FORMING PROCESS OF HOT-EXTRUDED SiC_w/6061Al COMPOSITES(Ⅰ)[①]

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ABSTRACT The pressure-displacement curves of hot-extruded 6061 aluminium alloy and SiC_w/6061Al composites under different forming temperatures were measured to show the difference between these two kinds of materials. Based on the analysis of the forming process, the directionality and breakage of whiskers in hot-extruded tubes and cup-like parts were also investigated. It is shown that, compared with aluminium alloy, the resistant force of deformation of the composite is remarkably higher; and when the back-extrusion in solid state is conducted, the phenomenon of work-hardening appears, but it does not appear when the sample is extruded in liquid-solid region. SiC whiskers tend to break and distribute directionally in extrusion processes and the degree of breakage and directional distribution is consistent with that of plastic flow of metals.

Key words SiC whisker aluminium matrix composite forming of hot-extrusion

1 INTRODUCTION

In recent years, more and more continuously or discontinuously reinforced metal matrix composites (MMCs) have been used to make structural components, because of their high specific strength and specific stiffness. It was indicated that discontinuously reinforced MMCs, would have a brighter future for practical application. In the application of discontinuously reinforced MMCs the key is plastic forming, which is the basis of a wide application.

Silicon carbide whiskers reinforced aluminium matrix composites(SiC_w/Al), as a representative of discontinuously reinforced MMCs, have been widely studied such as on the materials' fabrication techniques, interface, stress and properties[1-8]. But there are so few researches on the plastic forming that the application of this kind of materials is surely hindered.

In this paper the forming process of hot-extruded SiC_w/Al composites was studied and the hot-extrusion characteristics of SiC_w/Al composites compared with that of aluminium alloys was presented.

2 MATERIALS AND EXPERIMENTAL PROCEDURES

SiC_w/Al composites were fabricated by process of squeeze-casting with a preheating temperature of 510 ℃ and a pouring temperature of 800 ℃, as well as an extra pressure of 50 MPa.

The volume fraction of SiC whiskers with a mean length of 8.50 μm was 20%, and the solidus temperature of the alloy was 580 ℃.

Experiments of hot extrusion were conducted on a four hundred-ton oil press. Schematic diagrams of the extrusion devices are shown in Fig. 1. A Hitachi S-570 scanning electron microscope (SEM) was used to observe the microstructure. The length and orientation of the whiskers were measured by an image analyzer (MAGISCAN 2A, British).

3 RESULTS AND ANALYSES

3.1 Pressure-displacement curves

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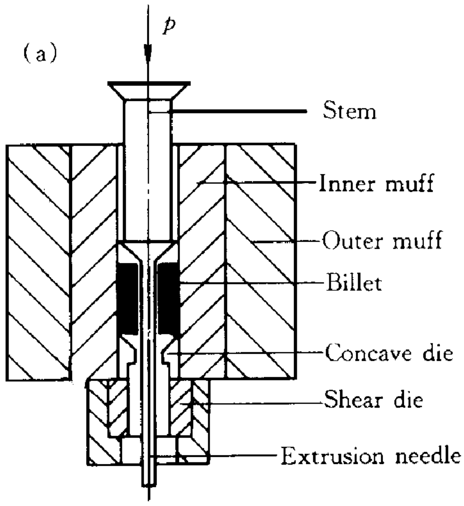

Fig. 1 Schematic diagram of extrusion devices
(a) —Normal extrusion; (b) —Back extrusion

Pressure-displacement curves of the SiC_w/6061Al composites and 6061 aluminium alloys are shown in Fig. 2. It can be seen that back-extrusion process of either the composites or the aluminium alloys may be divided into three steps: filling step (*OA*), continuous extrusion step (*AB*) and whole deformation step of the residual materials(*BC*) . Schematic diagrams of the back-extrusion steps are shown in Fig. 3.

Step one (*OA*): The stem contacts the billet, which is then pressed to fill the die. During this step the deformation is a whole one and its amount is high. The increase of extrusion pressure is also very rapid.

Step two (*AB*): The stem continues to move downward and the materials are forced to move upward along the ring-like space. As the deformation in this step is a partial one and a heat effect exists, the increase of hot extrusion pressure is very slow or even zero.

Step three (*BC*): With the progress of hot extrusion, residual thickness of the extruded materials becomes smaller and the extrusion pressure increases very rapidly.

From the pressure-displacement curves of aluminium alloys and composites it can be seen that the extrusion pressure of composites is evidently higher than that of aluminium alloys. When extruded at solid state(< 580 ℃), extrusion pressure of the composites in step two (*AB*) increases with the progress of deformation, while that of the aluminium alloys keeps constant. And when extruded at liquid-solid state

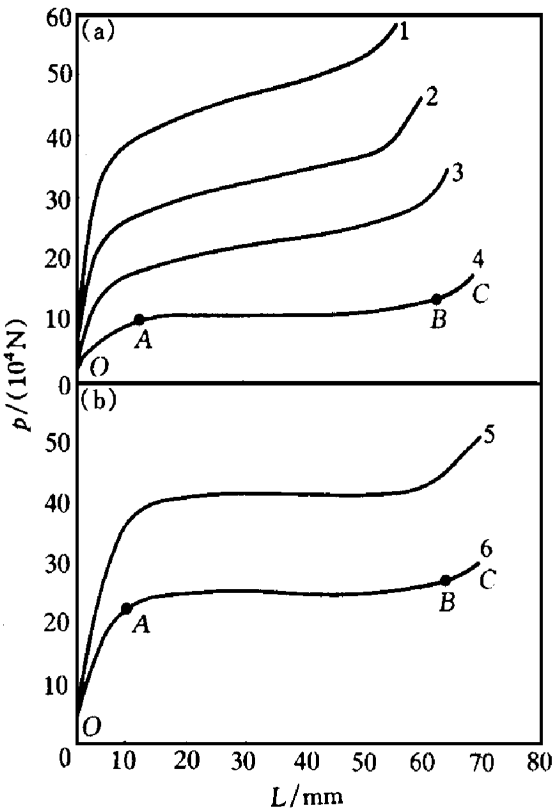

Fig. 2 Pressure-displacement curves of SiC_w/6061Al composites and 6061 aluminium alloy
(a) —Composites; (b) —Aluminium alloys
1 —420 ℃; 2 —460 ℃; 3 —540 ℃;
4 —580 ℃; 5 —420 ℃; 6 —500 ℃

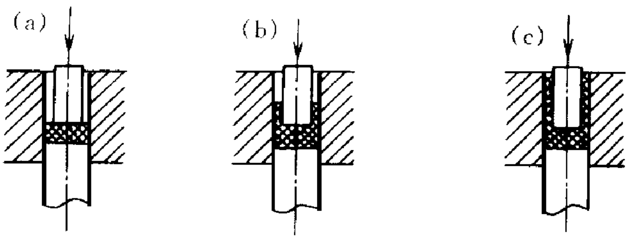

Fig. 3 Schematic diagrams of back-extrusion steps
(a) —Filling step; (b) —Continuous extrusion step; (c) —Whole deformation step of residual materials

(≥580 ℃), extrusion pressure of the composites keeps constant too, which is the same as that of aluminium alloys when extruded at solid state. For extrusion at solid state the increase of above extrusion pressure for SiC_w/6061Al composites in step two may be due to the existence of SiC whiskers. Since for the plastic deformation of metallic materials there exist two contrary processes: work hardening and softening, which determine the increase or decrease of the resistance to deformation. Therefore, as work hardening and softening effect of aluminium alloys in step two can be balanced each other, the extrusion pressure keeps constant. But for the SiC_w/6061Al composites SiC whiskers may hinder the dislocation movement in the aluminium matrix, which will put the work hardening effect in a predominant position and so lead to an pressure increase in step two.

For extrusion at liquid-solid state the unchanging extrusion pressure of the composites in step two may be a result of the presence of liquid phase. Here the presence of liquid phase works as a lubricant for the sliding and rotation of the grains and whiskers, which helps to finish the deformation of composites by mechanisms of plastic shear, sliding and rotation of grains. Therefore, both the degree of the matrix's plastic deformation and the constraint effect of whiskers on the matrix may decrease, and the work hardening effect is weakened, which finally leads to a constant extrusion pressure of the SiC_w/6061Al composites in step two.

Results in Fig. 2 show that the reason why the forming properties of SiC_w/6061Al composites are worse than those of aluminium alloys, is that the extrusion pressure of composites is in a higher level and there exists a work hardening tend in step two for the composites.

Since in the forming process of the composites' extrusion at liquid-solid two phase region, the level of extrusion pressure is a lower one and it keeps constant in step two, it is possible to improve the forming properties of SiC_w/6061Al composites.

3.2 Whiskers' orientation and breakage in forming process

3.2.1 Whiskers' orientation and breakage in back-extruded cups

Fig. 4 gives a longitudinal section of the back-extruded cup (extrusion temperature 540 ℃) and Fig. 5 presents some SEM photographs of the corresponding locations. Fig. 5 shows that all whiskers, in every locations of the cup, tend to align directionally along the extrusion direction; and during the plastic flow of metal matrix from region Ⅰ to region Ⅱ and Ⅲ, the whiskers' orientation, due to the constraint of dies, continuously changes from transverse to longitudinal direction, which always adapts to the metal's flowing direction. All facts above prove that the directional alignment of whiskers is caused by metal's plastic flow.

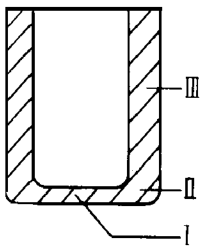

Fig. 4 Longitudinal section of extruded cup

Whiskers' orientation distribution in region Ⅲ is shown in Fig. 6. To consider the directional alignment degrees of whiskers in this region, the mid-part has the highest degree, the inner-part is lower, and the outer-part is the lowest. The above phenomenon appears in region Ⅰ and region Ⅱ too. The reason may be the smaller

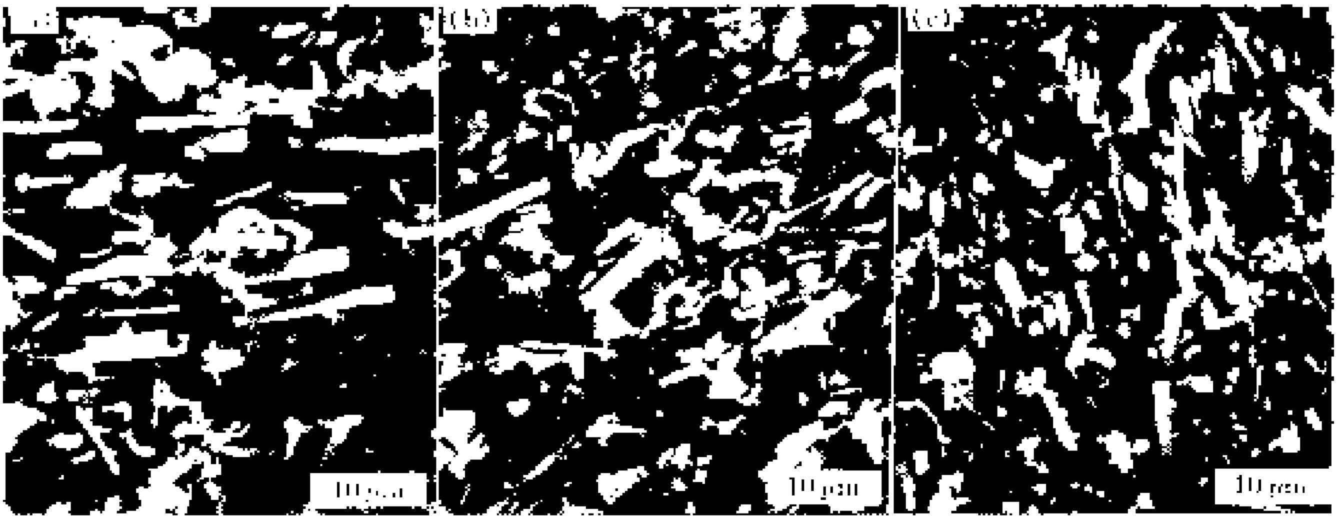

Fig. 5 SEM photographs of different locations in extruded cup
(a) —Region Ⅰ; (b) —Region Ⅱ; (c) —Region Ⅲ

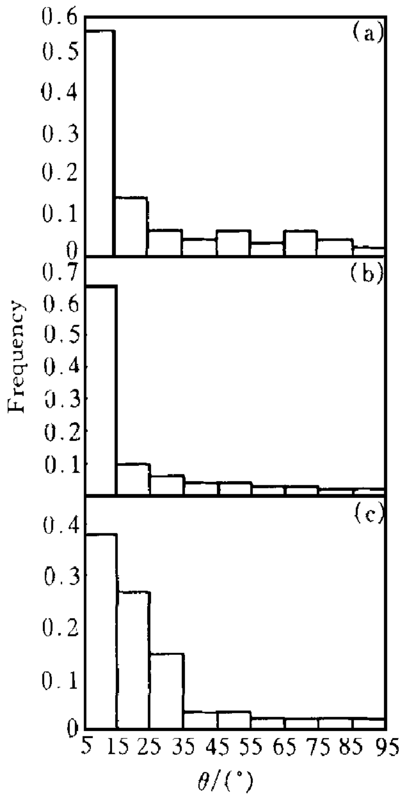

Fig. 6 Whiskers' orientation distribution in region Ⅲ of extruded cup
(a) —Inner-part in region Ⅲ;
(b) —Mid-part in region Ⅲ;
(c) —Outer-part in region Ⅲ

flowing amount of metals on both sides due to the frictional force, and the bigger flowing amount in the mid-part[9].

Whiskers' length distribution in different parts is shown in Fig. 7. The fact is that whiskers' length changes from 8.50 μm in as-cast state to 3.75 μm after back-extrusion, which proves that the breakage of whiskers in the forming process of back-extrusion is very serious. In the extruded cup different parts have

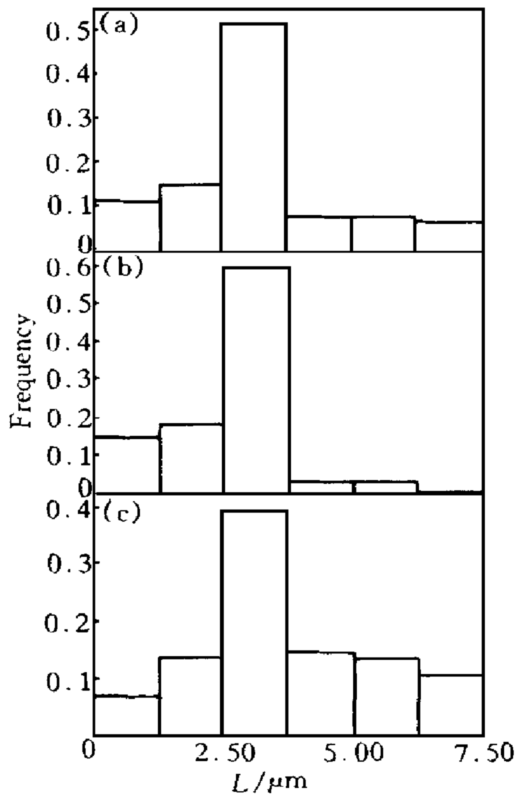

Fig. 7 Whiskers' length distribution in different parts in region Ⅲ of extruded cup
(a) —Inner-part; (b) —Mid-part; (c) —Outer-part

different degrees of breakage. The mid-part has the highest, the inner-part is lower, and the outer-part is the lowest, which corresponds to the flowing degrees of metals.

3.2.2 Whiskers' orientation and breakage in extruded tubes

The schematic diagram of the tube and some photographs of the corresponding locations are shown in Fig. 8. After extrusion, all whiskers align directionally along the extrusion direction; and during the metal flowing from region II to region I the whiskers, due to the constraint of dies, tend to align parallel to the longitudinal direction. Statistical results show that orientation and breakage of whiskers in extruded tubes are similar to those in back-extruded cups, that is, in the mid-part the orientation degree is the highest and the breakage is the most serious, case in the inner-part takes second place, and case in the outer-part takes third place.

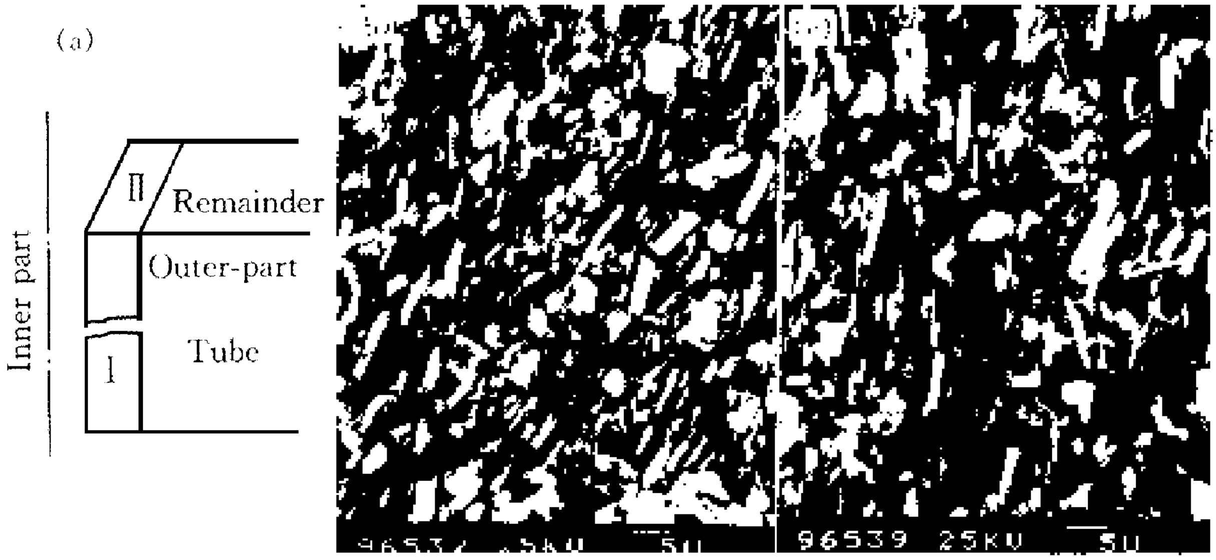

Fig. 8 Longitudinal section of tube and corresponding SEM photographs
(a) —Longitudinal section of tube; (b) —Remainder (region II); (c) —Tube (region I)

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