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DIRECTIONAL ANNEALING OF SiCw/6061Al EXTRUDED COMPOSITES

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Abstract

Directional annealing was applied to SiC whisker reinforced 6061 alloy omposites for the purpose of giving rise to improved high temperature strength by causing grain coarsening of the matrix. Directional annealing at 873K for 5h caused appreciable softening of SiCw/6061 extruded composites. The pole figures showed ⟨111⟩ texture of the 6061 alloy matrix for both as-extruded and directionally annealed materials. The obtained pole figures of the annealed materials obviously showed coarse grain structures of the matrix. At above 673K, thedirectionally annealed materials showed higher tensile strength than as-extruded ones. However, tensile strength at room temperature is decreased by 50 to 100 MPa by applying directional annealing. Thus, fine grain and subgrain structures of the matrix formed by hot extrusion are contributing to an appreciable strength increases of the composites at room temperature. In conclusion, directional annealing of SiCw/6061 extruded composites can give improved high temperature strength at the sacrifice of room temperature strength.

Introduction

By hot extrusion, fine grained microstructures are generally formed in the matrix of SiC whisker reinforced aluminum alloy composites. In such cases, tensile strength decreases and elongation increases markedly at high temperatures due to increased contribution of grain boundary sliding[1]. Superplasticity has been observed in the extreme cases[2-4]. Although such properties are suitable for hot working of metal matrix composites, much higher strength at elevated temperatures is desirable at their end uses. In this paper, directional annealing was applied to SiCw/6061 extruded composites for the purpose of obtaining improved high temperature strength by causing grain coarsening of the matrix and thereby suppressing grain boundary sliding in high temperature deformation. High temperature strength has been improved by applying directional annealing to ODS superalloys[5].

SiCw/6061 composites were fabricated by high pressure infiltration of the alloy melt into a whisker preform and subsequent hot extruion. Directional annealing was done for the extruded composites in a tubular furnace by moving the specimen at a predetermined rate. Metallography, crystallographic textures of the matrix aluminum alloy and mechanical properties at room and high temperatures were examined for both as-extruded and directionally annealed composite materials.

Experimental Procedure

β-SiC whiskers were used as the reinforcement of 6061 aluminuma alloy matrix. Cylindrical preforms of $\phi 35\times 90$ mm with two different packing densities, 13 and 20%, were used for pressure infiltration of the alloy melt to produce cast composites of two different volume fractions of the reinforcement. The SiC whisker preforms were supplied by Tokai Carbon Co., Ltd. The supplier's reference data show that the whiskers are 30 to 100 μm in length and 0.1 to 1.0 μm in diameter with the aspect ratio 50 to 200.

The fabrication process of the test materials are as follows. Extruded bars of 6061 alloy was melted and infiltrated into a SiC whisker preform under a pressure of 100 MPa at 1003K. The metal mold and whisker preforms were preheated to 623K and 1093K, respectively prior to pressure infiltration. The composite ingots were subsequently hot-extruded to rods of 7 mm in diameter at 723K at a reduction ratio of 25. Furthermore, some of the hot extruded rods were cold-swaged to 6 mm in diameter by using a rotary swaging machine with a areal reduction of 27%.

Softening behavior of the extruded composites were studied after annealing at various temperatures for 2h, and the optimum annealing temperature for directional annealing was determined. Vickers hardness was measured on the section normal to the extrusion direction. Directional annealing was carried out for both as-extruded and as cold swaged composites in a tubular furnace in an argon atmosphere by moving the specimen at a constant rate. Metallography of the composites was studied by TEM. Electropolishing was applied for preparation of the TEM specimens. Crystallographic textures of the matrix aluminum alloy were studied for both as-extruded and directionally annealed composites. The specimens for texture determination were prepared in the following way. The extruded composites of 40 mm in length were longitudinally sliced to 0.15 mm in thickness by using a wire saw, and chemically etched to remove the cut surface layer. Five slices of the composite specimens were pasted on the specimen holder side by side so as to keep the extrusion direction parallel to the vertical direction of the x-ray diffractometer. The specimen area covered in texture analysis is 34 mm in diameter. Tensile properties were examined at room temperature, 473, 573, 673 and 773K.

Results and Discussion

Annealing Behavior

Hardness of the composites before and after isochronal annealing for 2h at various temper-

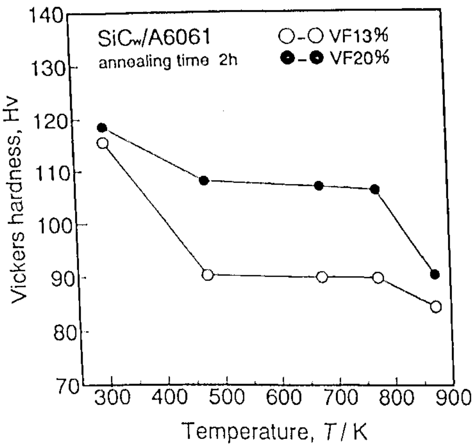

Fig. 1. Hardness changes of SiCw/6061 Al composites after isochronal annealing for 2h at various temperatures.

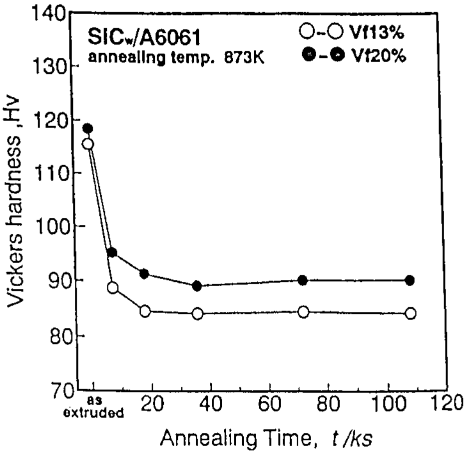

Fig. 2. Hardness changes of SiCw/6061 Al composites on annealing at 873K.

atures is shown in Fig. 1. Hardness changes by heating of extruded composites are different for different volume fractions of SiC whiskers. Softening occurs at lower heating temperature for lower volume fraction. However, annealing at 873K is needed to attain sufficiently soft materials. Hardness changes of the composites during isothermal annealing at 873K areshown in Fig. 2. Dead soft materials are obtainable by heating for 5h at this temperature. The hardness difference between as extruded and completely annealed state is about Hv 30. Hence, deformed structures of the matrix introduced by hot extrusion are significantly contributing to the strength of the as-extruded composites. Hereafter, annealing at 873K for 5h is determined as the optimum heating conditioin for directional annealing.

Structural Changes by Annealing

A typical microstructure of the as-extruded composites is shown in Fig. 3, in which fine

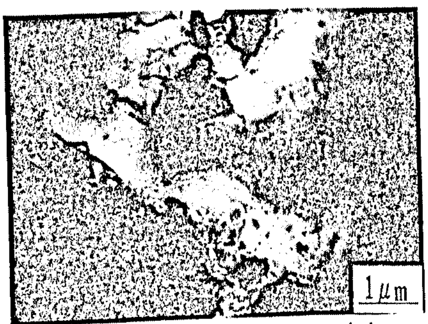

Fig. 3. TEM micrograph of as-extruded composite of SiCw/6061 Al (Vf13%).

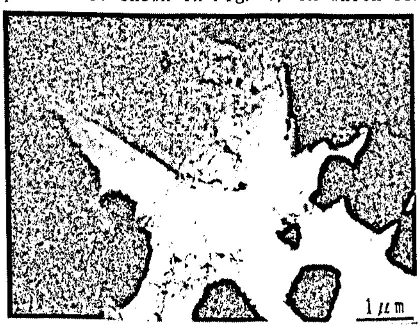

Fig. 4. TEM micrograph of directionally annealed composite of SiCw/6061 Al (Vf13%).

grain or subgrain structures are seen in the matrix. The average grain size is smaller than 1 μm. Microstructure of the composites after directional annealing at 873K for 5h is shown in Fig. 4. The grain size is now at least larger than 10 μm, and straight grain boundaries are obviously seen. The hardness decrease of the extruded composites caused by directional annealing can be well explained by these microstructural changes.

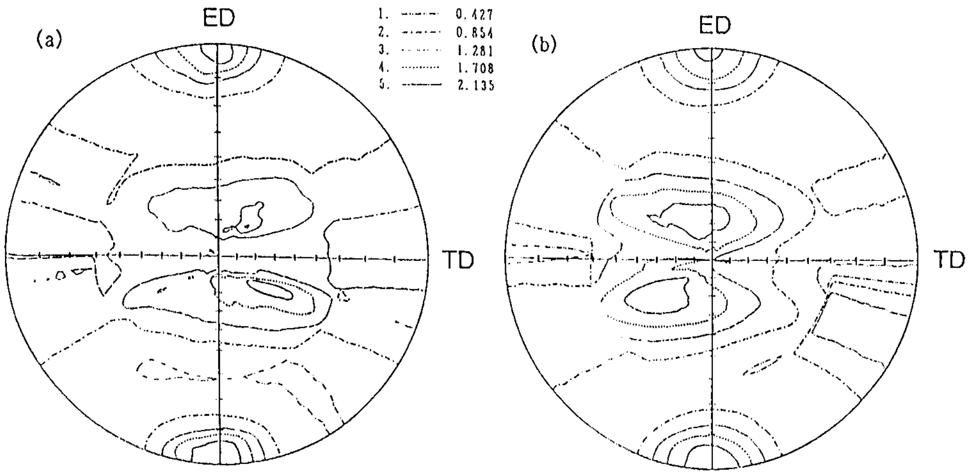

Fig. 5. ⟨111⟩ pole figures of the aluminum matrix of as-extruded composites of SiCw/6061 Al, (a) Vf13% and (b) Vf20%.

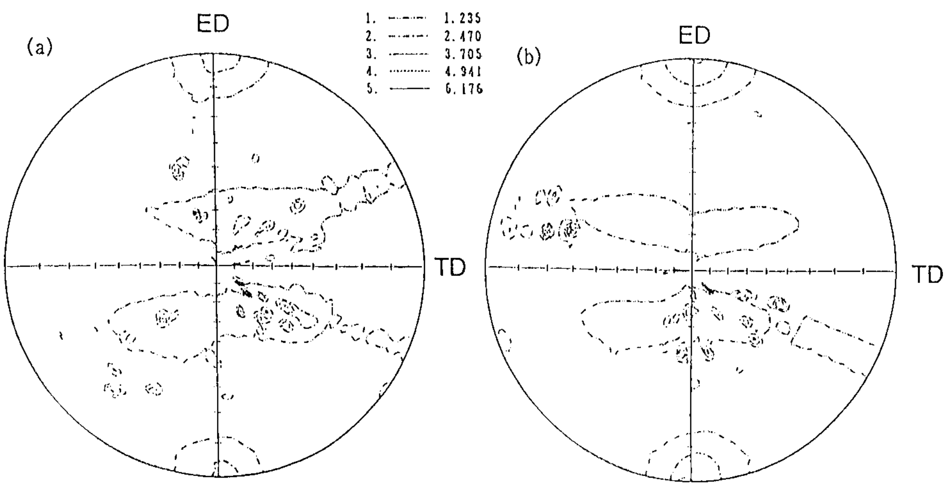

Fig. 6. ⟨111⟩ pole figures of the aluminum matrix of directionally annealed composites of SiCw/6061 Al, (a) Vf13% and (b) Vf20%.

The ⟨111⟩ pole figures of the aluminum matrix of the as-extruded composites of Vf 13 and 20% are shown in Fig. 5. The ⟨111⟩ direction of the aluminum matrix is preferentially oriented parallel to the extrusion direction, that is, ⟨111⟩ fiber texture is formed in the matrix of the as-extruded composites of two different whisker volume fractions. Pole figures of the composites after directional annealing are shown in Fig. 6. In the annealed composite specimens, the contour lines for pole distribution are less continuous although more pronounced ⟨111⟩ fiber texture is noted. Furthermore, small isolated areas of high pole density are obviously seen in these pole figures, indicating partial formation of coarse matrix grains in the order of several mm in diameter since the specimen area covered in texture analysis was as large as 34 mm in diameter.

Changes in Mechanical Properties

Tensile strength at room temperature, 473, 573, 673 and 773K is shown in Fig. 7 for the extruded composites with or without directional annealing. Data for specimens cold-swaged prior to directional annealing are also shown in this figure. Tensile strength at room temperature is decreased by 50 to 100 MPa by applying directional annealing. Fine grain and subgrain structures of the matrix formed by hot extrusion are contributing to an appreciable strength increases of the composites at room temperature. Up to 573K, the as-extruded composites show the higher tensile strength than directionally anneald ones with or without cold swaging. On the contrary, tensile strenth is higher for directionally annealed composites above 673K. Thus, tensile strenth of extruded composites is decreased at lower temperatures, but increased at higher temperatures by applying directional annealing. Tensile elongation at room temperature, 473, 573, 673 and 773K is shown in Fig. 8 for the extruded composites with or without directional annealing. Elongation increases

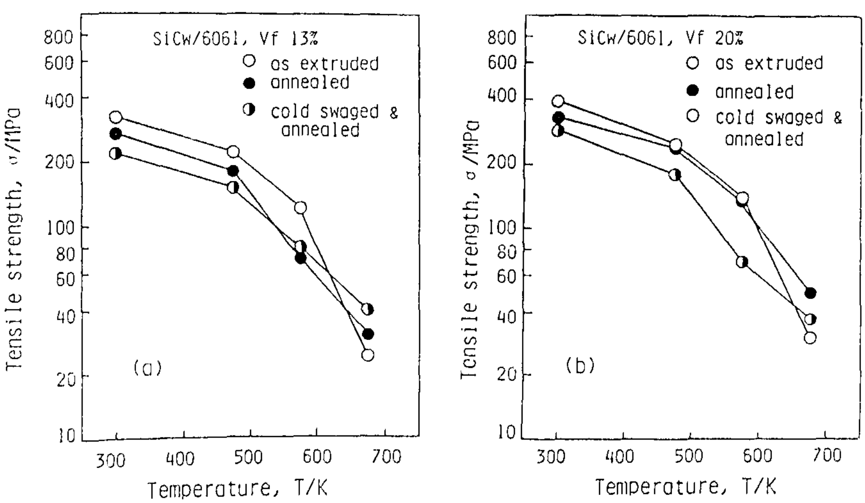

Fig. 7. Tensile strength at various temperatures of SiCw/6061 Al composites with and without directional annealing, (a) Vf13% and (b) Vf20%.

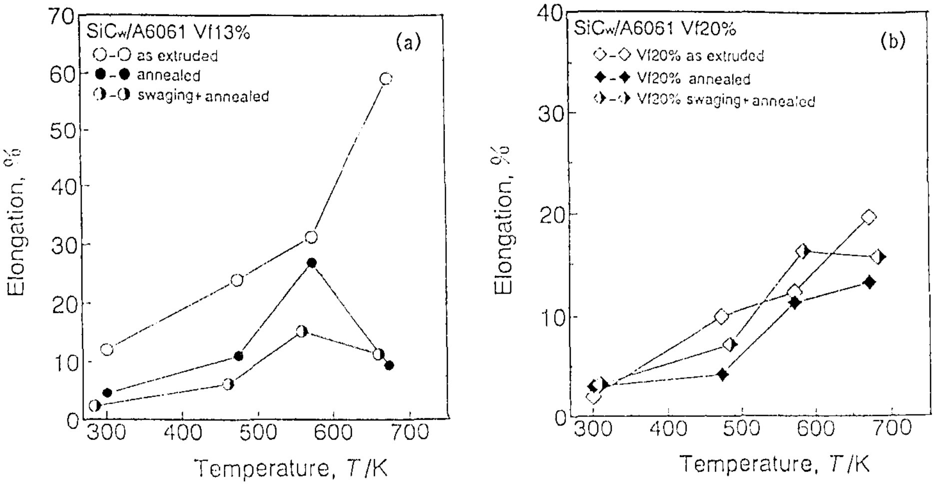

Fig. 8. Tensile elongation at various temperatures of SiCw/6061 Al composites with and without directional annealing, (a) Vf13% and (b) Vf20%.

drastically with testing temperature. Directionally annealed composites show lower elongation at high temperatures than as-extruded ones.

Directional annnealing of SiCw/6061 extruded composites can cause grain growth of the aluminum matrix. Appreciable hardeness decreases were also observed during directional annealing. Fine grain and subgrain structures of the matrix formed by hot extrusion are contributing to an appreciable strength increases of the composites at temperatures below 573K. Such fine grained structures cause further strength decreases at higher temperatures above 673K due to more pronounced contribution of grain boundary sliding. Grain coasening of the aluminum matrix attained by directional annealing can suppress grain boundary sliding, thus, strength at higher temperatures above 673K can be improved at the sacrifice of strength at lower temperatures.

Conclusion

Directional annealing at 873K for 5h caused appreciable softening of SiCw/6061 extruded composites. The pole figures showed ⟨111⟩ texture of the 6061 alloy matrix for both as-extruded and directionally annealed materials. The obtained pole figures of the annealed materials obviously showed coarse grain structures of the matrix. At 673K, directionally annealed materials showed higher tensile strength than as-extruded ones. However, tensile strength at room temperature is decreased by 50 to 100 MPa by applying directional annealing. Thus, fine grain and subgrain structures of the matrix formed by hot extrusion are contributing to an appreciable strength increment of the composites at lower temperatures below 573K. Directional annealing of SiCw/6061 extruded composites can improve high-temperature strength above 673K at the sacrifice of room-temperature strength.

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