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Effects of crystal boundary gliding and dislocation on superplastic deformation of SiC_w/6061 Al composite①

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[Abstract] SiC_w/6061Al composite was fabricated with squeeze casting method, hot extruded and superplastically tensile tested. At the temperature of 570 ℃ and the strain rate of $2.0\times10^{-3}\,s^{-1}$, an elongation of 280% was obtained. The change of grain shape, dislocation density and distribution was observed by TEM. The results show that during the superplastic deformation grain shape on the whole is unchanged, but the dislocation density and distribution vary quite a lot with the tensile action. Under the optimal straining conditions, dislocation mainly distributes along the grain boundary, which has an important effect on cooperative strain especially. When the strain magnitude is big enough, there appears stacking faults and twin crystals, which also has some effect on the cooperative strain.

[Key words] composite; superplasticity; grain dislocation; stacking fault; twin crystal
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1 INTRODUCTION

Metal matrix composite is a new kind of material developed in recent 20 to 30 years compared to the conventional metal materials, this composite has many good performances on one hand; but on the other hand, its actual application is restrained due to its poor plasticity under normal conditions. Recently, researches have been done to its superplasticity and some progress has been made[1, 2], but many micro-process during the superplastic deformation of this composite is not well known[3]. This paper describes the law of the changes of grain boundary gliding and dislocation during the process of superplastic deformation of metal matrix composite, and on this basis, deformation mechanism is discussed.

2 EXPERIMENTAL

The matrix material for producing the composite is 6061 aluminum alloy, the contents in mass were: 0.44% Cu, 0.67% Mg, 0.27% Mn, 0.014% Cr, 0.37% Fe, 97.1% balanced Al and 0.15% other elements. The fortifier is β type SiC crystal whisker, with the diameter of 0.1~ 1 μm and a length of 30~100 μm. First, the composite was produced with the method of squeeze casting, and then, at the temperature of 470 ℃, extruded into plates with 30 mm in width and 5 mm in thickness. The composite was measured with the method of specific gravity, the content of whisker in mass was 25%. Tensile test samples are of two types: one is the longitudinal test samples parallel to the direction of extrusion, the other is the transverse samples perpendicular to the direction of extrusion. At the temperature of 570 ℃ and the strain rate of $2.0\times10^{-3}\,s^{-1}$, the longitudinal samples obtained an elongation up to 280%, the transverse samples obtained an elongation of 210%. But the flow stress of the transverse samples was bigger than that of the longitudinal samples.

The above samples which were stretches to different lengths under the above conditions and other comparative samples under other conditions were made into TEM test samples, Under the Philip CM12TEM (transmission electronic microscope), the change of grain shape and their internal dislocation were observed.

3 RESULTS AND DISCUSSION

Fig. 1 shows the grain shapes and appearances of samples which were stretched to different lengths. It can be seen that the grains remained unchanged as equiaxed during the process of drawing. This manifests that deformation is realized mainly through the mechanism of grain boundary and gliding interface. Detailed study has been done in other paper[4~ 6].

Fig. 2 are the TEM pictures showing the dislocation pattern of the samples which were stretched to different lengths. It can be seen clearly from the figure that dislocation density increases with the process of stretching concurrently and dislocation pattern changes, forming winding and cellular structure gradually. Fig. 3 are TEM pictures showing the dislocation density and distribution of the test samples which were stretched to 20% under different straining conditions. The figure shows that, at the beginning of the stretching process, dislocation density of the test

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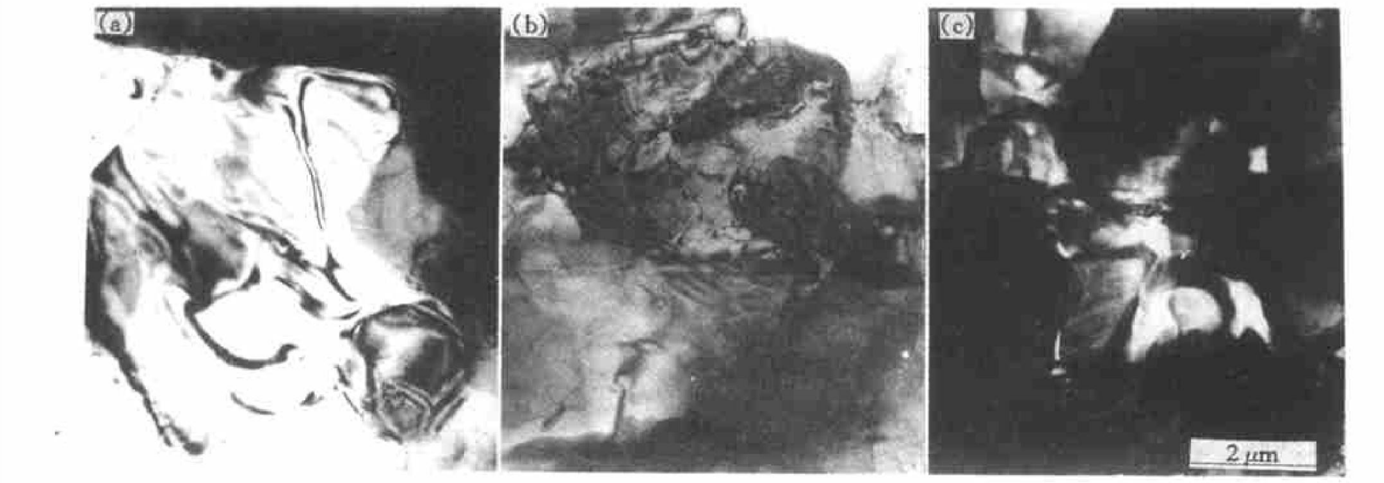

Fig. 1 Grain shapes of samples stretched to different lengths
(a) —120%; (b) —150%; (c) —200%

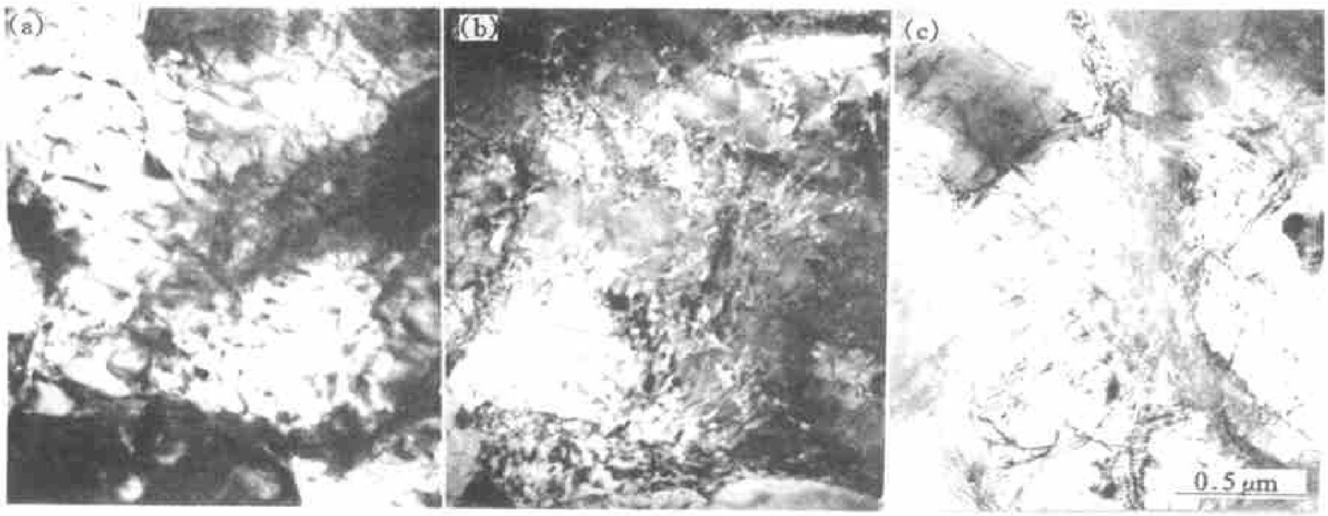

Fig. 2 Dislocation patterns of samples stretched to different lengths
(a) —120%; (b) —150%; (c) —200%

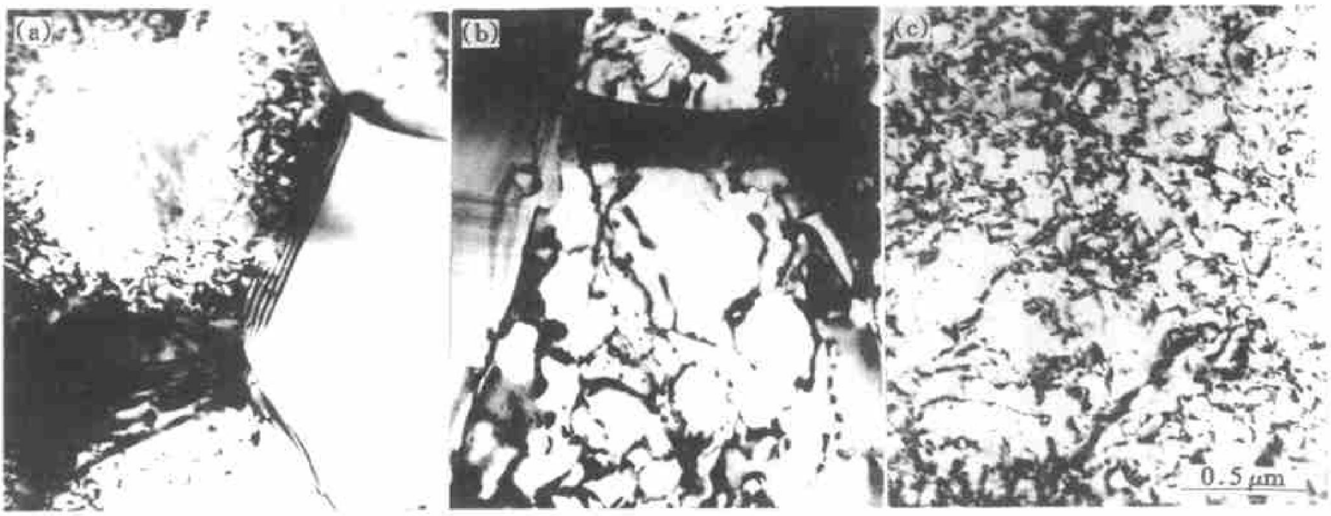

Fig. 3 Dislocation density and distribution of samples stretched to 120% under different straining conditions
(a) —570 ℃, $8.33\times 10^{-3}\ s^{-1}$; (b) —570 ℃, $5.0\times 10^{-3}\ s^{-1}$; (c) —540 ℃, $8.33\times 10^{-3}\ s^{-1}$

samples under different conditions begins to show a little difference, but the difference in distribution pattern of dislocation is much more obvious. When under optimal strain conditions the average dislocation density is a bit lower, and mainly distributed near the grain boundary. When the straining conditions are different from the optimal conditions, the dislocation density is a little bit higher, and the distribution is even. Comparing Fig. 3(b) with Fig. 3(c), it can be seen that the dislocation distribution in Fig. 3(c) is much more even, and the average density is larger. This manifests that the effect of temperature and strain rate during the process of superplastic deformation are different.

Fig. 4 shows two stress-strain curves of two different drawing conditions in Fig. 3. Obviously, the stress at 540 ℃ is much higher than that at 570 ℃, this is in accord with the fact that the dislocation density at 540 ℃ is higher than that at 570 ℃.

When the strain magnitude is over 50%, it is found that there appear stacking faults and twin crystals in the matrix material. Figs. 5(a) and (b) are the TEM pictures showing the stacking faults and twin crystals. Fig. 6 shows the electronic diffraction calibration of Fig. 5. It can be seen that, in Fig. 5(a), there are two sets of spots: one set is the face centered cube, the other is the close-packed hexagon. In Fig. 6(b), two sets of spots are mirror symmetry, proving the existence of the above mentioned stacking faults and twin crystals.

It can be seen from the above results that, during the process of superplastic deformation, the grain shape on the whole remains unchanged as equiaxed, being obviously different from the fact that the grain shape changes significantly during normal plasticity strain. Viewed from the deformation process, normal plastic deformation is realized by the lengthening of each grain, but superplastic deformation is realized by grain sliding[7]. Therefore, whether grain boundary and interface gliding can be realized smoothly is an important evaluation factor in realizing super-plastic deformation[8]. Because early growing of cavities must be avoided in realizing this kind of gliding, it is necessary that deformation of grains takes place to make up the cavities during the process of sliding[9]. The deformation of grains is bound to be concerned with dislocation movement, which makes the dislocation have an important coordination effect in the process of superplastic deformation[10].

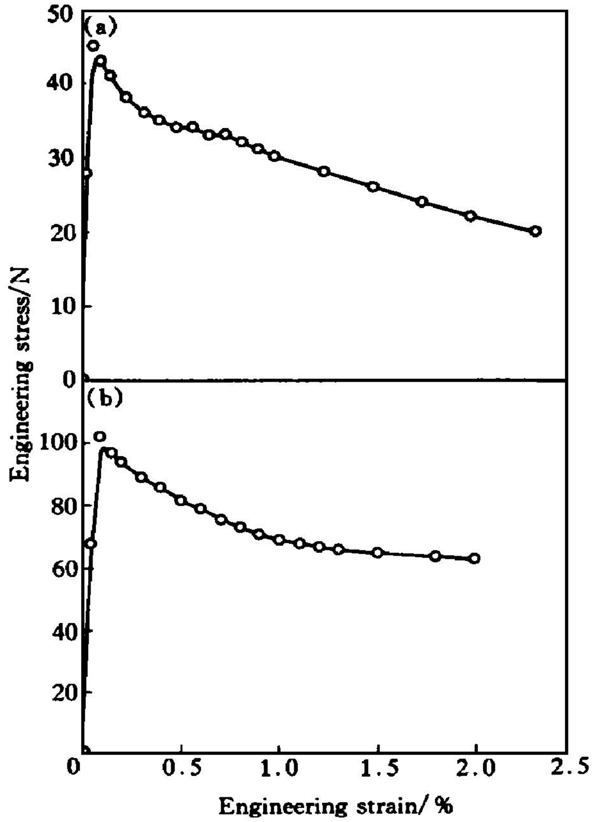

Fig. 4 Stress-strain curves of two different drawing conditions
(a) —570 ℃, $8.33\times10^{-3}s^{-1}$;
(b) —540 ℃, $8.33\times10^{-3}s^{-1}$

The phenomenon that dislocations are mainly

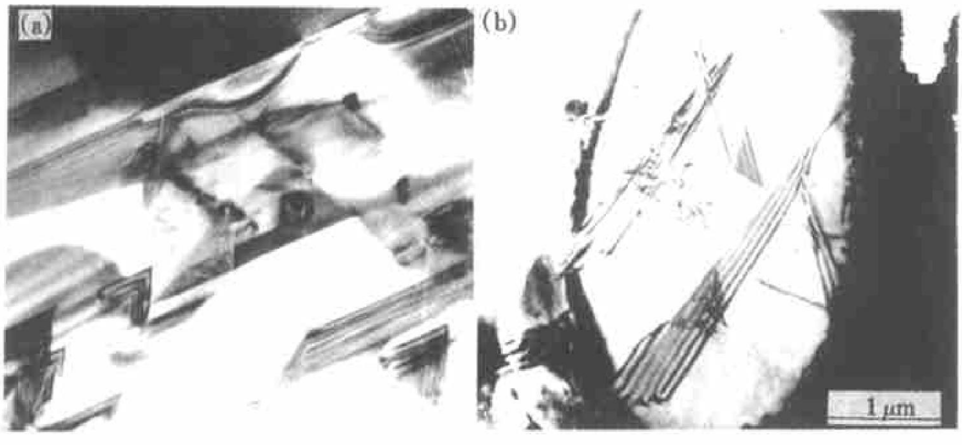

Fig. 5 Stacking faults and twin crystals
(a) —Stacking faults; (b) —Twin crystal

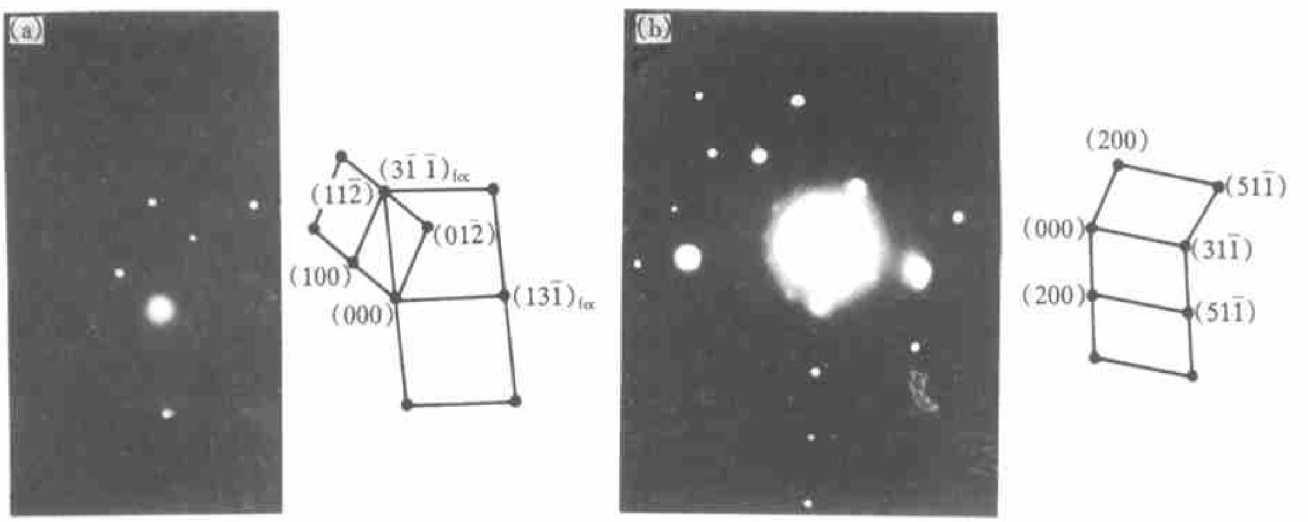

Fig. 6 Electronic diffraction patterns of samples in Fig. 5
(a) —Diffraction of Fig. 5(a); (b) —Diffraction of Fig. 5(b)

distributed around the grain boundaries under optimal straining conditions is also concerned with the coordination effect of dislocation. Due to the fact that strain is realized by grain boundary gliding and that grain deformation necessarily takes place during gliding to avoid early growing of cavities it is certain that the grains near the boundaries have much bigger deformation. This is the main reason why dislocations are mainly distributed near the grain boundaries.

When the straining conditions are different, dislocations are no longer collectively distributed near grain boundaries, which lowers the coordination effect of dislocations on grain deformation taken place in gliding between grains. Under optional conditions, when straining continues, cellular sub-structure formed by dislocation in grains, stacking faults and twin crystals are also concerned with the above-mentioned coordination effect of dislocation. Due to the fact that grain deformation intensifies when stretching continues, grain deformation can not be realized only by the dislocation movement near the grain boundaries, therefore, some sub-structure will come into being inside the grains. And the appearance of stacking faults and twin crystals can promote further dislocation movement via changing the sliding direction of dislocation when dislocation movement is restrained. Therefore, it can be considered that they have some positive influence on improving the coordination effect of dislocation.

4 CONCLUSIONS

Superplastic deformation of metal matrix composite can be realized by grain boundary and interface gliding. During the process of boundary gliding, dislocation plays an important role in coordinating grain shape change. Under different straining conditions, dislocation density and distribution are quite different. At big strain magnitude, stacking faults and twin crystals will come into being, which have some influence on superplastic deformation.

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