Effect of interfacial reaction on the Young's modulus of aluminium borate whisker reinforced aluminium composite

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The interface plays a very important role in the properties of composites. One of the effects of the interface on the properties of the composite is that it may affect the load transfer from the matrix to the reinforcement. As it is well known that the Young's modulus of composites is influenced mainly by the load transfer [1, 2], the interfacial reaction has a great effect on the bonding and strength of the interface [3], which can affect the Young's modulus of the composite.

Recently, a low cost aluminium matrix composite reinforced by aluminium borate whisker ($Al_{18}B_4O_{33}w$, denoted by ABOw) has been studied by many researchers [4–8]. Although the interfacial reaction, mechanical properties and ageing behaviours of the composite have been investigated extensively, there have been few studies on the effect of the interfacial reaction on the Young's modulus of ABOw/Al composite. This letter aims to report this effect.

The ABOw/AC8A-Al composite used was fabricated by the squeeze casting method. The volume fraction of the whisker was 25%. The composition of the matrix alloy was Si: 12.0 wt%, Mg: 1.0 wt%, Cu: 0.8 wt%, Ni: 1.0 wt%, Al: 85.2 wt%. To obtain different degrees of the interfacial reaction, the composites were fabricated at various temperatures: 660 °C, 720 °C, 760 °C, 800 °C and 840 °C. The specimens for tensile testing were solutionized at 500 °C for 5 h then quenched into water maintained at 80 °C, to prevent the effect of precipitation on the properties of the composite.

The microstructure and the interfacial reaction were studied by transmission electron microscopy (TEM). The specimens for TEM observation were thinned by the ion milling method. The Young's modulus of the composite was measured by the slope of the tensile stress–strain curves.

The dependence of Young's modulus of the composites on the casting temperature is shown in Fig. 1. It can be seen that when the casting temperature is lower than 800 °C, the Young's modulus of the composite increases with the casting temperature. When the casting temperature is higher that 800 °C, however, the Young's modulus of the composite decreases with increasing casting temperature. That is to say, there exists an optimal casting temperature for the Young's modulus of the ABOw/AC8A composite.

The microstructure of the ABOw/AC8A composite was studied using TEM. As shown in Fig. 2, an

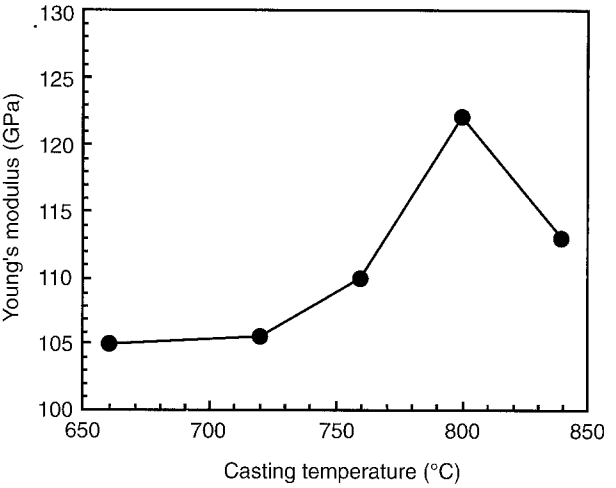

Figure 1 Dependence of Young's modulus of the composite on the casting temperature.

obvious interfacial reaction existed between the whisker and matrix. The interfacial reaction in ABOw/AC8A composite has been well studied [6–8]. The results indicated that the product of the interfacial reaction is $MgAl_2O_4$ with spinel structure. In Fig. 2, it can be seen that the degree of interfacial reaction increases with increasing casting temperature. When the casting temperature is lower, the interfacial reaction product is small (see Fig. 2a), but the reaction product in the composite cast at high temperature is very large. As the casting temperature reaches 840 °C, the surface of the whisker is almost covered by the reaction product. It can also be seen that there exist many steps on the whisker surface when the casting temperature is lower. The number of steps increases with the casting temperature below 800 °C. When the casting temperature is higher than 800 °C, the step on the whisker surface disappears due to heavy interfacial reaction. The mechanism of the step formation had been discussed by Suganuma *et al.* [7] and Hu [8].

According to the TEM observation, the effect of interfacial reaction or casting temperature can be discussed as follows:

Firstly, the interfacial strength may be enhanced by the interfacial reaction. In this case, the load transfer from matrix to whisker increases, the number of effective whiskers ("effective whisker" means that in the whisker, the load transferred from matrix is enough that the whisker has an obvious

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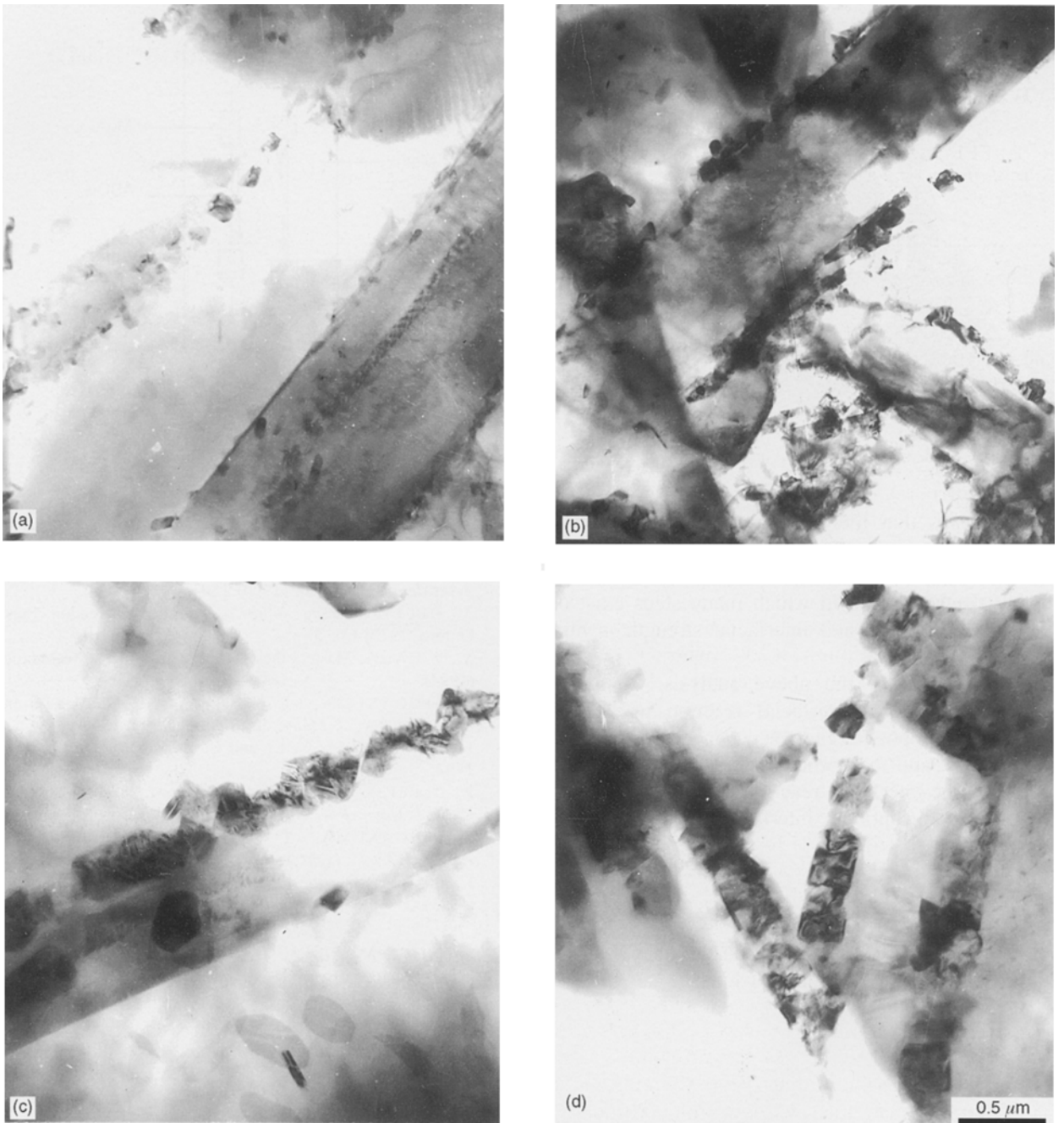

Figure 2 TEM micrographs of the composite cast at: (a) 660 °C, (b) 720 °C, (c) 760 °C and (d) 840 °C.

strengthening effect on the composite [2]). Thus, the modulus of the composite should increase with increasing interfacial reaction degree or casting temperature.

Secondly, the effective volume fraction of whisker can be increased by interfacial reaction product (see Fig. 1), which results in the modulus of composite increasing with increasing casting temperature.

Thirdly, the results of TEM observation of the interfacial reaction indicates that the degree of interfacial reaction increases with increasing casting temperature (Fig. 1). Thus, all of the effects of interfacial reaction discussed above lead to the modulus of the composite increasing with increasing casting temperature. However, the modulus of the composite decreases with the casting temperature when the temperature is higher than 800 °C, which means that there exists another factor to affect the Young's modulus of the composite.

In Fig. 2, many steps on the whisker surface can be seen, and the number of the steps increases with the casting temperature, when the casting temperature is lower than 800 °C. A high magnification TEM micrograph of a step is shown in Fig. 3. The effect of the step on the load transfer is shown schematically in Fig. 4. The deformation of the matrix should be restricted by the step even at the condition that there is no binding strength in the area in which there is no interfacial reaction. In this case, the load in the matrix should be transferred to the whisker by the restricting effect of the steps on the matrix deformation. From Fig. 2d, it can be seen that the degree of the interfacial reaction is so heavy that the step disappears at the casting temperature of 840 °C,

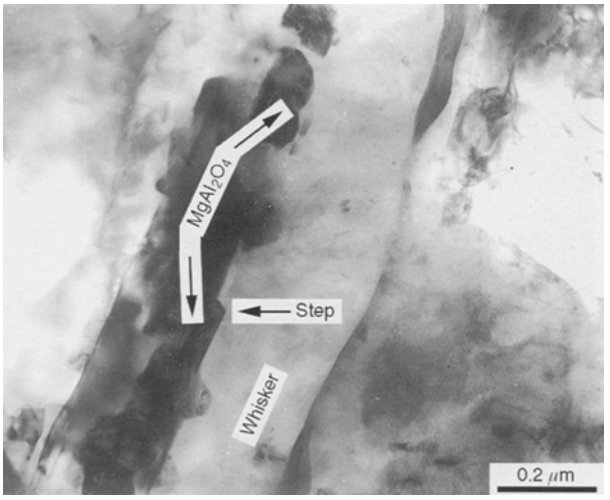

Figure 3 TEM micrograph of the step on the whisker surface.

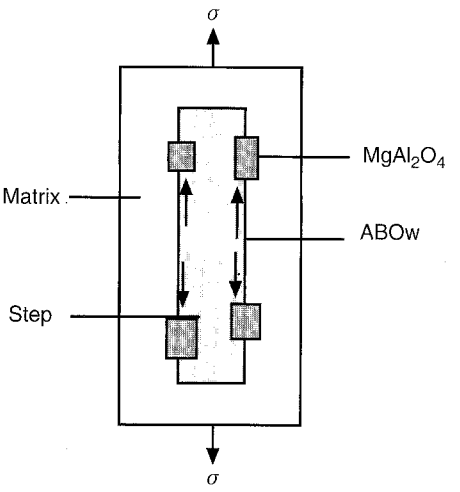

Figure 4 Schematic diagram of the load transfer by the step on the whisker surface.

which means that the load transfer by the step is very weak and results in the modulus of the composite cast at this temperature being lower than that in the composite in which many steps exist on the whisker surface and interfacial strength is high (e.g. cast at 800 °C).

On the basis of the above analysis, it can be concluded that the interfacial reaction in ABOw/AC8A-Al composite can be changed by casting temperature, and the higher the casting temperature, the heavy the interfacial reaction. For the modulus of composite, an optimal interfacial reaction degree exists.

Acknowledgement

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References

1. G. T. MAHON, J. M. MOWE and A.K. KASUDEVAN, *Acta Metall. Mater.* **38** (1990) 1503.
2. A. KELLY, *"Strong solids"*, 2nd edn (Clarendon Press, Oxford, 1973) Ch. 5.
3. X. D. JIANG, Masters thesis, Harbin Institute of Technology (1994).
4. K. SUGANUMA, T. FUJITA, N. SUZUKI and K. NIIHARA, *J. Mater. Sci. Lett.* **9** (1990) 633.
5. J. HU, W. D. FEI, C. LI and C. K. YAO, *ibid.* **13** (1994) 1797.
6. W. D. FEI, X. D. JIANG, S. WU, C. LI and C. K. YAO, *Chin. J. Mater. Res.* **9** (1995) 94.
7. K. SUGANUMA, T. FUJITA, N. SUZUKI and K. IRIIHARA, *Light Met.* **41** (1991) 279 (in Japanese).
8. J. HU, Masters thesis, Harbin Institute of Technology (1993).

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