EFFECT OF INTERFACIAL REACTION ON STRENGTH OF $Al_{18}B_4O_{33}$ REINFORCED Al Alloy COMPOSITES

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ABSTRACT Aluminum borate whisker reinforced pure Al, 6061Al, AC8A and Al-9%Cu alloy composites were prepared by squeeze casting. If an appropriate amount of interfacial reaction between whisker and matrix happened, composite strength could be improved. When composites were re-heated at 500℃ for longer than a few hours or at liquid Al temperature for a few minutes, whisker reacted with matrix severely. A severe interfacial reaction weakened whisker by whisker surface damage and whisker shortening. T6 treatment could strengthen Al-9%Cu matrix composite but was not efficient for 6061Al and AC8A matrix composites.

Keywords: *Aluminum borate whisker, Al alloy, squeeze casting, bending strength, interfacial reaction*

1. INTRODUCTION

Off all the whisker reinforcements for metal matrix composites, aluminum borate ($Al_{18}B_4O_{33}$) whisker is one that has been paid a great attention recently, because it has a higher cost-performance and some $Al_{18}B_4O_{33}$/Al alloy composite components have been applied in automobile engine practically [1,2]. In fact, there are so many kinds of whiskers that are used as reinforcements. As the representative ones, SiC and Si_3N_4 are often mentioned for their chemical stability and excellent mechanical properties in Al alloy matrix composites. But their high costs maybe limit the practical application. Some oxide series whiskers, such as $K_2O{\cdot}6TiO_2$, MgO, ZnO and TiO_2 whisker, are easy to react with aluminum and lead to property degradation, consequently are also not ideal reinforcements [3-6]. Generally, $Al_{18}B_4O_{33}$ whisker reacts with aluminum too, but not severely as other oxide whiskers [7-11]. If a suitable process or a pre-treatment on whisker is employed, their reaction could be restricted considerably [1,2,12]. In the present work, a squeeze casting process has been used to prepare $Al_{18}B_4O_{33}$ whisker reinforced Al alloy composites. Interfacial chemical reaction of composites in different heat-treated states has been studied by SEM, XRD, HRTEM etc. By observing the change of whisker's microstructure and measuring the whisker length of the composites in various states, the effect of chemical reaction on composite strength has been discussed.

2. MATERIALS AND EXPERIMENTAL PROCEDURE

$Al_{18}B_4O_{33}$ whisker, manufactured by Shikoku Chemicals Industry in Japan, was employed as reinforcement. This whisker has an octagonal prism shape and grows in [001] direction [8]. The principal characteristic contains: length 10-30μm, diameter 0.5-1.0μm, density 2.93g/cm^3, Young's modulus 400GPa, tensile strength 8GPa and Moh's hardness 7. The following aluminum matrices were used respectively: pure aluminum (Al>99.99%), 6061Al(Mg:0.8-1.2%, Si:0.4-0.8%, Cu:0.15-0.4%, Al:bal.), AC8A(Si:12%, Mg:0.96%, Cu:0.91%, Al:bal.) and Al-9%Cu. The composites were prepared by a squeeze casting method. In order to study the interfacial reaction between whisker and matrix, whisker/AC8A composite was prepared under different Al melt pouring temperatures form 720℃ to 840℃, whisker/pure Al composite was re-heated at different temperatures for 5min, and some composites were T6 treated. Whiskers were extracted from the composites in different states using 15%HCl aqueous solution and then were analyzed by means of SEM (HITACHI/S-800 type scanning electron microscope), XRD (JEOL/JRX-12VC type X-ray diffractometer) and TEM (JEOL/2000EX-II type transmission electron microscope), respectively. Composite strength was evaluated using three-point bending test.

3. RESULTS AND DISCUSSION

3.1 Effect of a slight reaction

Fig.1 gives composite strength changes along with AC8A Al alloy melt temperature during squeeze casting. The average bending strength was 637MPa(720℃), 654MPa(760℃) and 680MPa(800℃), respectively, showing a raising tendency with the increase of melt temperature. But when the melt temperature was 840℃, the composite strength went down to 616MPa. This is related to the interfacial reaction between $Al_{18}B_4O_{33}$ and aluminum matrix. In the previous work it was found from SEM observation of the extracted whisker that there were many small particle-like products adhered on the whisker surface for $Al_{18}B_4O_{33}$/AC8A composites squeezed at 800℃

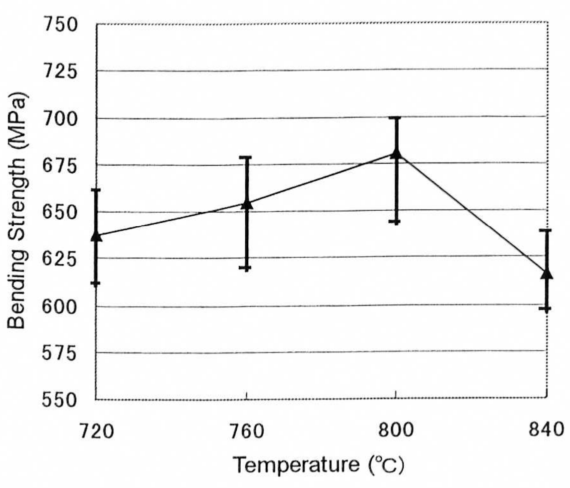

Fig.1 Effect of aluminum melt temperature on bending strength of $Al_{18}B_4O_{33}$/AC8A composites fabricated by squeeze casting.

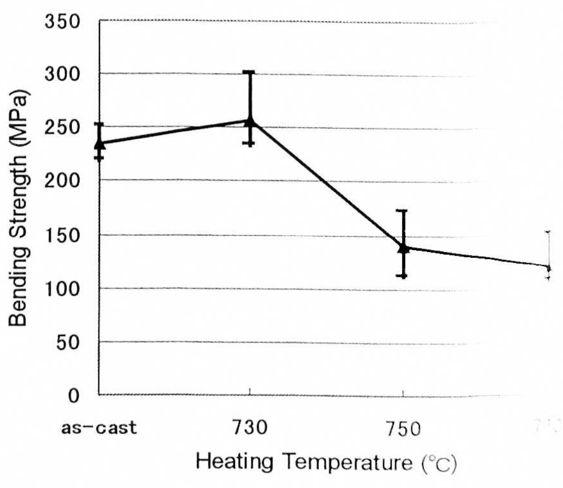

Fig.2 Bending strength of $Al_{18}B_4O_{33}$/pure Al composites heated for 5min at different temperatures.

These small particles are considered as a result of a slight interfacial reaction. They have a strong bond with the whisker and hence play an anchoring role in the interface. Therefore, such a slight reaction is favorable to increase whisker strengthening effect, which leads to composite strength have an enhancement. In another hand, pure Al matrix composite strength did not change after

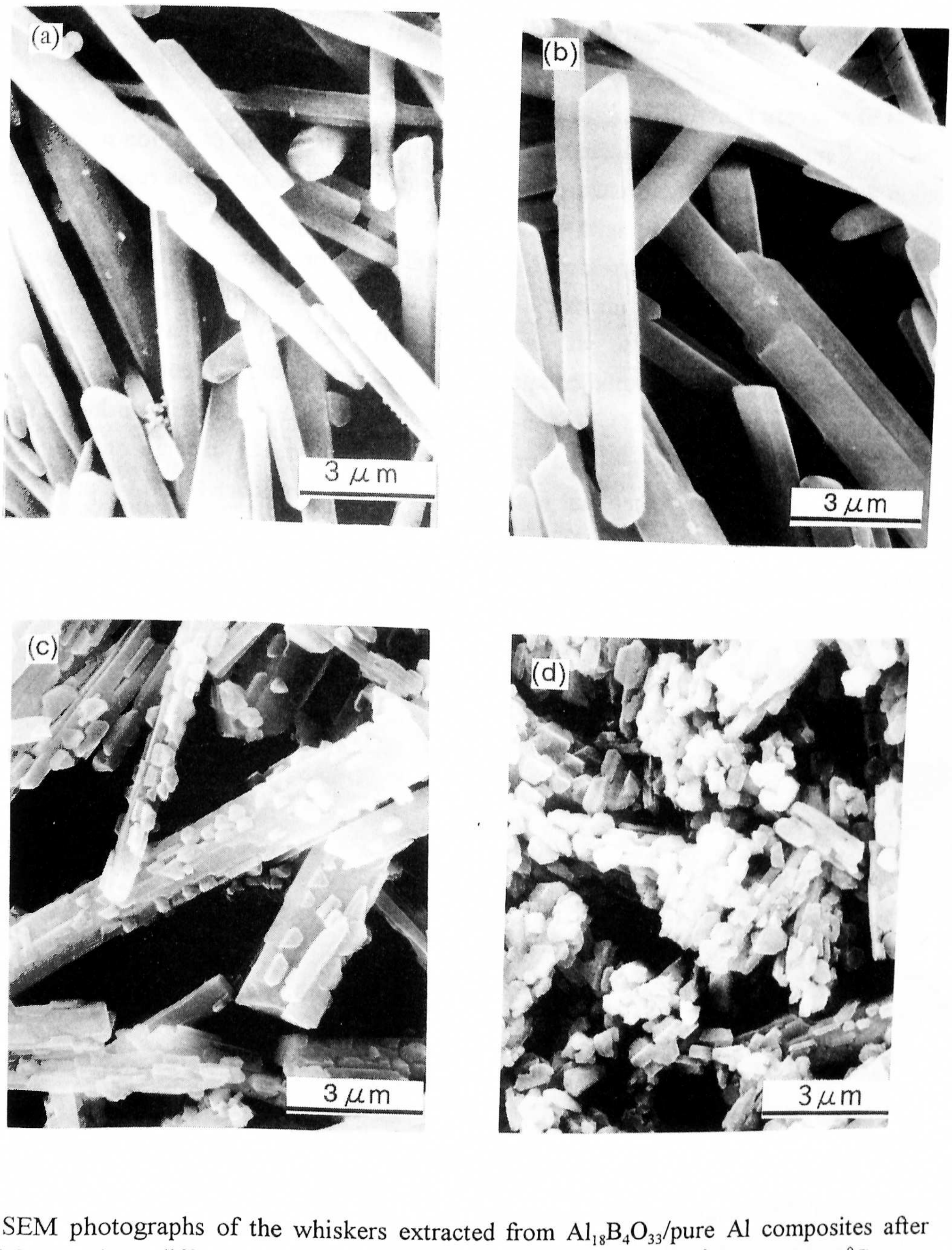

Fig.3 SEM photographs of the whiskers extracted from $Al_{18}B_4O_{33}$/pure Al composites after heated for 10min at different temperatures: (a) 660^{0}C, (b) 700^{0}C, (c) 750^{0}C and (d) 800^{0}C.

squeeze casting at 700-800℃, which indicated that the interface kept a stable state under these conditions. But after $Al_{18}B_4O_{33}$/pure Al composites were re-heated a similar strength change can be seen as shown in Fig.2, where composite strength increased little after the composite was heated at 730℃, and dropped down rapidly if heated at 750℃ and 770℃ for 5min. The same phenomenon can be found when $Al_{18}B_4O_{33}$/pure Al composites were re-heated at 730℃ for 5-15min. This illustrates that a suitable interfacial reaction is beneficial.

3.2 Effect of a severe reaction

In Fig.1 and Fig.2, it can be seen clearly that when the treatment condition surpassed a certain limitation the composite strength went down dramatically, which should be resulted from a severe interfacial reaction of $Al_{18}B_4O_{33}$ with aluminum matrix. Fig.3 shows SEM photographs of the whiskers extracted from different treated $Al_{18}B_4O_{33}$/pure Al composites. Whisker surfaces in Fig.3a and Fig.3b are clear and smooth, no reaction product can be seen. But some particle-like products began to appear when composite was heated at 750℃(Fig.3c). The whisker almost became fragments as shown in Fig.3d, after composite was heated at 800℃. From XRD results, it was confirmed that there were γ-Al_2O_3 and δ-Al_2O_3 phases in the extracted whiskers. This severe reaction induces whisker damage. The primary injury is a direct damage on whisker surface structure. Fig.4 exhibits a whisker that is being nibbled by a product $MgAl_2O_4$ phase, where the whisker lost its flat crystal side surface. In Fig.5 two surface etched pits at one whisker can be seen. Certainly, these whisker surface damages due to interfacial reaction must weaken whisker. Another injury for whisker is its length shortening during reaction, which can be seen in Fig.3.

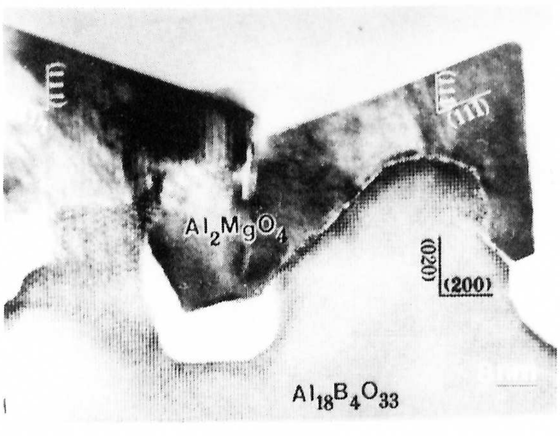

Fig.4 HRTEM image of an interfacial reaction product in as-cast $Al_{18}B_4O_{33}$/6061Al composite.

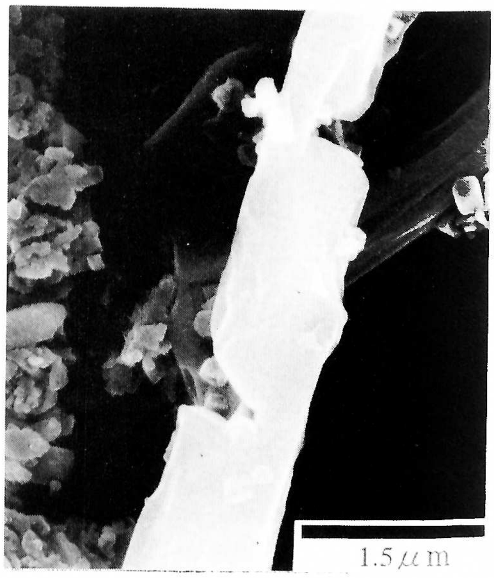

Fig.5 SEM image of whisker extracted from $Al_{18}B_4O_{33}$/AC8A composite after heated at 530℃ for 72h.

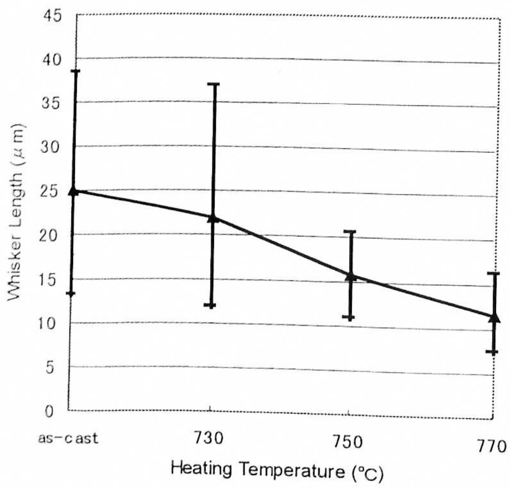

Fig.6 Whisker length after $Al_{18}B_4O_{33}$/pure Al composite being heated for 5min at different temperatures.

Table 1 Bending strength comparisons of $Al_{18}B_4O_{33}$/Al alloy composites in as-cast and T6 treated state

Matrix	As –cast	T6 state
6061Al	649	636
AC8A	660	590
Pure Al	426	459
Al-9%Cu	560	670

(MPa)

A quantitative measurement result whisker length is shown in Fig.6. After the composite was heated at 770℃ for 5min, whisker length shortened a half. This whisker shortening should be unfavorable to composite strength.

3.3 Effect of T6 treatment

T6 aging treatment is often used for Al alloy strengthening. For $Al_{18}B_4O_{33}$/Al alloy composites, because of interfacial reaction, aging strengthening effect is different. Table 1 lists the bending strength of $Al_{18}B_4O_{33}$/Al alloy composites in as-cast and T6 treated state. In the case of Mg-included alloy 6061Al and AC8A matrix composites, composite strength had an obvious degradation after T6 treatment. The previous research work indicates that there was an exothermic peak beginning at about 517℃ in DTA profile for $Al_{18}B_4O_{33}$/AC8A composite, and product $MgAl_2O_4$ was discovered [14]. It is considered that there is an interfacial reaction during solution treating on composite at about 510-530℃. This reaction damages whisker and exhausts magnesium in matrix, consequently leads to matrix hardening negated. When the same treatment was done on pure Al matrix composite, the strength enhanced about 10%, which means there should not be any detrimental interfacial reaction during this heat treatment. In the case of Al-9%Cu matrix composite, bending strength increased from 560MPa to 570MPa. This is benefited from the interface stability and matrix aging strengthening during T6 treatment.

4. SUMMARY

Aluminum borate whisker can be used for metal matrix composites a suitable reinforcement. A slight interfacial chemical reaction is favorable for composite strength improvement by an anchoring effect. T6 treatment can enhance the strength of Al-9%Cu matrix composite, but is not efficient for Mg-included alloy 6061Al and AC8A matrix composites. Furthermore, if heated at a temperature higher than 500℃ for a long time, or heated into the molten state of matrix, composite strength drops down rapidly due to whisker damage and shortening during interfacial reaction.

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