JOURNAL OF MATERIALS SCIENCE LETTERS 6 (1987) 343–345

$K_2O \cdot 6TiO_2$ whisker–aluminium composite

T. IMAI, Y. NISHIDA, M. YAMADA, H. MATSUBARA, I. SHIRAYANAGI
Government Industrial Research Institute, Nagoya, Japan

The ceramic whisker-reinforced aluminium alloys exhibit excellent mechanical properties, especially at high temperature. These composites are produced mainly by powder metallurgical methods or casting. If the composite is fabricated by casting, whisker breakage might be slight, because it is produced with no metal working step, e.g. extrusion, rolling etc. On the other hand, if the composite is used as a machine part, the whole volume of the part is not necessarily required to be of composite in many cases, i.e. some part of the machine part must have an excellent wear property, and the other part is required, in some cases, to have a high toughness. For fabricating such machine parts, casting is more suitable than the powder metallurgical methods. For applications of these composites, the machinability of these is an important property. In general, most of ceramic whisker-reinforced metals are so hard for machining that it is difficult to make the best use of them in many cases.

There are many studies [1–3] relating to SiC whisker-reinforced aluminium alloys, but very few papers [4] concerning $K_2O \cdot 6TiO_2$ whisker have appeared. $K_2O \cdot 6TiO_2$ whisker has the advantage of low cost, and because its hardness is not as high as SiC whisker, machining might not be so difficult. Fukunaga *et al.* [4] pointed out that the relatively low tensile strength of $K_2O \cdot 6TiO_2$ whisker/aluminium composite compared with the SiC whisker/aluminium composite might be caused by the reaction between molten metal and whiskers during casting. The reaction should be related to temperature and reaction time. Therefore, if the reaction time is very short, the degradation of the whisker would be small. Therefore the $K_2O \cdot 6TiO_2$ whisker/aluminium composite was fabricated by squeeze casting [5] under conditions where the reaction time was shorter than 15 sec.

The properties of the $K_2O \cdot 6TiO_2$ whisker (produced by Otsuka Chemical Co., Ltd, Japan) used in this study are given in Table I, compared with SiC whisker. The whisker preforms were made by an aspiration method. The whiskers mixed with distilled water were poured into a bottomless vessel which is placed on a filter paper, and aspirated until all the water was filtrated. The plate-like fibrous preforms obtained were dried gradually in an oven. The composite was fabricated by infiltration of molten aluminium into a fibrous preform set in the metal mould by the application of a pressure of 100 MPa immediately after pouring molten aluminium. The time required to complete the pressure application after the pouring of molten metal was started was 8 to 10 sec. As the solidification time was very short (about 15 sec) under high pressure [5], the contact time between whiskers and molten aluminium should be extremely short, much shorter than 15 sec, except for the preform surface.

COMPO photographs of the composite analysed by EPMA are shown in Fig. 1, where (a) and (b) are the cross-sections of the composite cut in the thickness direction of the preform and in the direction normal to that, respectively. According to the line profile of the EPMA, the $K_2O \cdot 6TiO_2$ whiskers and aluminium were confirmed to be white and black areas in the photographs, respectively. Most of whiskers appear to be perpendicular to the cross section (a). This result indicates that if preforms are made by the technique employed in this study, most of the whiskers would lie horizontally.

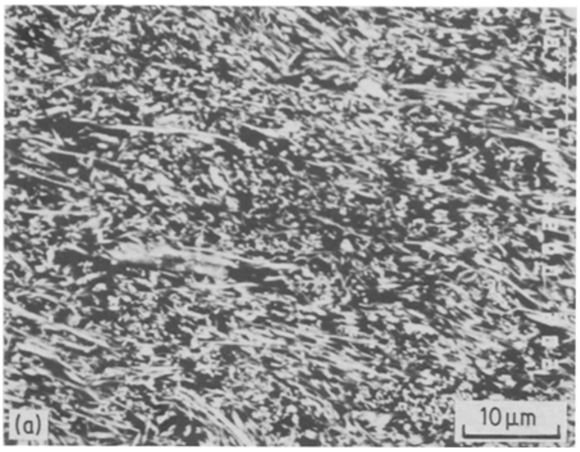
A magnified COMPO photograph of the composite is shown in Fig. 2. Some bundles of very fine $K_2O \cdot 6TiO_2$ whiskers can be seen in the COMPO photograph. Perhaps these bundles originate from preform making. Improvement of mixing of the whisker with water would result in a more homogeneous dispersion of whiskers.

Some properties of the composite are shown in Table II. As can be seen from the table, this composite consists of 56 vol % whiskers, which was determined by measuring the density of the composite. This result can also be estimated from the fact that the thickness of the preform with about 27 initial vol % was almost halved during squeeze casting. The marked characteristic of this composite is that it was possible to machine this composite with high-speed steel tools. The relatively low hardness of $K_2O \cdot 6TiO_2$ whisker in Table I compared with the SiC whisker supports this result.

The tensile strength of the $K_2O \cdot 6TiO_2$ whisker/aluminium composite at high temperature is presented in Fig. 3. The tensile strength, which is improved significantly at room temperature when compared with aluminium, does not fall as much as the temperature is raised and is more than 200 MPa at 300° C. This

TABLE I Properties of whiskers

Whisker	Diameter (μm)	Length (μm)	Density ($g\,cm^{-3}$)	Tensile strength (GPa)	Elastic modulus (GPa)	Hardness (Moh)
$K_2O \cdot 6TiO_2$	0.2–0.3	10–20	3.3	6.9	274	4
SiC	0.1–1.0	50–200	3.17	2.1–13.8	551	>9



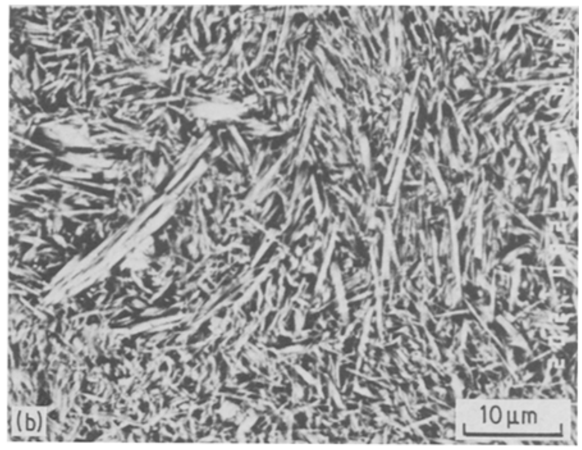


Figure 1 COMPO photographs of the composite analysed by EPMA. Cross-section cut in (a) the thickness direction of the preform, (b) normal to the direction of (a).

TABLE II Some properties of $K_2O \cdot 6TiO_2$ whisker/aluminium composite

Material	Volume fraction of whisker (%)	Vickers hardness (H_v)	Density ($g\,cm^{-3}$)	Modulus (GPa)
$K_2O \cdot 6TiO_2$/Al composite	56	154	3.04	85

result suggests that this composite is an excellent heat-resisting material among aluminium alloys, and the degradation due to the reaction between whiskers and molten aluminium is not inevitable.

For fibre reinforcement, the length-to-diameter ratio is of importance. The length of this whisker is much shorter than that of SiC whisker as can be seen in Table I. Therefore, this composite was not expected to have a high tensile strength. On the other hand, since whiskers are genrally very fine, a dispersion strengthening mechanism may be important for whisker-reinforced metals, especially for the $K_2O \cdot 6TiO_2$ whisker, which has a finer average diameter than SiC whisker.

Fig. 4 shows the fracture surface observed by SEM. There are many whiskers almost parallel to the fracture surface. Therefore, the crack appears to have passed through weak places, where gathered whiskers

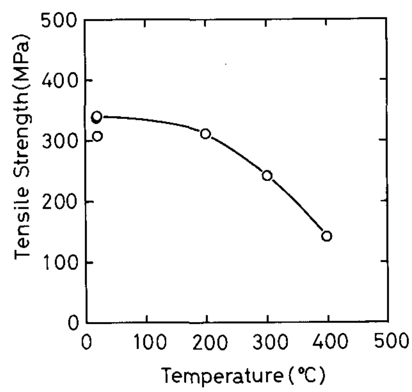


Figure 3 Tensile strength of $K_2O \cdot 6TiO_2$ whisker/aluminium composite.

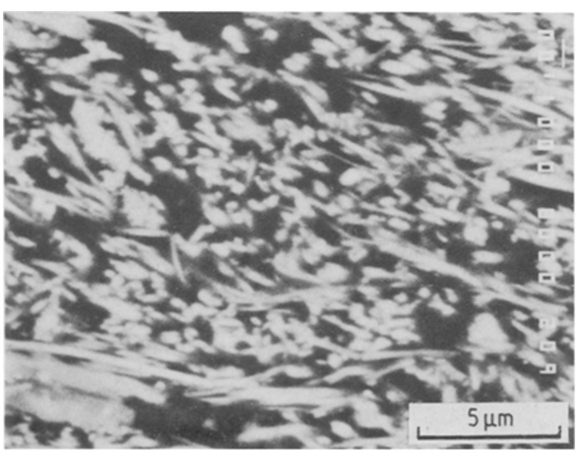


Figure 2 Magnified COMPO photograph of Fig. 1a.

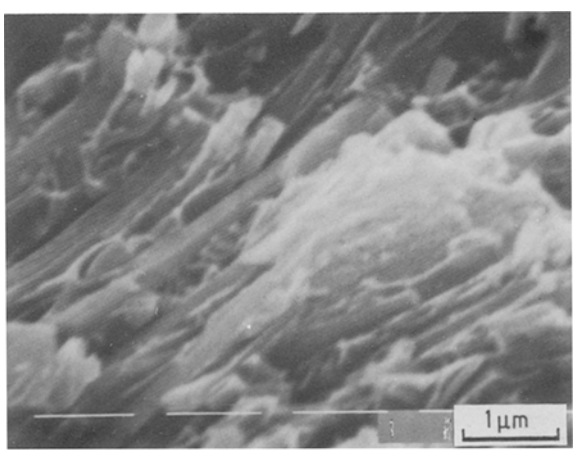


Figure 4 Fracture surface of $K_2O \cdot 6TiO_2$ whisker/aluminium composite observed by the SEM.

lie along the crack propagation direction. This result indicates that there is a possibility of improving the strength of this composite by dispersing whiskers more homogeneously.

References

1. T. G. NIEH and R. F. KARLAK, *J. Mater. Sci. Lett.* **2** (1983) 119.
2. D. F. HASSON, S. M. HOOVER and C. R. CROWE, *J. Mater. Sci.* **20** (1985) 4147.
3. D. WEBSTER, *Met. Trans. A* **13** (1982) 1511.
4. H. FUKUNAGA, K. GODA and N. TABATA, *J. Soc. Mater. Sci. Jpn* **34** (1985) 64.
5. Y. NISHIDA, H. MATSUBARA, I. SHIRAYANAGI and S. SUZUKI, *Bull. Jpn Inst. Met.* **19** (1980) 895.

Received 18 August
and accepted 10 September 1986