JOURNAL OF MATERIALS SCIENCE **34** (1999) 565–569

Microstructures evaluation of isothermally-forged SiCw/Al composites

W. G. CHU, J. HU, W. D. FEI, C. K. YAO, L. LIU*
*School of Materials Science and Technology, P.O. Box 433, Harbin Institute of Technology, Harbin 150001, People's Republic of China; *Department of Physics, Jilin Normal College, Jilin 130004, People's Republic of China*

Isothermal forging of SiCw/Al composite was carried out. Microstructures were investigated by means of SEM. The results indicated that directional alignment and breakage of whiskers in deformed zones were strongly dependent on the deformation form and degree in the zones. Based on the results of SEM observation, the isothermally-forging deforming process was discussed in detail.

1. Introduction

It is well-known that metal matrix composites are characterized by high specific strength, high specific stiffness, good thermally-forming ability and low thermal expansion coefficient. Although they have been applied to many fields such as vehicles, sports and aerospace etc., due to poor plasticity, many precise and complicated components or parts are not easily fabricated by means of simple and traditional forming processes. To this end, some investigations on deforming processes such as extrusion, hot rolling and microstructures related to them have been conducted [1–4]. However, extrusion and hot rolling are inadequate to meet the needs of forming precise and complicated parts or components. Therefore, to investigate traditional isothermal forging of metal matrix composites is theoretically and practically significant.

2. Experimental

Silicon carbide whiskers (SiCw) reinforced aluminum (4032Al) matrix composites with 20% volume fraction were employed to thermally form with the constraint of the upper and lower dies placed in the furnace with controllable temperatures. The materials used to form were roughly machined into an outer shape similar to that of a complicated component, heated in another furnace up to forging temperature 520 °C (about 10 °C below the melting point of the matrix alloy) and held for some time, as were the two dies. Before forging, the heated materials were shifted to the lower die and kept at forging temperature for a time. After that, isothermal forging would take place. The whole process was completed on the hydraulic press and the deformation velocity was able to be precisely controlled. Slow deformation velocity (between 5×10^{-4} s^{-1} and 1×10^{-3} s^{-1}) was used to allow stresses in the materials incorporated by forging to have enough time to be relaxed. An isothermally-forged specimen is schematically shown in Fig. 1.

3. Results and discussion

As shown in Fig. 1, the part can be divided into several zones, here labeled I, II, III, IV, V and VI. The morphology of microstructures in Zone I is illustrated in Fig. 2. The whiskers in the zone are aligned almost perpendicular to the forging direction, which indicates that during the deformation process, the matrix under the limit of the upper and lower dies radially flowed in all directions parallel to the end plane of the upper die and the inner end plane of the lower die, and whiskers were compelled to rotate with the flow of the matrix to smoothly complete the whole deformation process. As a consequence, the whiskers in Zone I were seriously broken compared with those in the squeeze cast. The distribution percentage of the length of whiskers in Zone I was given in Fig. 3a and that in the squeeze cast in Fig. 3b. From Fig. 3a, the length of whiskers predominantly ranged from 3 μm to 11 μm compared to that of the squeeze cast with predominant length distribution from 20 μm to 27 μm. This indicated that serious plastic deformation took place in the zone and the deformation content was quite large. From the apparent directional alignment of whiskers shown in Fig. 2, the same conclusion could also be drawn. Therefore, the deformation process was directly reflected by SEM observation of microstructures such as length distribution, breakage and the degree of directional alignment of whiskers.

Fig. 4a and b are SEM photos of microstructures in Zone II and Zone III respectively. The length distributions of whiskers in Zone II and III are shown in Fig. 5a and b, respectively. Due to the existence of the circular angle of the upper die, the whiskers in Zone II and III both aligned parallel to its transverse direction and had a fairly strong directionality, as shown in Fig. 4a and b. To compare Fig. 5a with b, it was found that the percentage of length of whiskers in Zone II ranging from 8 μm to 11 μm was 72% greater than that in Zone III with only 47%. Eighteen percent were more than 14 μm in length in Zone III, also greater than the 6% that were longer than 14 μm in Zone II. Twenty-nine percent ranged

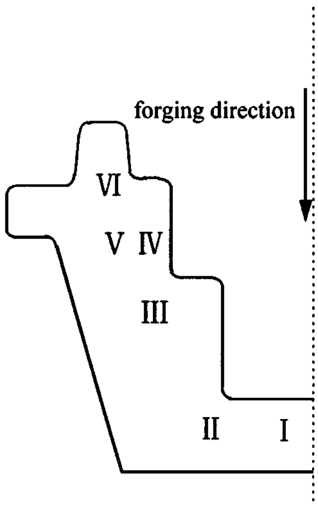

Figure 1 Schematic diagram of the component with divided different zones.

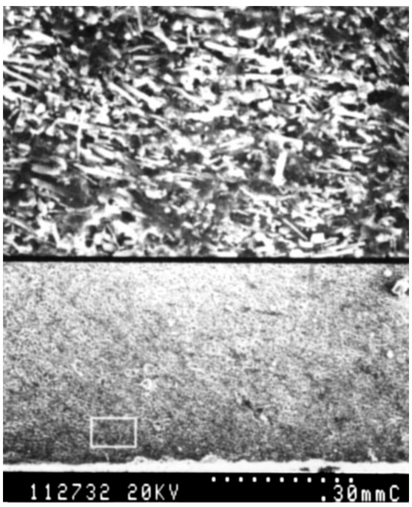

Figure 2 SEM micrograph of microstructures in Zone I.

from 3 μm to 7 μm in Zone III, a little greater than the 22% in that range in Zone II. [So it was obvious that the breaking degree of whiskers in Zone II was greater than that in Zone III, which was easily understood in that Zone II deformed more seriously than Zone III.] With the upper die going further downwards, the previously deformed materials in Zone II would further deform, while the materials nearby and in Zone III deformed comparatively less than in Zone II. Therefore, the shape of the upper die had a great influence on deformation process, and the deformation of metal matrix composites was strictly conditioned by the shape of the dies.

The morphologies of microstructures in Zone IV closer to the upper die and Zone V are illustrated in Fig. 6a and b, respectively. Fig. 7a shows the length distribution of whiskers in Zone IV and Fig. 7b shows that in Zone V. As shown in Fig. 6a and b, the directionality of whiskers in Zone IV was somewhat obvious, but that in Zone V was hardly observed. This was attributed to different deformation degrees in the two zones. Zone V was far away from the outer surface of the upper die and affected less by it during the deformation process. In contrast, Zone IV was close to the outer surface where the upper die exerted pressure, forcing the materials in Zone IV to deform preferentially. Fig. 7a and b indicates that the 32% shorter whiskers in Zone IV was greater than the 21% in Zone V, providing support for the inference of a deformation degree in Zone IV greater than that in Zone V.

Microstructures in Zone VI with different degrees of etching are illustrated in Fig. 8. In the case of serious etching, as shown in Fig. 8a, it was found that the distribution of whiskers seemed to be on the whole somewhat chaotic. Observed in detail, two bands of whiskers were aligned directionally and made a certain angle, which showed that deformation in Zone VI was quite complicated. The complicated deformation was mainly caused by the fact that, when the deformation process reached

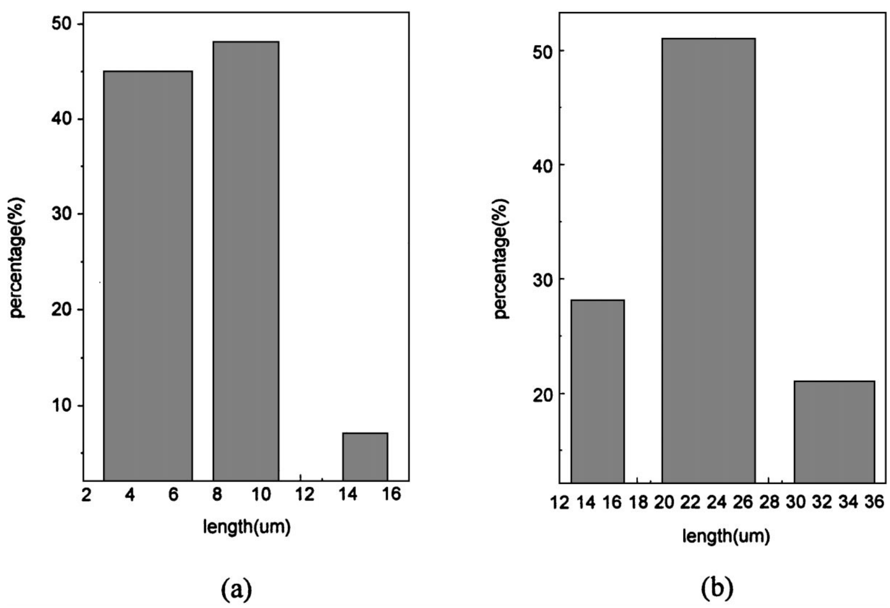

Figure 3 Length distribution of whiskers in Zone I (a) and in the squeeze cast (b).

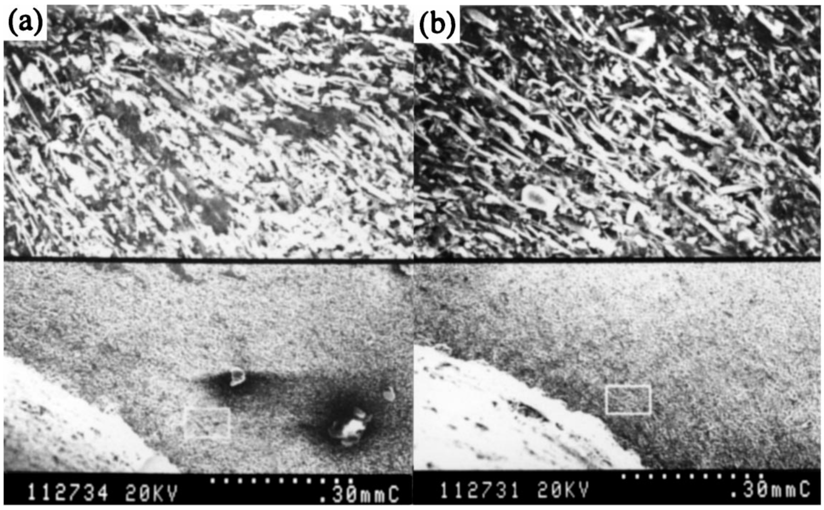

Figure 4 SEM micrographs of microstructures in Zone II (a) and III (b).

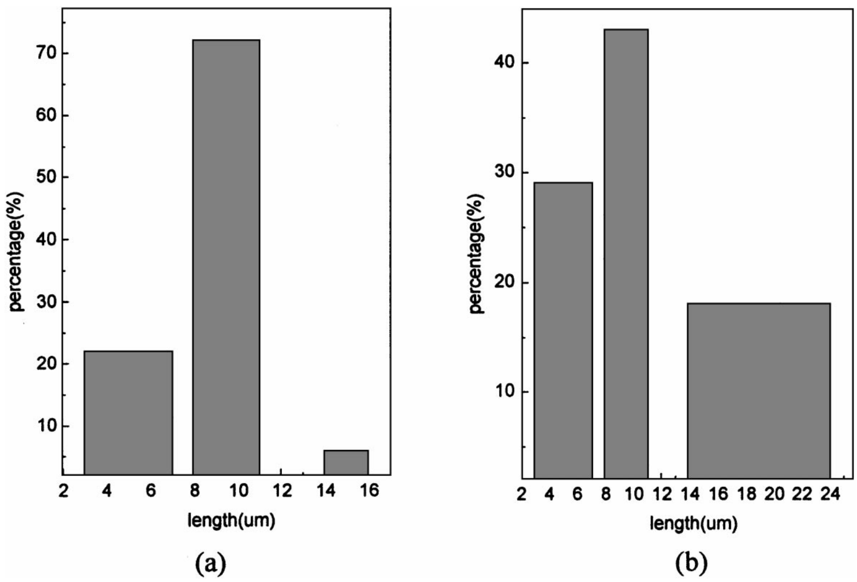

Figure 5 Length distribution of whiskers in Zone II (a) and III (b).

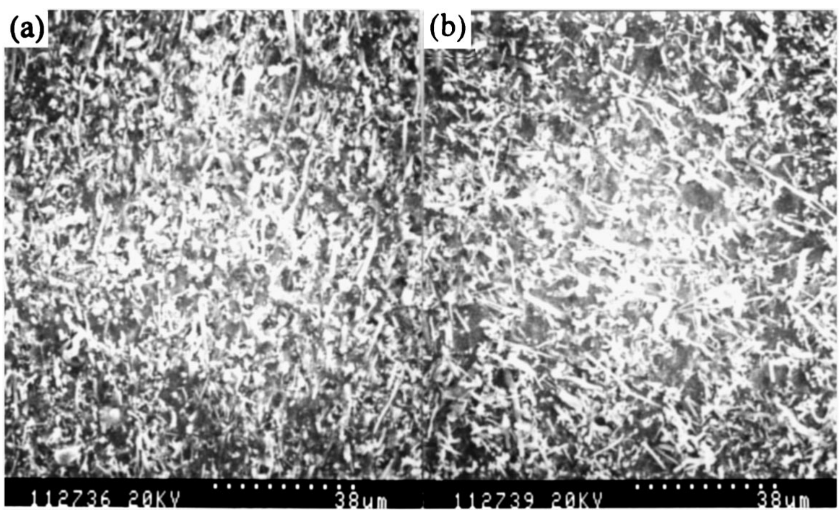

Figure 6 SEM micrographs of microstructures in Zone IV (a) and V (b).

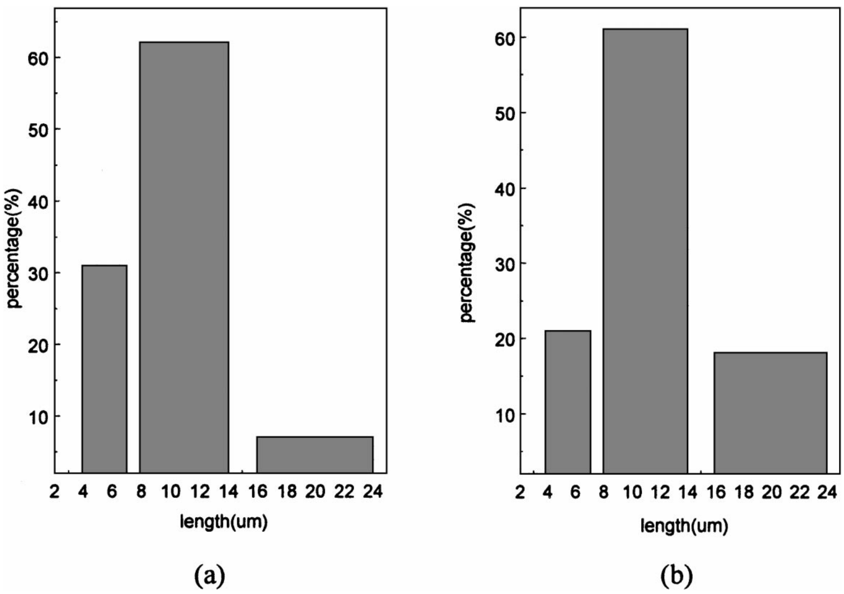

Figure 7 Length distribution of whiskers in Zone IV (a) and V (b).

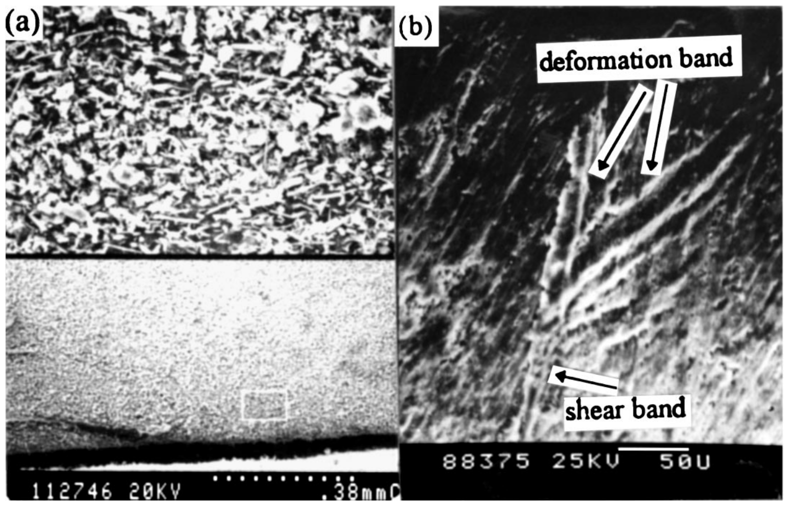

Figure 8 SEM micrographs of microstructures (a), and deformation bands and shear band (b) in Zone VI.

the later stage, the stress state in the front of the materials to deform became very complicated because of the changing of the constraint of the upper and lower dies. As a result, the deformation was completed without the strict constraint of the upper and lower dies. Thus the materials flowed chaotically, which was not beneficial to deformation of materials with poor plasticity. Furthermore, deformation band and shear band similar to that reported in the reference [5] were also observed, as shown in Fig. 8b (with weak etching). This also indicated complicated deformation. During the deformation process, due to the complicated stress state, deformation bands with different orientations were formed. When they met with one another and interacted, two deformation bands developed further into a so-called shear band which oriented the texture-softening direction being the easily-deforming one. On the other hand, formation of the shear band was related to local melting of the base alloy caused by exothermic energy in the forging deformation at temperatures near the melting point. The melts with trifle volume under the load were compelled to converge and formed the whisker-free zones (aluminum belts). The whisker-free zones were easy to deform. It was worth noting that formation of a lot of deformation bands and shear bands was harmful to the deforming of materials.

From the above discussion and analysis, the materials touching the upper die deformed first. With its further downward motion, more and more materials were involved in the deformation. At the same time, although mechanical stress introduced into the deformed materials was partly relaxed by keeping the materials at constant forging temperature, the stress would gradually increase with further deformation. The whole isothermally-forging forming process was in large part completed under the constraint of the upper and lower dies, and it was the later stage of deformation that was carried out without their strict constraint. To ensure the isothermally forging formation of good quality materials before devising the dies, the maximum possibility of completion of the whole deformation process under the strict constraint of the dies should be taken into consideration. This was vital to the forming of metal matrix composites.

4. Conclusion

Through discussing the morphologies of microstructures of isothermally-forged SiCw/Al and deformation process, some conclusions can be obtained as follows:

1. Isothermal forging is a practical and feasible forming method for SiCw/Al composites.

2. Different degrees of directionality and breakage of whiskers were produced in different zones of the component during the deforming process of SiCw/Al composites, and the degree of directionality along with that of the breakage of whiskers reflected deformation characteristics and clearly revealed the real deforming process.

3. Deformation band and shear band were also found in some certain zones in the isothermally-forged SiCw/Al, in which the stress state was very complicated.

Acknowledgement

The authors would like to thank the National Nature Science Foundation of China for support, under grant number 59631080.

References

1. STANFORD, C. A. BEALE and T. W. CLYNE, *Sci. Tech.* **35** (1994) 121.
2. Z. XIONG, L. GENG and C. K. YAO, *Composite* **39** (1990) 117.
3. J. R. PICKENS, T. J. LANGAN, R. O. ENGLAND and M. LEIBSON, *Metall. Trans.* **18A** (1988) 303.
4. T. G. NIEH and D. J. CHELLMAN, "Rolling of 2124Al-15% SiC whisker Composites," presented at 113th AIME Annual Meeting, Los Angeles, 1984; Feb. 26–Mar. 1.
5. S. H. LEE, KYUNG-MOXCHO and K. C. KIM, *Metall. Trans.* **24A** (1993) 895.

Received 4 April
and accepted 21 August 1998