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"High Resolution Electronmicroscope Studies on Interfaces" (Part III)

"Interfacial Reaction Products & Mechanical Properties on Al Matrix Composites"

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THE WHISKER/MATRIX INTERFACIAL REACTIONS IN SiC, Si_3N_4 AND $Al_{18}B_4O_{33}$ WHISKER-REINFORCED ALUMINUM MATRIX COMPOSITES

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The whisker-reinforced aluminum composites have been of much interest for their high specific strength, high modulus, high wear resistance and thermal stability. Among them, SiC[1], Si_3N_4[2] and $Al_{18}B_4O_{33}$[3] whisker-reinforced aluminum composites appear more promising in industry. Recently, systematic investigations of the mechanical properties of these composites have been reported[4], considering the composites in as-fabricated (F) and T6-treated (T) states, which gave the bending strength: 760.4MPa (F) and 893.4MPa (T) for SiC/6061Al (V_f=25.5%), 789.6MPa (F) and 946.2MPa (T) for Si_3N_4/6061Al (V_f=30.0%), 649.1MPa (F) and 636.4MPa (T) for $Al_{18}B_4O_{33}$/6061Al (V_f=28.0%). Here V_f represents the volume percentage of the whiskers in the composites. In the composites the whisker/matrix interfaces take up much volume percentage and will influence the mechanical properties of the composites. Thus it has been of much interest to study the interface structure and interfacial reactions for well understanding the relationship between the interface and the mechanical properties. This work will present recent research results about the characterization of the whisker/matrix interfacial reactions in these composites, which were

fabricated by squeeze casting.

High resolution transmission electron microscopy (HRTEM) observations in previous work showed that there were two kinds of interface structure in the whisker-reinforced aluminum matrix composites[5-7], i.e., directly bonded interface and interface bonded with a amorphous transition layer with the width of nanometer scale. For instance, SiC[5] and Si_3N_4[6] whisker bonded with aluminum matrix with an amorphous layer, and $Al_{18}B_4O_{33}$ whisker directly bonded with the aluminum matrix[7]. Figure 1(a) shows the HRTEM image of the SiC/6061Al(Al-Mg-Si alloy) interface, from which we can see 1 nm thick amorphous transition layer between SiC and Al matrix. Figure 1(b) and (c) show the energy dispersive analysis (EDS) results in the Al matrix (b) and at the SiC/Al interface (c). The atomic ratios of Mg:Al are 1:27 (b) and 1:15 (c), which indicates Mg segregation at the SiC/Al interface. MgO particles at the SiC/Al interfaces have been observed in the SiC whisker-reinforced aluminum alloy matrix composites[8,9], which resulted from the Mg segregation at the interfaces. Mg segregation was also found at the Si_3N_4/6061Al[10] interfaces and $Al_{18}B_4O_{33}$/6061Al[7] interfaces, which resulted in the interfacial reactions. Figure 2(a), (b) and (c) show the Si_3N_4 whiskers in Si_3N_4/pure Al (a), Si_3N_4/6061Al-as-fabricated) (b) and Si_3N_4/6061Al-T6-treated (c) composites. The incident electron beam direction was parallel to the whisker growth axis [001]. It can be seen from figure 2 that no interfacial reaction happened in Si_3N_4/pure Al composite because of Mg absence, but the interfacial reactions existed in Si_3N_4/6061Al composite due to Mg segregation. Figure 2 also shows the EDS results in the matrix (d), at the whisker/matrix interface (e) and at the interfacial reaction product (f). The atomic ratios of Mg:Al are 1:18 (d), 1:11 (e) and 1:6 (f), from which the Mg segregation at the interface can be found. The EDS results at the interfacial reaction product in figure 2(f) indicated that the reaction products were Mg compounds. Detailed

analysis showed that the mostly particles at the interface in as-fabricated composite were $MgAl_2O_4$ and few were MgO[10], which was different from the case at the SiC/6061Al interfaces[8]. In T6-treated state, the Mg_2Si particles of the strengthening phase in the 6061Al alloy preferred to precipitating at the Si_3N_4/6061Al interfaces, which were shown by marks m in figure 2(c). This kind of precipitation may be beneficial to the interface strength. The detailed observations showed that in SiC/6061Al and Si_3N_4/6061Al composites the interfacial reactions did not continue to occur during T6-treatment. Therefore the bending strength of the composites increased after T6 treatment due to the matrix strengthening.

Figure 3(a), (b) and (c) show the $Al_{18}B_4O_{33}$ whiskers (marked by W) in $Al_{18}B_4O_{33}$/pure Al(a), $Al_{18}B_4O_{33}$/6061Al-as-fabricated(b)and $Al_{18}B_4O_{33}$/6061Al-T6-treated(c)composites. It can be seen that no interfacial reaction occurred at the $Al_{18}B_4O_{33}$/Al interfaces in $Al_{18}B_4O_{33}$/pure Al composite. However serious interfacial reactions existed at the whisker/matrix interfaces in $Al_{18}B_4O_{33}$/6061Al composites. In figure 3(b) and (c), the reaction products were marked by black dots. It has been found that the $Al_{18}B_4O_{33}$ whiskers themselves took part in the interfacial reactions[8], which may be found by comparing figure 3(b), (c) with (a). This kind of interfacial reactions certainly ate parts of the whiskers[8]. The interfacial reactions became more serious after T6-treatment (comparing figure 3(b) and (c)), i.e., the reaction products became more and larger in T6 state than in as-fabricated state. Figure 3(d) and (e) were the EDS results at the $Al_{18}B_4O_{33}$/matrix interfaces without interfacial phase in as-fabricated (d) and T6 (e) states. The Mg:Al atomic ratios were 1:21 (d) and 1:29 (e), which indicated the Mg segregation decreased in T6 state due to the continued interfacial reactions. This phenomenon can be used to explain why the bending strength in T6 state did not increase and even decreased (F:649.1MPa, T:636.4MPa).

It can be seen that the interfacial reaction style depends upon the interface structure

character. Moreover the interface structure character depends upon the surface state of the isolated whiskers. The amorphous layers existed on the surfaces of isolated SiC[12] and Si_3N_4 whiskers[6], and the surfaces of the isolated $Al_{18}B_4O_{33}$ whiskers were very clean[7], which resulted in the existence of amorphous transition layer at the SiC- and Si_3N_4-Al interfaces and the directly bonded $Al_{18}B_4O_{33}$-Al interface. Moreover, the unstable character of the $Al_{18}B_4O_{33}$ surfaces [7] gave that the whiskers took part in the interfacial reactions.

In conclusions, it was found that the Mg segregation at the whisker/matrix interfaces was the important factor resulting in the interfacial reactions. There were two kinds of interfacial reactions: (1) the segregated Mg atoms reacted with the interface transition layers and the whiskers themselves did not take part in the reactions; (2)the segregated Mg atoms directly reacted with the whiskers in the composites without interface transition layers. The latter case may be harmful to the mechanical properties of the composites due to the decreasing of the bending strength after T6 treatment.

ACKNOWLEDGEMENT

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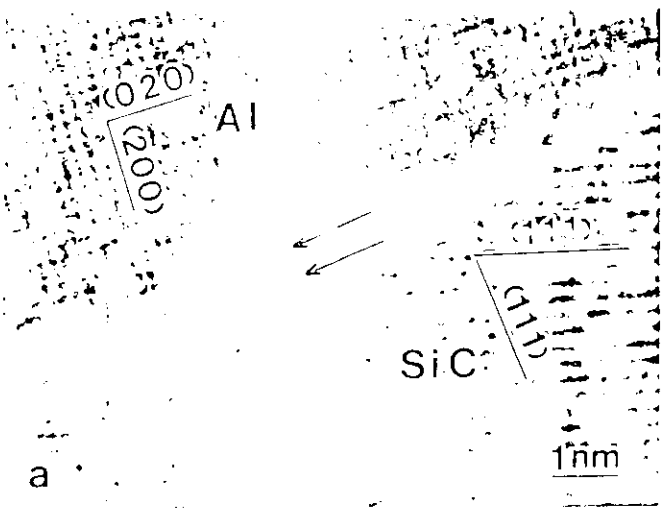
Figure Captions

Figure 1: HRTEM image of the SiC/Al interface (a) and EDS result at the interface (b).

Figure 2: Diffraction contrast images of the Si_3N_4 whiskers in the Si_3N_4/pure Al composite (a), the Si_3N_4/6061Al-as-fabricated composite (b) and the Si_3N_4/6061Al-T6-treated composite (c), viewed along the whisker growth axis. EDS results in the matrix (d), at the whisker/matrix interface (e) and at the reaction product (f).

Figure 3: Diffraction contrast images of the $Al_{18}B_4O_{33}$ whiskers in the $Al_{18}B_4O_{33}$/pure Al composite (a), the $Al_{18}B_4O_{33}$/6061Al-as fabricated composite (b) and the $Al_{18}B_4O_{33}$/6061Al-T6-treated composite (c). EDS results at the whisker/matrix interfaces in as-fabricated (d) and T-6 treated (e) states.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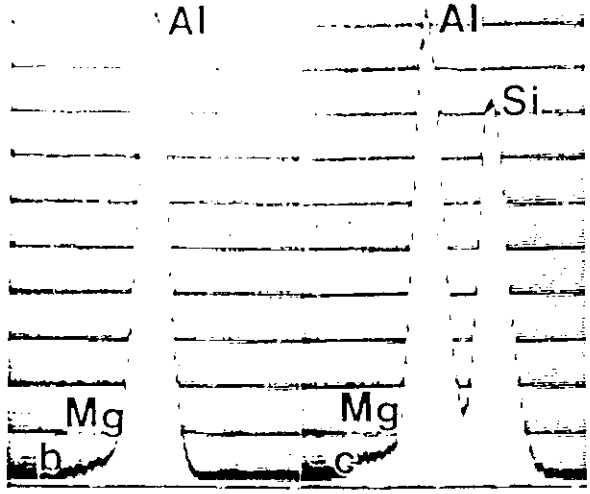
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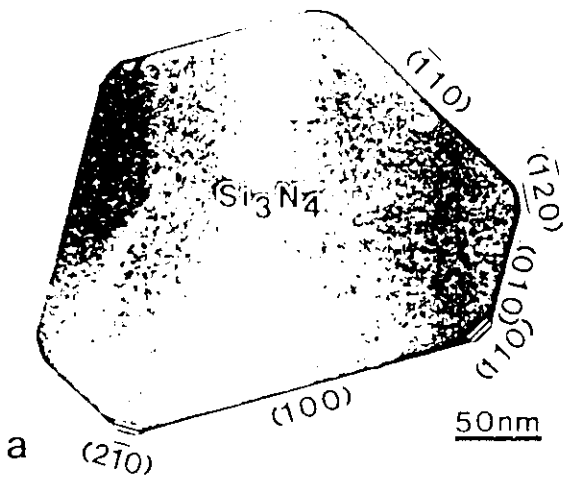
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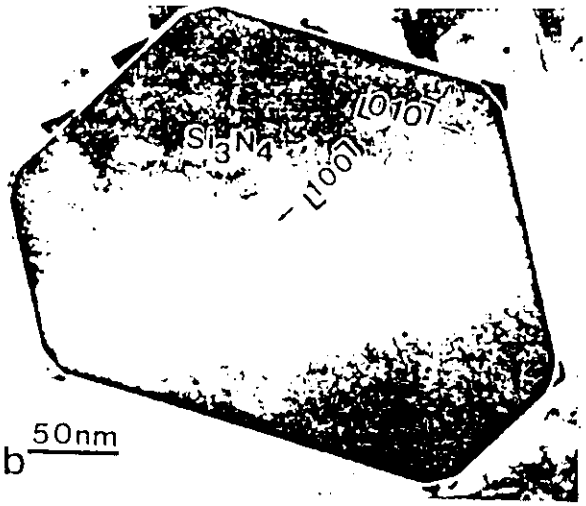
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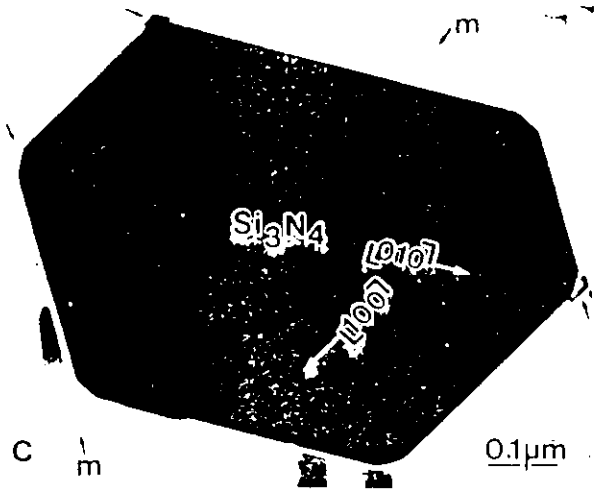
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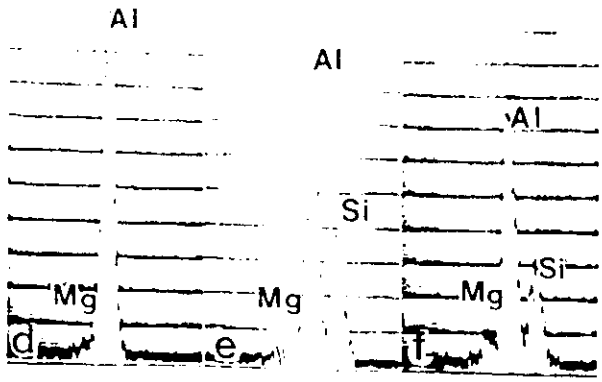
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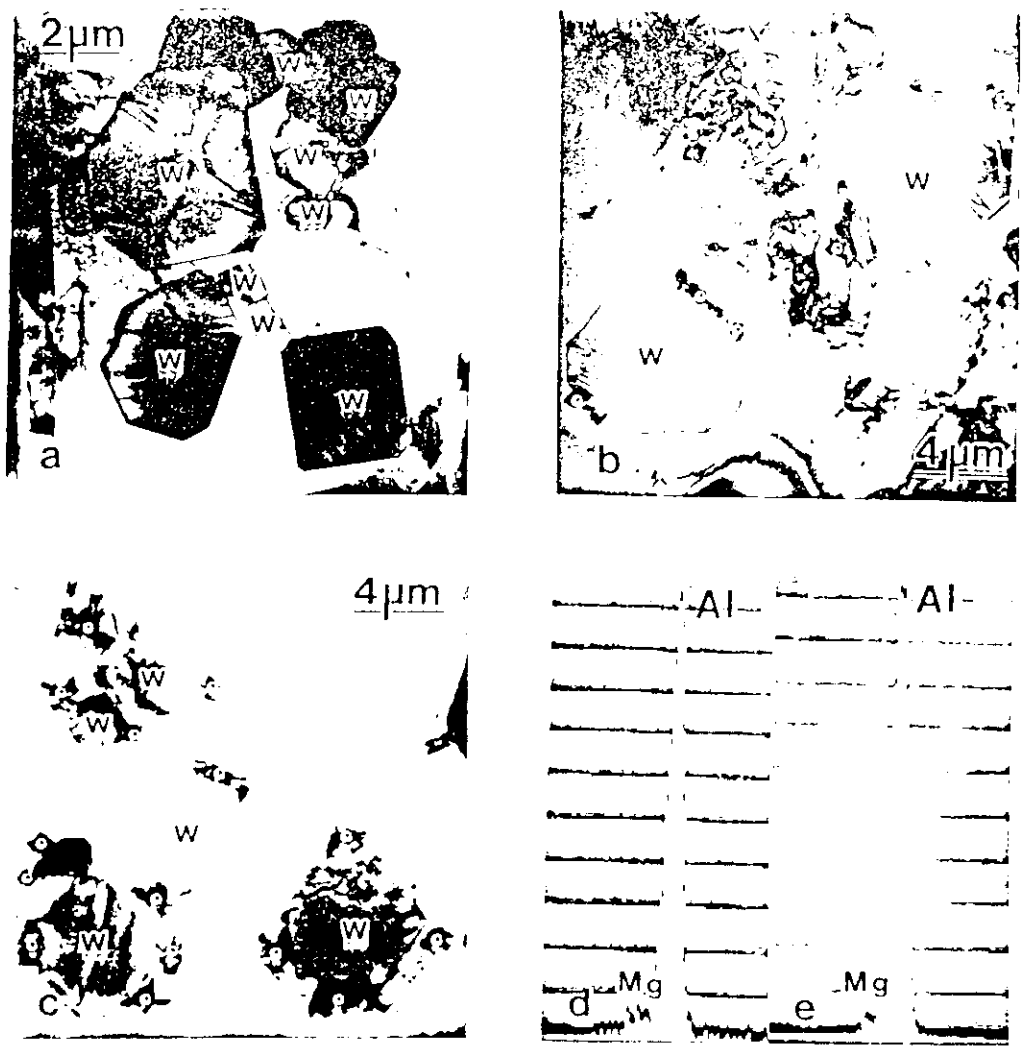
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