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Wear Behavior of Ceramic Particle Reinforced Metal Matrix Composites

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Abstract

The effects of the reinforcement phase on the wear behavior of ceramic particulate reinforced aluminium matrix composites were investigated. And wear behavior according to experimental condition such as sliding velocity and distance were examined as well. The specific wear loss with the Pv factor for the SiC_p/Al matrix composite was not much changed, whereas the Al matrix indicated higher wear loss as the Pv factor are increase in. The effect of particle size as reinforcement phase in the SiC_p/Al matrix composite indicated that bigger particles represented lower fractional work than those with smaller particles, and the reason of these phenomena were revealed by fractography of both MMC. And, the specific fractional work with volume fractions of Al_2O_{3p}/Al matrix composites increased with increasing the volume fraction. The wear mechanism of SiC and Al_2O_3 particle reinforced metal matrix composites represented abrasive wear generally and some adhesive wear were indicated as the sliding velocity become higher.

Key words : Ceramic particle reinforced metal matrix composites, Friction coefficient, Wear loss, Specific frictional work

Ⅰ. Introduction

Metal matrix composites(MMC) reinforced by ceramic particles are regarded as potential materials for aerospace and automotive industries because of their high specific strength at room or elevated temperatures, low coefficient of thermal expansion and good wear resistance compared to monolithic materials. Especially, tailored properties of metal matrix composites through the change of the type of reinforcement phase and their composition have led the many development in the area of manufacturing technology of metal matrix composites(Ray, 1993; Liu et al., 1994; Sai et al., 1994). Recently pressureless infiltration technology for the fabrication of metal matrix composites have receiving significant attention. These manufacturing processes solve the wetting problem and lead spontaneous infiltration of molten metal into the ceramic preforms or loose powders by the use of in-situ reaction between the reinforcement phase and molten metal, whereas conventional liquid state processes avoid the chemical reaction and diffusion between the two phases(Urquhart et al., 1991;

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Aghajanian et al., 1991; Aghajanian et al., 1993).

The effects of processing parameters on the wear properties of ceramic particles reinforced metal matrix composites fabricated by pressureless metal infiltration method were investigated. And wear behavior according to experimental condition such as sliding velocity were examined as well. The fractography of the composites and wear mechanism were also discussed.

Ⅱ. Experimental Procedures

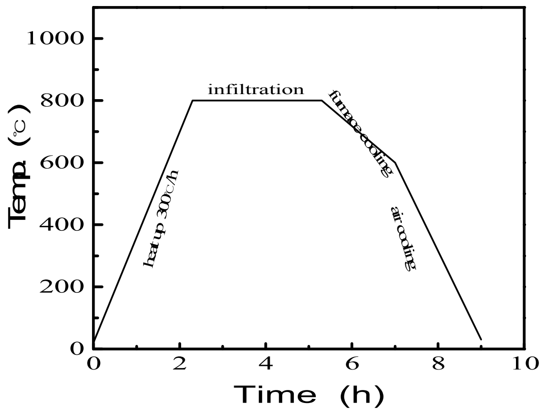
2.1 Fabrication of Composites

The matrix material of composites used in this study was AC8A alloy, which was used in piston material for automotive engine in general owing to their excellent heat and wear resistance property, and <Table 1> shows the chemical composition of AC8A alloy.

<Table 1> Chemical composition of AC8A alloy

Elements	Cu	Si	Mg	Fe	Ni	Pb	Ca	Al
wt%	1.10	11.33	1.07	0.17	1.20	.010	0.17	Bal.

Various type of composites were fabricated by changing the material variables. In case of SiC/Al matrix composites, particle size of reinforcement phase were changed with 3 type, whereas volume fraction were changed with 3 type in case of Al_2O_3/Al matrix composites. The composites were fabricated in a furnace with vacuum condition of nitrogen atmosphere. [Fig. 1] shows the processing temperature cycle for fabrication of both composites.



[Fig. 1] Processing temperature cycle for fabrication of composites

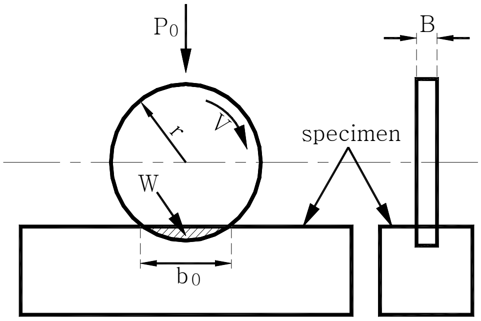
2.2 Wear Test

The universal wear tester was used in sliding wear test. And surface-hardened S45C carbon steel was used as friction material for the composites. Sliding wear test were carried out at fixed sliding distance of 100 m and applied load of 12.6 Kgf. Main experimental parameter in sliding wear test was sliding velocity, and wear test were progressed under the various sliding velocity of 0.62, 1.14, 2.38 and 3.53 m/s in the state of fixed sliding distance and applied load.

The specific wear loss was calculated using Eq.(1). [Fig.1] shows the schematic wear tester.

$$W_s = (B \cdot {b_0}^3)/(8 \cdot r \cdot P_o \cdot L_o) \quad \cdots\cdots\cdots\cdots (1)$$

Where, Ws is specific wear loss, B width of the counterpart material, b0 width of worn surface, r radius of friction material, Po applied load and Lo sliding distance.



[Fig. 2] Schematic wear tester

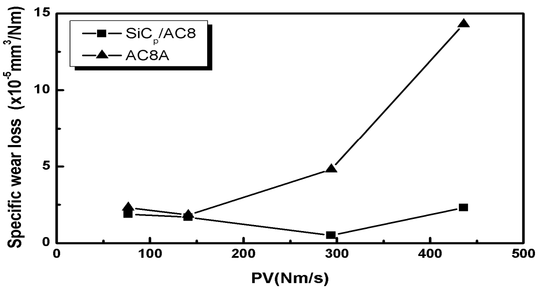
Ⅲ. Result and Discussion

The experimental condition, which have influence to wear and friction for the materials, are wear mode, hardness and shape of counterpart material, sliding velocity and distance, applied load, temperature and humidity etc. Among them the product of applied load and sliding velocity can be defined as Pv factor, and this factor act as important parameter to decide experimental conditions. The concept of specific frictional work by friction can be defined as Eq. 2 as well.

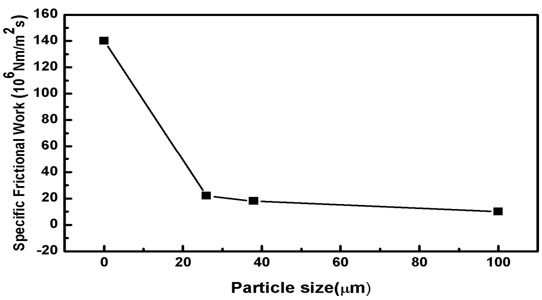
$$Wf = \rho Pv(Nm/m^2 s) \cdots\cdots (2)$$

where ρ is friction coefficient. Therefore, Pv factor describe tribological standard of load bearing power for the load supporting materials.

[Fig. 3] shows the effect of Pv factor on wear loss of SiC_p/Al matrix composite and Al matrix. In case of SiC_p/Al matrix composite, the variation of the wear loss is not much changed with Pv factor, However, wear loss of Al matrix indicated high wear loss as the Pv factor are increase in. From the above results, it was revealed that load capability of Al matrix are limited in high Pv factor region due to the high wear loss, whereas SiC_p/Al matrix composite can be kept high load supportable capability regardless of Pv factor.



[Fig. 3] Effect of Pv factor on wear loss of SiC_p/Al matrix composite and Al matrix.

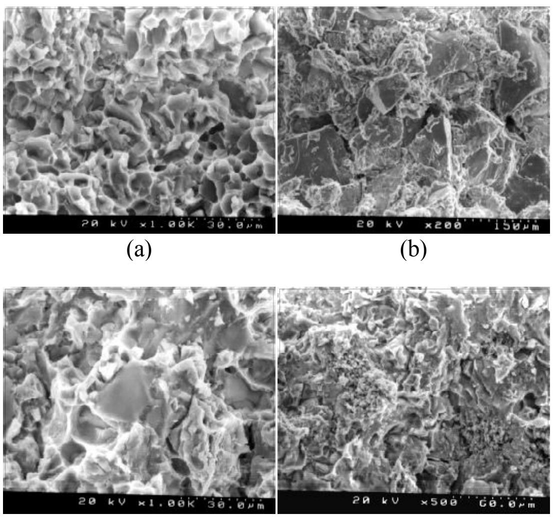


[Fig. 4] Effect of reinforcement particulate size on fractional work of SiC_p/Al matrix composites.

[Fig. 4] shows the effect of reinforcement particulate size on fractional work of SiC_p/Al matrix composites, and describe that composites with big particles represented lower fractional work than those with smaller particles.

These phenomenon could be explained the fractography of Al matrix and SiC_p/Al matrix composites in [Fig. 5]. [Fig. 5](a) shows failure surface of the Al matrix, and it can be ascertained that there are a lot of small shallow dimples of classical ductile pattern. The composites with larger particles indicate brittle fracture which shows debonding between the interface of two materials and pullout of particles as shown in [Fig. 5](b). However, the composites with smaller particles display some dimples and particle fracture which represent strong interfacial bonding as shown in [Fig. 5](c).

Hadinfard revealed that interface of matrix and particle play a significant function on the fracture process of composite materials(Hadinfard et al., 1994). The composites with strong interface between the reinforcement phase and matrix material caused more particle fracture in general. However, the composites with weak interface lead to more interface debonding between the two materials. It turn out that small particle in the composite materials have strong interfacial bonding compared to large particle in these composites.

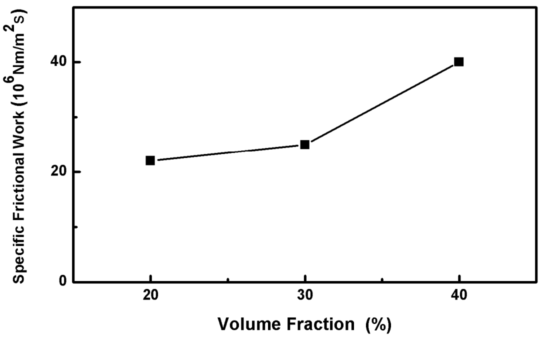


(a) (b) (c) (d)

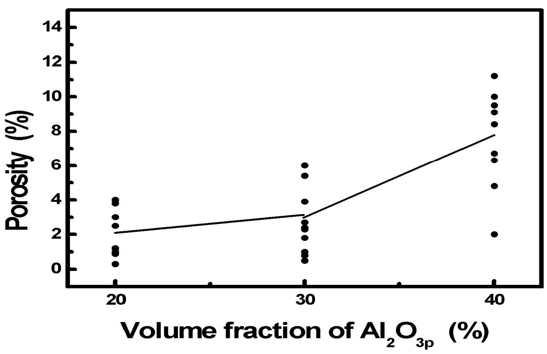
[Fig. 5] Scanning electron micrograph of fractured surface : (a) Al matrix, (b) SiC_p/Al matrix composites, particle size 100㎛, (c) SiC_p/Al matrix composites, particle size 38 ㎛, (d) Al_2O_{3p}/Al matrix composite (Vf:40%)

[Fig. 6] shows the specific fractional work with volume fractions for Al_2O_{3p}/Al matrix composites, and indicates that fractional work increased with increasing the volume fraction. These aspect could be explained in [Fig. 7]. [Fig. 7] represented that as the increasing the volume fraction of reinforced particles, the porosity of composites indicate higher porosity and greater scattering level. High porosity level of Al_2O_{3p}/Al matrix composites with high volume fraction could be found in [Fig. 5](d).

It is believed that higher porosity level of MMC cause higher fractional work, however, a further study is necessary in the future.

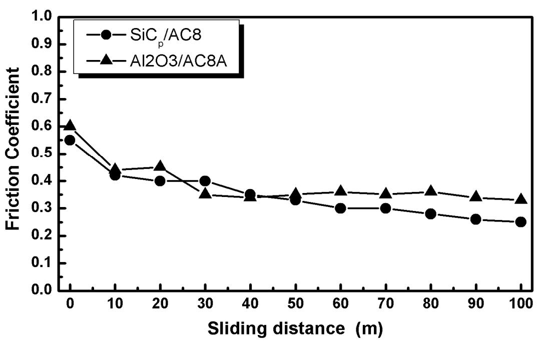


[Fig. 6] Effect of volume fraction on fractional work of Al_2O_{3p}/Al matrix composite.

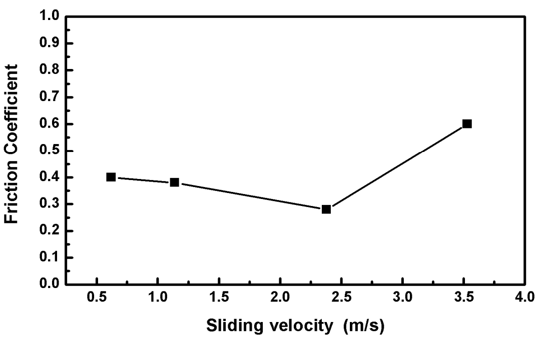


[Fig. 7] Porosity level of Al_2O_{3p}/Al matrix composite with volume fraction.

[Fig. 8] represent the friction coefficient according to sliding distance for MMC. The friction coefficients were indicated maximum value at the initial stage of friction, however, level of friction coefficient decreased soon after and kept stable level until the last stage for both MMC. These phenomena, those are friction coefficient kept stable level, were revealed with the effect of MML(mechanically mixed layer) and transfer film etc. by former studies(Wang et al., 1991: Sannimo et al., 1996: Papworth et al., 1997). However, detailed studies related to this mechanism are necessary.



[Fig. 8] Friction coefficient plotted vs sliding distance of SiC_p/Al matrix composites.



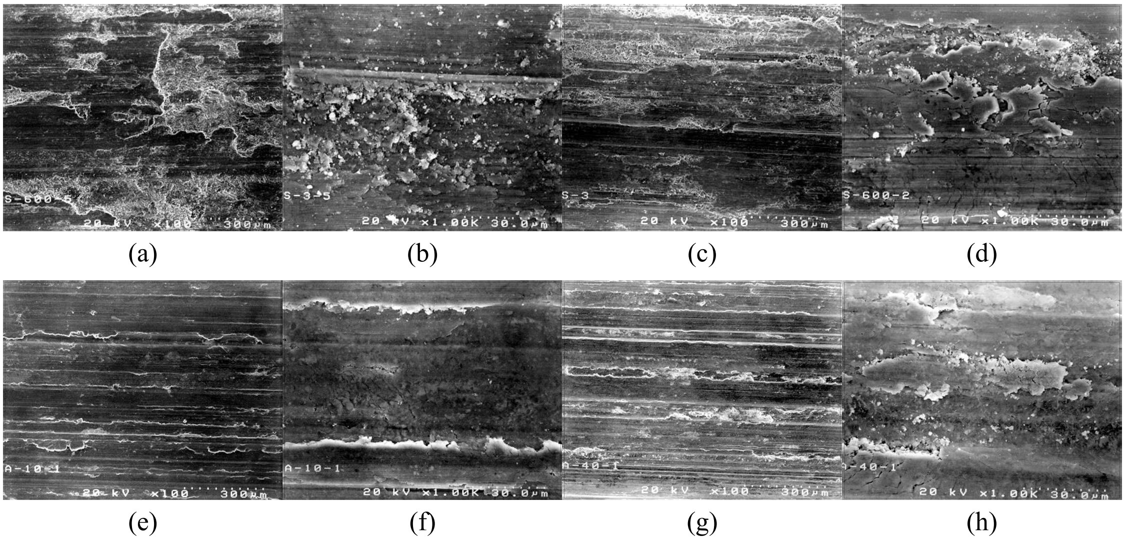
[Fig. 9] Friction coefficient plotted vs sliding velocity of SiC_p/Al matrix composites.

[Fig. 9] shows the friction coefficient according to sliding velocity of SiC_p/Al matrix composites. The result of experiment show that there is a transition sliding velocity, that is 2.5 m/s, where decreasing the friction coefficient greatly. Zhang et al. investigated that how the transition load and velocity will be changed for the ceramic particle reinforced MMC, and revealed that the transition load increase in with increase of volume fraction for the MMC (Zhang et al., 1995).

[Fig.10] indicate morphology of worn surface of SiC_p/Al matrix and Al_2O_{3p}/Al matrix composites. Two composite materials represented similar aspect throughout the all sliding velocity. And, both composites indicate abrasive wear generally which have marks of scratching and ploughing on the worn surface when the sliding velocity are slow as shown in [Fig.10](b) and (f). However some adhesive wear is appeared when the sliding velocity become faster as indicated in [Fig.10](d) and (h). Meanwhile, in case of Al_2O_{3p}/Al matrix composites, oxidation wear was also made due to the long sliding period when the sliding velocity are slow as shown [Fig.10](a).

Ⅳ. Conclusions

By analysis of specific wear loss that are applying the Pv factor, it was proved that load capability of aluminium alloy are limited in high Pv factor region due to the high wear loss, whereas ceramic particle reinforced aluminium matrix composites can be kept high load capability regardless of Pv factor. And it was ascertained that Pv factor, that is product of applied load and sliding velocity, was useful parameter to decide the experimental conditions as well.



[Fig. 10] Morphology of worn surface : (a) SiC_p/Al matrix composites at sliding velocity of 0.6 m/s, (b) high magnification of (a), (c) SiC_p/Al matrix composites at sliding velocity of 3.53 m/s, (d) high magnification of (c), (e) Al_2O_{3p}/Al matrix composites at sliding velocity of 0.6 m/s, (f) high magnification of (e), (g) Al_2O_{3p}/Al matrix composites at sliding velocity of 3.53 m/s, (h) high magnification of (g).

The effect of particle size as reinforcement phasein metal matrix composites indicated that bigger particles represented lower fractional work than those with smaller particles, and the reason of these phenomena were revealed by fractography of both MMC.

The wear mechanism of SiC and Al_2O_3 particle reinforced metal matrix composites represented abrasive wear generally and some adhesive wear is indicated as the sliding velocity become higher.

References

Aghajanian M .K.・Langensiepen R. A.・Rocazella M. A.・Leighton J. T. & Anderson C. A(1993). J. of Mater. Sci., Vol. 28, 6683.

Aghajanian M. K.・Rocazella M. A.・Burke J. T. & Keck S. D.(1991). The fabrication of metal matrix composites by pressureless infiltration technique, J. of Mater. Sci., Vol. 26, 447.

Hadinfard M.・Healy J. & Mai Y. W.(1994). Fracture characteristics of a particulate-reinforced metal matrix composite, J. of Mater. Sci., Vol. 29, 3906.

Liu, Y. B.・Lim, S. C.・Lu, L. & Lai, M. D.(1994). Recent Development in the Fabrication of Metal Matrix-Particulate Composites Using Powder Metallurgy Techniques, J. of Mat. Sci., Vol. 29, 1999.

Papworth, A. & Fox, P.(1997). Formation of MgAl2O4 at interface between a squeeze cast piston alloy and Saffil fibre reinforcement, Mat. Sci. & Eng., Vol. 13, 912.

Ray, S.(1993). Review : Synthesis of Cast Metal Matrix Particulate Composites, J. of Mat. Sci., Vol. 28, 5397.

Sai, S. W. & Chung, D. D. L.(1994). Fabrication of Particulate Aluminium-Matrix Composites by Liquid Metal Infiltration, J. of Mat. Sci., Vol. 29, 3128.

Sannino. A. P & Rack. H. J.(1996). Tribological investigation of 2009 Al-20 vol.% SiC_p/17-4 PH

Part Ⅰ: Composite performance, Wear, Vol. 197, 151.

Urquhart A. W.(1991). Novel reinforced ceramics and metal : a review of Lanxide's composite technologies, Mat. Sci. & Eng., Vol. A144, 75.

Wang. A. & Rack. H. J.(1991). Transition wear behavior of SiC particulate and SiC whisker-reinforced 7091 Al metal matrix composites, Mat. Sci. & Eng., Vol. 147, 1991, 211.

Zhang Z. F.・Zhang L. C. & Mai Y. W.(1995). Wear of ceramic particle-reinforced metal matrix. part 1 Wear mechanism, J. of Mater. Sci., Vol. 30, 1967.

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