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Fabrication and Properties of Reaction Squeeze Cast($Al_2O_3 \cdot SiO_2$+Ni)/Al Hybrid Metal Matrix Composites

Il - dong Choi *

SUMMARY

Mechanical properties of (10%$Al_2O_3 \cdot SiO_2$+5%Ni)/Al hybrid composites fabricated by the reaction squeeze casting were compared with those of (15%$Al_2O_3 \cdot SiO_2$)/Al composites. Al - Ni intermetallic compounds (10~20㎛) formed by the reaction between nickel powder and molten aluminum were uniformly distributed in the Al matrix. These intermetallic compounds were identified as Al_3Ni using X - ray diffraction analysis and they resulted in beneficial effects on room and high temperature strength and wear resistance. Microhardness values of (10%$Al_2O_3 \cdot SiO_2$+5%Ni)/Al hybrid composite were greater by about 100Hv than those of (15%$Al_2O_3 \cdot SiO_2$)/Al composite. Wear resistance of (10%$Al_2O_3 \cdot SiO_2$+5%Ni)/Al hybrid composites was superior to that of (15%$Al_2O_3 \cdot SiO_2$)/Al composites regardless of the applied load. Tensile tests were carried out at room temperature and 300 ℃. While tensile and yield strength of (10%$Al_2O_3 \cdot SiO_2$+5%Ni)/Al hybrid composites were greater at both temperature, strength drop at high temperature was much smaller in hybrid composites.

KEYWORD : reaction squeeze cast, hybrid MMC, wear resistance, room and high temperature strength

INTRODUCTION

The application of Al alloy metal matrix composites for automotive parts has been limited due to softening of Al matrix and interfacial reaction between matrix and reinforcement at the high temperature(more than 300℃)[1 - 2]. Recently the new reaction squeeze casting techniques have been proposed to overcome the deterioration of Al matrix at high temperatures. Intermetallic compounds formed by the reaction between aluminum melt and the metal powder(Fe, Cu, Ni) or the metal oxide powder(TiO_2, NiO) during the squeeze casting are very

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* Department of Material Engineering, Korea Maritime University.

effective for improving the mechanical properties such as hardness, wear resistance, and high temperature strength[3 - 4].

Intermetallic compounds can be formed by the processes such as plasma arc melting, powder metallurgy, plastic deformation and reaction squeeze casting. Plasma arc melting is difficult to obtain a proper composition in the formation of Ti - Al type intermetallic compounds by the difference of melting point. Powder metallurgy is apt to contaminate the surface of the powders by the oxygen adsorption. Plastic deformation must be performed at the high temperature and has difficulty in fabricating complicated shape. However, reaction squeeze casting which is newly applied to form intermetallic compounds has advantages of low cost, simple process, low product defects, mass producibility of near - net - shape parts, and save energy(form easily intermetallic compounds near the melting point of low melting metal).

In the present study, (10%$Al_2O_3 \cdot SiO_2$+5%Ni)/Al hybrid composites were fabricated with reaction squeeze casting technique with a variation of pouring temperature of the pure aluminum melt. To understand the reaction characteristics, the differential thermal analysis of the reaction squeeze cast samples was performed. Microrstructure has been analyzed by the SEM, XRD and mechanical properties such as bending strength, wear properties, elevated temperature properties have been characterized for the (10%$Al_2O_3 \cdot SiO_2$+5%Ni)/Al hybrid composites. Microstructure and mechanical properties of (15%$Al_2O_3 \cdot SiO_2$)/Al composites and Al have been also analysed for comparison.

EXPERIMENTAL

Pure aluminum (purity 99.9%) was chosen for matrix, Kaowool short fibers (amorphous structure with average dimensions of 2.8㎛ in diameter and 200㎛ in length, 47%Al_2O_3 - 53% SiO_2 : Isolite Co.) and pure nickel powders (purity 99.9%, 2 - 3㎛ in diameter) were used as reinforcements for the fabrication of reaction squeeze cast (10%$Al_2O_3 \cdot SiO_2$+5%Ni)/Al hybrid composites. The hybrid preforms were prepared by employing the vacuum suction method. The mixture of reinforcements, 3% silica colloidal inorganic binder and 2% starch organic binder was dispersed in distilled water and consolidated with vacuum suction method[5]. The aiming volume fraction of reinforcement in the preform (20 × 32 × 84mm) was about 15% and preform was roughly controlled with vacuum suction pressure. Preforms were dried at room temperature for 3 days and at 110℃ for 7 days. Reaction squeeze casting was carried out by pouring the molten aluminum of 750℃, 800℃, 850℃ and 900℃ into the hybrid preform placed in the mold preheated to 400℃. Preform was also preheated to 400℃ to improve the wettability bewteen matrix and reinforcements. After pouring molten aluminum, pressure of 35MPa was applied within 7 seconds, and was held for 60 seconds. SEM, XRD and DTA analyses were carried out for the investigation of the microstructure. For the composites fabricated by pouring the molten aluminum of 800℃, microhardness test, three point bending test, wear test, and tensile test were carried out to characterize the mechanical properties of composites.

RESULTS AND DISCUSSION

Microstructure

Figure 1(a) and 1(b) are SEM micrographs of the $Al_2O_3 \cdot SiO_2$ and the $Al_2O_3 \cdot SiO_2$+Ni preform respectively. Regardless of the size of reinforcement in Figure 1(b), both reinforcements of $Al_2O_3 \cdot SiO_2$ short fibers and Ni powders were uniformly distributed and thus preforms were successfully prepared by the vacuum suction method. Figure 2(a) and 2(b) show SEM microstructures of the (15%$Al_2O_3 \cdot SiO_2$)/Al composite and the (10%$Al_2O_3 \cdot SiO_2$+5%Ni)/Al hybrid composite fabricated from the preforms shown in Figure 1. Reinforcements in composites were uniformly distributed and revealed no casting defects. SEM microstructure for the hybrid composites in Figure 2(b) revealed that Al−Ni intermetallic compounds (10∼20㎛) formed by the reaction between nickel powder and molten aluminum.

According to thermodynamics, the equation of the reaction between nickel powder and molten aluminum can be written as :

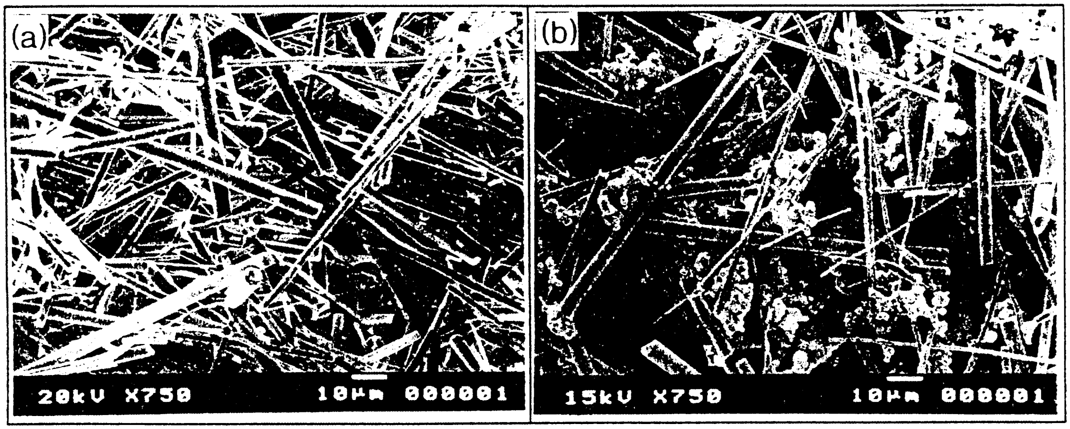

Figure 1. The Preforms fabricated by the vacuum suction method with the reinforcement of (a) $Al_2O_3 \cdot SiO_2$ (b) $Al_2O_3 \cdot SiO_2$+Ni

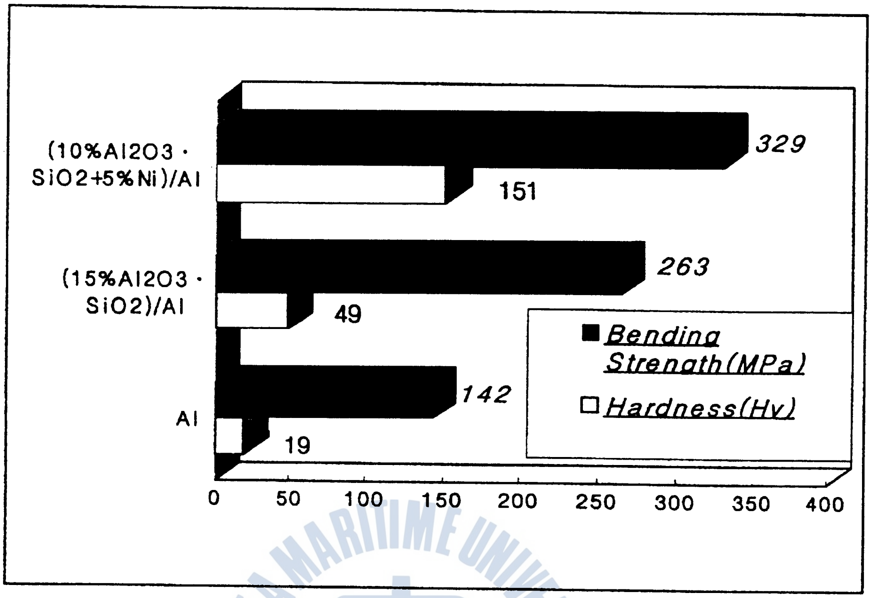

Figure 5. Hardness(Hv) and bending strength(MPa) of squeeze cast Al and Al matrix composites

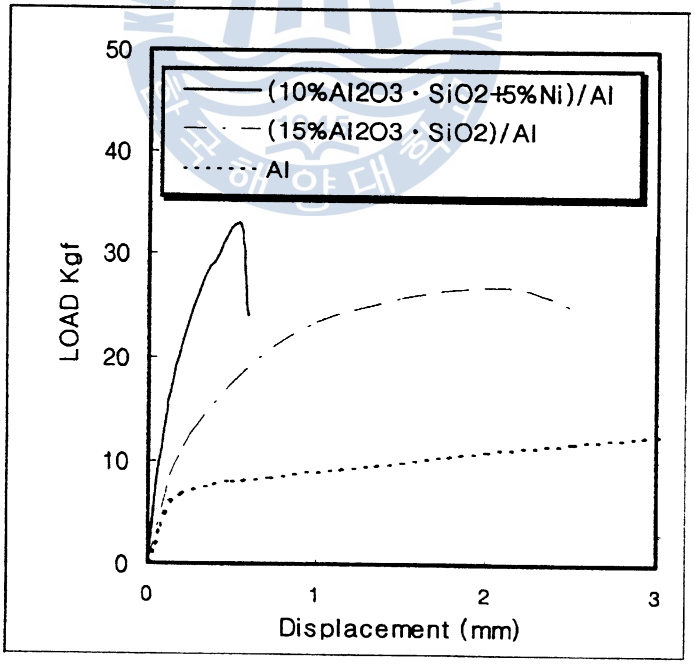

Figure 6. Load - Displacement curve of the Al and Al matrix composites with the three - point bending test

Wear loss was measured employing a total sliding contact block - on - roller type wear testing machine with variations of applied load(42M, 66.5N, 91N) at ambient temperature under dry condition. Sliding speed was 0.64m/sec and sliding distance was set to 1000m which was long enough for the onset of the steady state wear. Wear tests were performed with block specimens(12.7×12.7×12.7mm) against counterface ring of S45C steel(HRC=63, 60mm in diameter and 20mm in thickness). Figure 7 shows the wear loss of squeeze cast Al matrix, (15%$Al_2O_3 \cdot SiO_2$)/Al composite and the (10%$Al_2O_3 \cdot SiO_2$+5%Ni)/Al hybrid composite as a function of applied load at ambient temperature. As the applied load increased, for all specimens, the wear loss increased. Wear resistance of (10%$Al_2O_3 \cdot SiO_2$+5%Ni)/Al hybrid composite is highly superior to that of (15%$Al_2O_3 \cdot SiO_2$)/Al composites regardless of the applied load. In order to characterize the wear behavior observed in Figure 7, worn surfaces and wear debris collected at the end of wear experiment were examined. Figure 8 shows worn surfaces of the three specimens tested at 66.5N load. Worn surfaces of Al and (15%$Al_2O_3 \cdot SiO_2$)/Al composites deformed severely by the softening of aluminum. On the other hand, worn surface of the (10%$Al_2O_3 \cdot SiO_2$+5%Ni)/Al hybrid composites reveals the flat tracks with the crushed fine intermetallic compound particles on the worn surfaces. Conclusively speaking, wear resistance is likely to be increased due to the hard intermetallic compound particles. It was found that the shape of debris particles produced during wear tests coincided with the above features observed on worn surfaces as shown in Figure 9.

Tensile tests were utilized to evaluate the room and elevated temperature properties of the composites. All tensile-test data are summarized in Table 1 for the sake of quick reference.

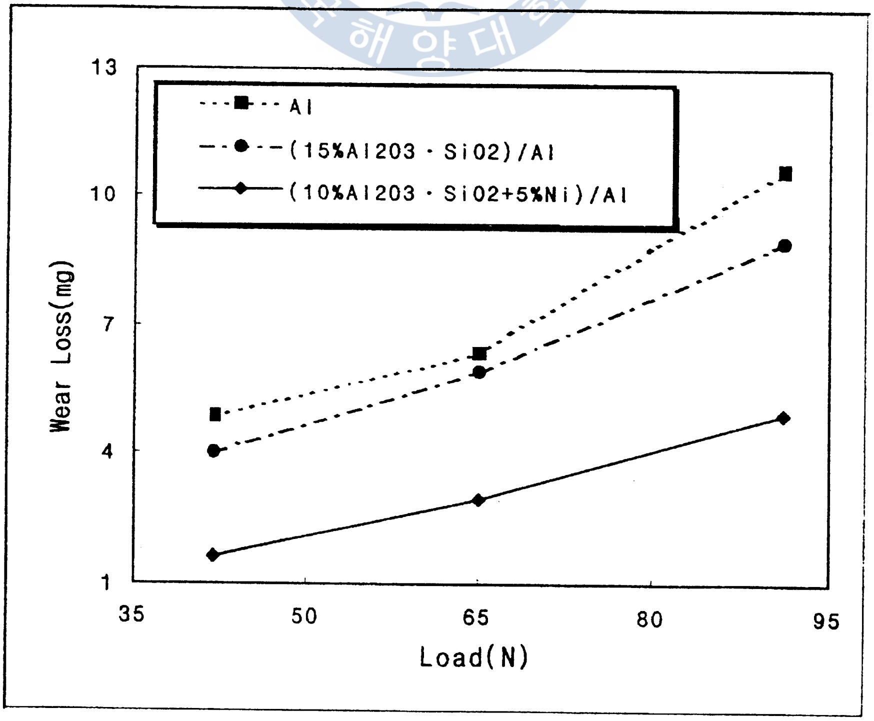

Figure 7. Wear loss of Al and Al matrix composites with variations of applied load

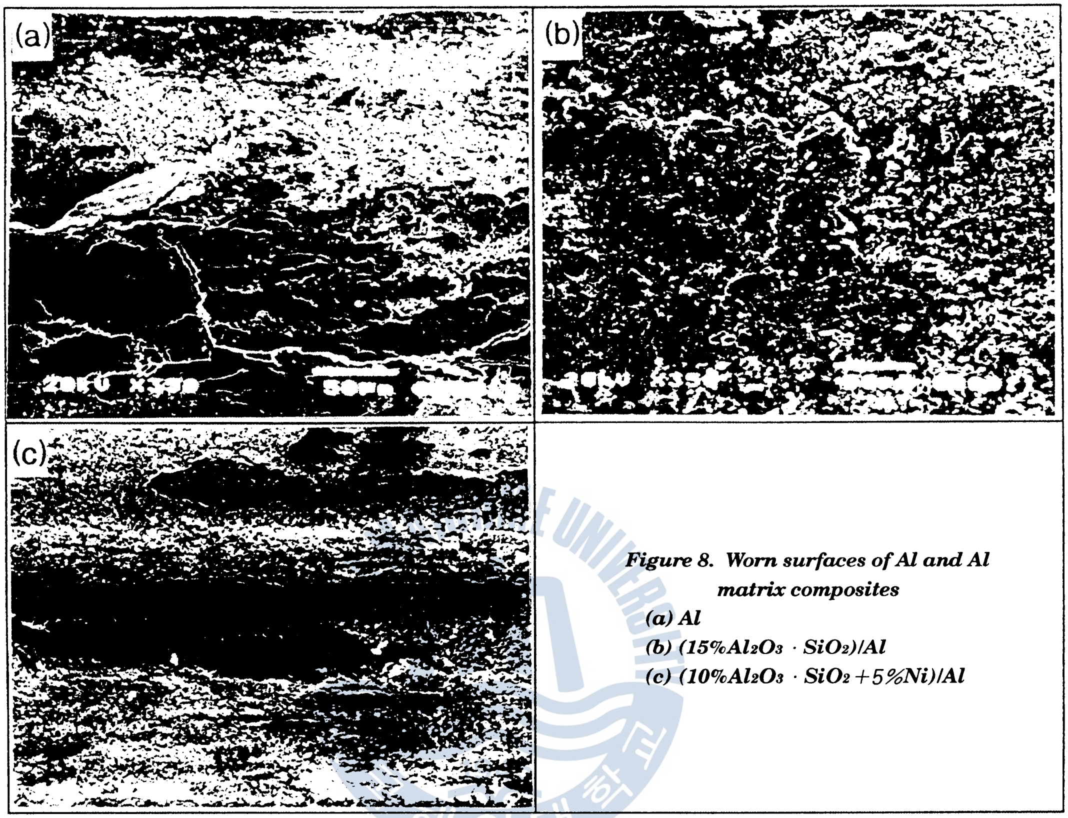

***Figure 8.** Worn surfaces of Al and Al matrix composites*
(a) Al
(b) (15%$Al_2O_3 \cdot SiO_2$)/Al
(c) (10%$Al_2O_3 \cdot SiO_2$ + 5%Ni)/Al

Tensile and yield strength of (10%$Al_2O_3 \cdot SiO_2$+5%Ni)/Al hybrid composites are greater at both temperature(25℃, 300℃), strength drop at 300℃ is much smaller in hybrid composites.

The improvement of elevated temperature strength in hybrid composites is considered that the intermetallic compound particles act as barriers to the slip behavior of the aluminum matrix as schematically shown in Figure 10. This strengthening mechanism is similar to the conventional theory of grain – boundary strengthening in which the grain boundaries block the dislocation movement during plastic deformation. However, this effect of the intermetallic compound particles in the matrix is obviously much stronger than that of grain boundary[7].

Table1. The results of tensile test of the Al matrix composites at the 25℃ and 300℃

composites	(15%$Al_2O_3 \cdot SiO_2$)/Al		(10%$Al_2O_3 \cdot SiO_2$+5%Ni)/Al	
	25℃	300℃	25℃	300℃
0.2% Y.S., MPa	83	52	130	123
U.T.S., MPa	118	89	135	130
Elongation, %	5	9	1.2	2.3

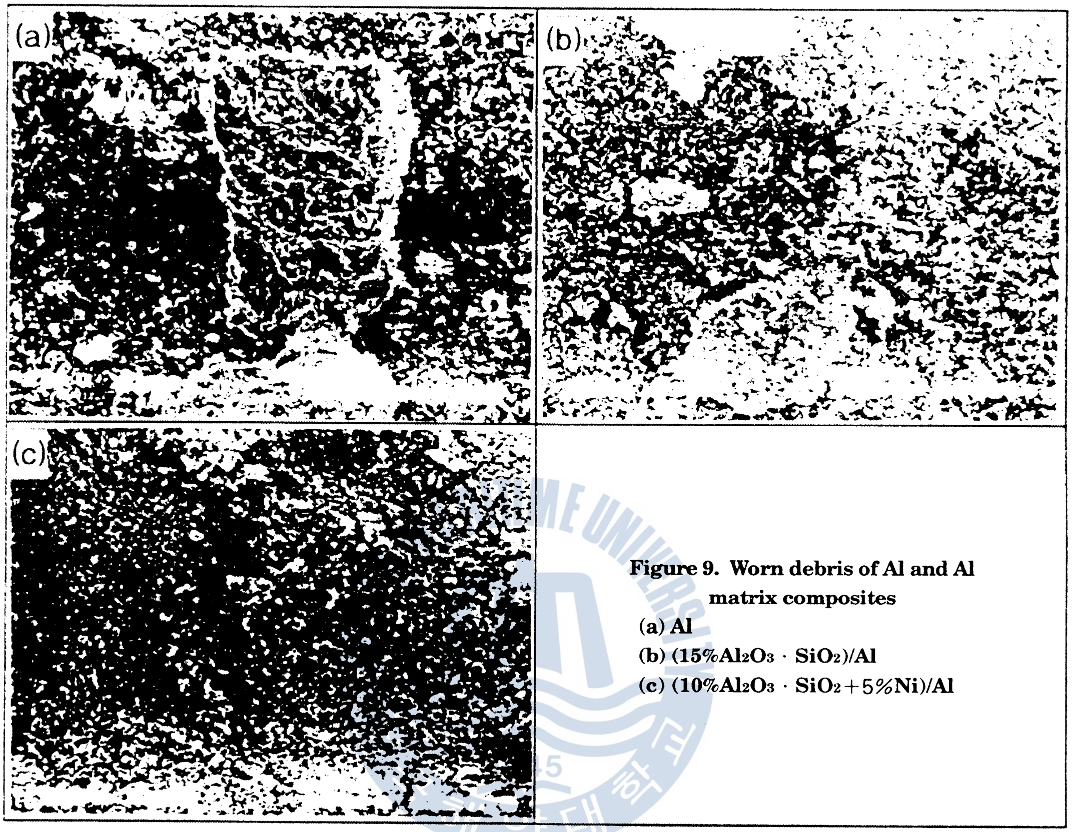

Figure 9. Worn debris of Al and Al matrix composites
(a) Al
(b) ($15\%Al_2O_3 \cdot SiO_2$)/Al
(c) ($10\%Al_2O_3 \cdot SiO_2+5\%Ni$)/Al

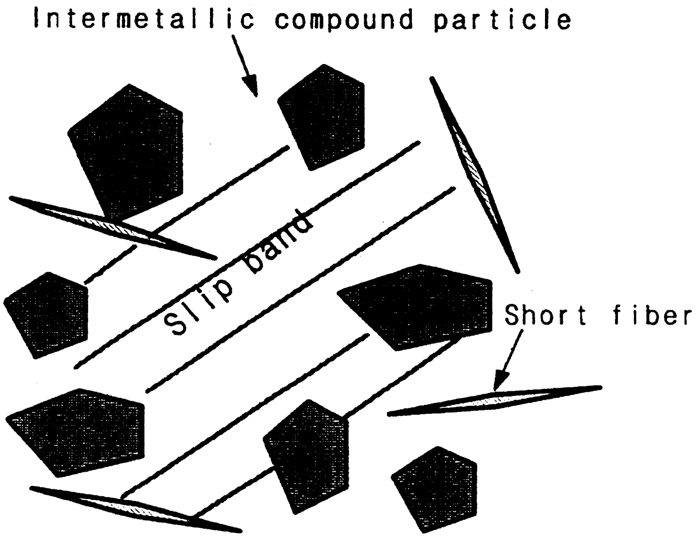

Figure 10. Schematic illustration showing the role of intermetallic compound particles for interfering slip behavior of the MMCs

The differences in the high temperature fracture behaviors between the $(15\%Al_2O_3 \cdot SiO_2)/Al$ composite and the $(10\%Al_2O_3 \cdot SiO_2+5\%Ni)/Al$ hybrid composite can be found in the SEM fractographs of Figure 11. Figure 11(a), (c) are showing the overall feature of the ductile fracture which has mostly circular - shaped dimples and a number of short fibers distributed irregularly are to be pulled out. Figure 11(b), (d) exhibit the interfacial debonding between the intermetallic compound particles and Al matrix. It is considered that the interfacial debonding of matrix - intermetallic compounds particles plays an important role in the microcrack formation of hybrid composite. Therefore, $(10\%Al_2O_3 \cdot SiO_2+5\%Ni)/Al$ hybrid composite exhibited somewhat brittle fracture in comparison with $(15\%Al_2O_3 \cdot SiO_2)/Al$ composite.

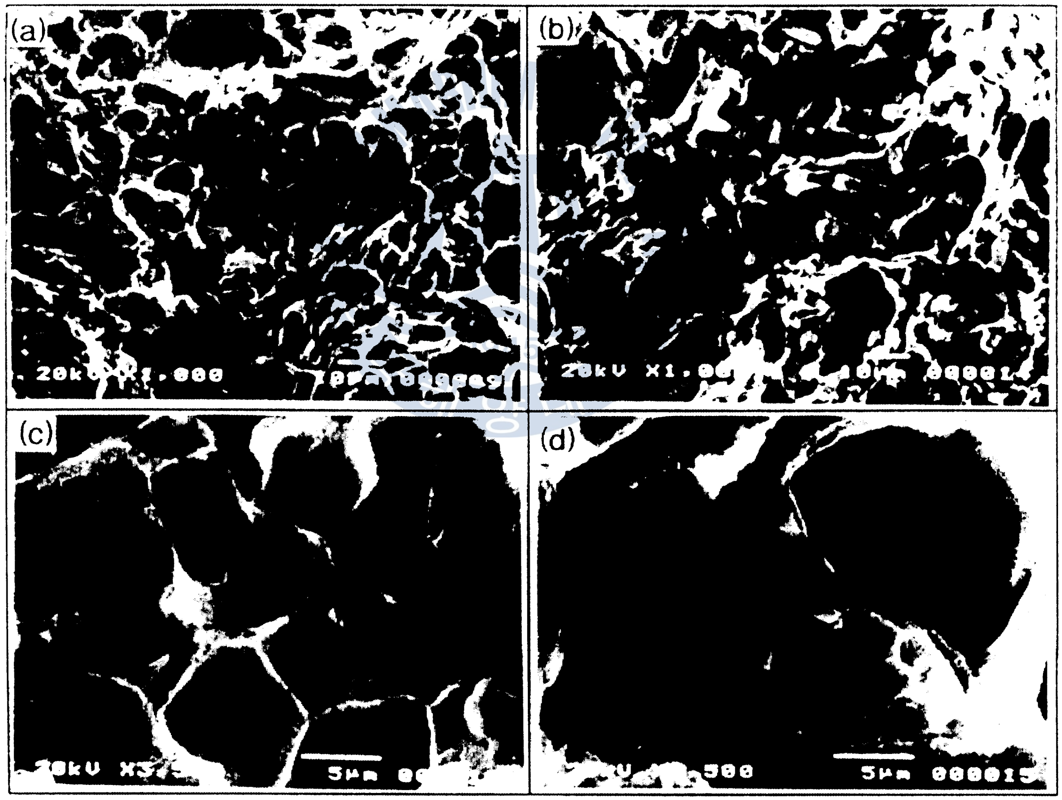

Figure 11. SEM fractographs of squeeze cast Al matrix composites tested at 300℃
(a) $(15\%Al_2O_3 \cdot SiO_2)/Al$ (b) $(10\%Al_2O_3 \cdot SiO_2+5\%Ni)/Al$
(c) and (d) is magnification of (a), (b), respectively.

COMCLUSIONS

1. $(10\%Al_2O_3 \cdot SiO_2+5\%Ni)/Al$ hybrid composites were fabricated successfully by the reaction squeeze casting.

2. It was exhibited that a major portion of the Al_3Ni was formed regardless of the pouring temperature of the molten aluminum. The Al_3Ni intermetallic compounds are formed more easily than the other intermetallic compounds due to their lower formation temperature.

3. Microhardness and bending strength of (10%$Al_2O_3 \cdot SiO_2$+5%Ni)/Al hybrid composite are higher than those of (15%$Al_2O_3 \cdot SiO_2$)/Al composite 100Hv and 66MPa, respectively. And besides, wear resistance of (10%$Al_2O_3 \cdot SiO_2$+5%Ni)/Al hybrid composite is highly superior to that of(15%$Al_2O_3 \cdot SiO_2$)/Al composites regardless of the applied load. The enhancement of these mechanical properties is likely to be due to the hard intermetallic compound particles.

4. The improvement of elevated temperature strength is considered that the intermetallic compound particles act as barriers to the slip behavior of the aluminum matrix. Interfacial debonding between the matrix and intermetallic compound particles which was observed in the fractographs plays a role in the microcrack formation and, hence, (10%$Al_2O_3 \cdot SiO_2$+5%Ni)/Al hybrid composite exhibited somewhat brittle behavior in comparison with (15%$Al_2O_3 \cdot SiO_2$)/Al composite.

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