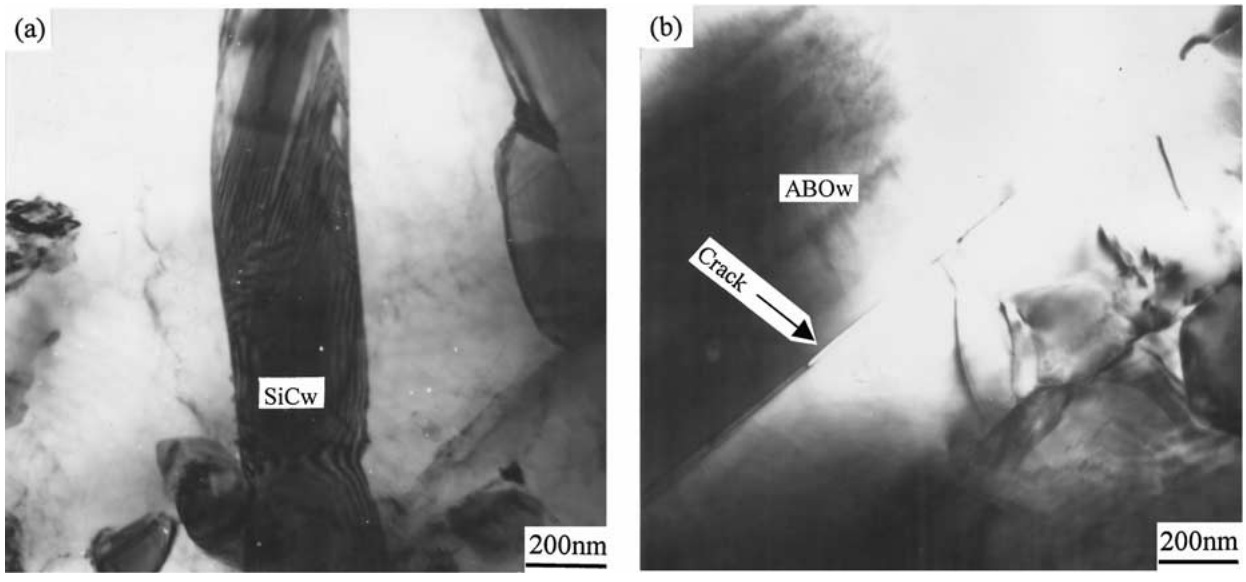

Figure 5 TEM photos of interfaces in as-cast SiCw/Al (a) and ABOw/Al composites (b).

TEM observation, and the results are shown in Fig. 5. No crack can be found at the interface of SiCw/Al composite (see Fig. 5a), but the crack can be observed at the interface of ABOw/Al composite (see Fig. 5b). The sharp wedge-shape crack at the interface in ABOw/Al composite means that the crack was formed during the thinning process of TEM specimen. Therefore, one can conclude that the interface strength between ABO whisker and aluminium matrix is weaker then that between SiC whisker and aluminium matrix in the composites. So the interface slide in SiCw/Al composite during hot rolling is much difficult. The rotation of SiC whisker and matrix deformation can not be harmonized well and many cracks are induced during the hot rolling.

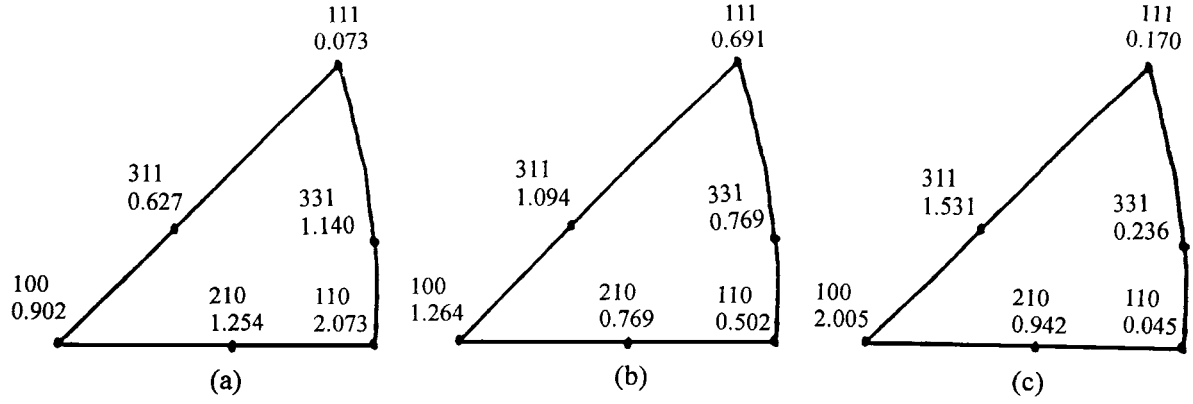

Figure 6 Anti-pole figures of hot rolled SiCw/Al composite, (a) TD, (b) RD, (c) ND.

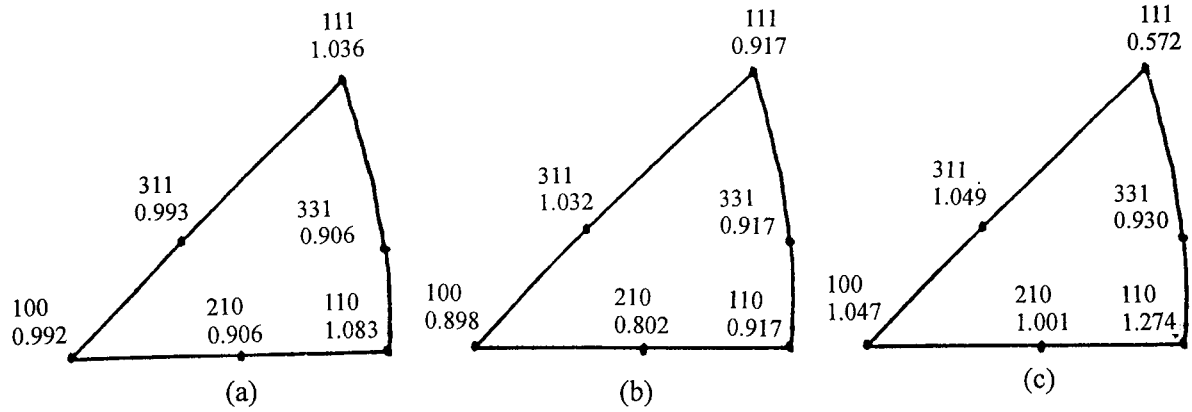

Figure 7 Anti-pole figures of hot rolled ABOw/Al composite, (a) TD, (b) RD, (c) ND.

3.2. Anti-pole figure

The anti-pole figure employed here is not to study in detail the rolling texture of the composites, although it is very important for the understanding of deformation behavior of composites. We want to examine the effect of the interface state on the rolling behavior and the difference of microstructure between the two composites with different interface state. The anti-pole figures of aluminium matrixs in SiCw/Al after hot rolling are given in Fig. 6. It can be found that {110} plan is perpendicular to the TD direction with highest probability, {100} plan to the RD direction with highest probability, and {100} plan to the ND direction with highest probability. That is to say, after hot rolling, an obvious texture of aluminium matrix in SiCw/Al composite was caused. As shown in Fig. 7 of anti-pole figures of aluminium matrix in ABOw/Al composite, all densities of poles are almost same, which suggests that no obvious texture is induced after hot rolling in ABOw/Al composite.

As mentioned above, the interface strength of SiCw/Al composite is very strong [8, 9]. Some orientation relationships between SiC whisker and aluminium in squeeze cast SiCw/Al composite had been found by TEM, HRTEM (high resolution transmission electronic microscope) [8, 9]. Because of high interface strength, the interface slide is difficult to occur, which leads to the deformation behavior of aluminium around SiC whisker is restricted by the rotation of SiC whisker. As the longitudinal direction of SiC whisker tend to parallel to the rolling direction, the texture of aluminium which has orientation relationships with the whisker may be evaluated in SiCw/Al composite during hot rolling process. The texture formation of aluminium matrix in SiCw/Al composite suggested that interface slide during hot rolling is difficult and the crack may be induced easily as shown in Fig. 4.

In ABOw/Al composite, no certain orientation relationship between the aluminum and whisker has been found, and the interface strength in the composite is weaker. In this case, the obvious texture of aluminium matrix in the composite cannot be introduced due to easy slide of interface, although the longitudinal direction of ABO whisker also tends to parallel to the rolling direction. Because of the interface slide in ABOw/Al composite, the cracks can be avoided in the composite during hot rolling.

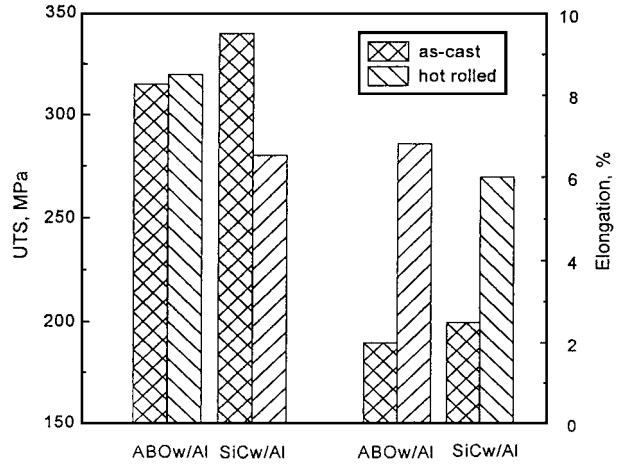

Figure 8 Tensile properties of hot rolled SiCw/Al and ABOw/Al composite.

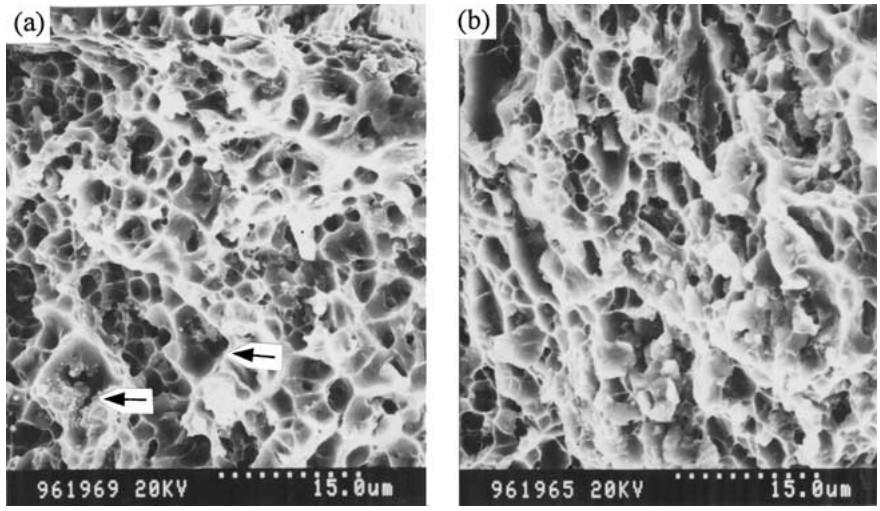

Figure 9 Tensile Fractographs of hot rolled SiCw/Al (a) and ABOw/Al (b) composites.

3.3. Tensile properties of hot rolled composites

The tensile properties of hot rolled composite are demonstrated in Fig. 8, the tensile direction is parallel to RD direction. It can be found that the ultimate tensile strength (UTS) of hot rolled ABOw/Al composite is enhanced compared to that of as-cast ABOw/Al composite, but the UTS of hot rolled SiCw/Al composite is decreased compared with that of as-cast SiCw/Al composite. The elongation for both hot rolled composites is increased greatly. For ABOw/Al composite, the increasing of strength of hot rolled composite results from more whiskers are parallel to the tensile direction and reinforced effect is enhanced. For SiCw/Al composite, the UTS of hot rolled composite is weakened by the cracks formed during hot rolling. The above results indicated that the composite with suitable interface strength is very important for forming by hot rolling technique.

The tensile fractographs of hot rolled composites are shown in Fig. 9. In the fractograph of SiCw/Al specimen, many dimples resulted from fracture of aluminium matrix can be found, and bigger voids (as denoted by arrows in Fig. 9a) can also be found, which results from cracks formed during hot rolling. The dormitory feature of the fractograph of ABOw/Al composite is dimple resulted from fracture of aluminium matrix and whisker and evulsion of whisker as shown in Fig. 9b.

4. Conclusions

1. After hot rolling, the whisker in both SiCw/Al and ABOw/Al composite is reorientated, and the longitudinal directions of the whiskers tend to parallel to the rolling direction.

2. There exist many cracks in hot rolled SiCw/Al composite compared to ABOw/Al composite. The formation of cracks in hot rolled SiCw/Al composite may result from the high strength interface in SiCw/Al composite, which leads to the interface slide is difficult during hot rolling.

3. Because of high interface bonding and orientation relationship between SiC whisker and aluminium matrix, an obvious texture is formed in hot rolled SiCw/Al composite, but no obvious texture can be found in hot rolled ABOw/Al composite.

4. After hot rolling, the tensile strength of ABOw/Al composite is higher then that of SiCw/Al composite.

Acknowledgement

The work was supported by National Science Foundation of China under the grant number of 59631080.

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Received 10 March 2000
and accepted 3 August 2001