Effect of Magnesium on Wear Characteristics of Silicon Carbide and Alumina Reinforced Aluminum-Metal Matrix Composites

Md. Habibur Rahman, Dr. H. M. M. A. Rashed

Abstract— Magnesium (Mg) plays an important role in improving interfacial bond strength between reinforcing particles and aluminum (Al) matrix in aluminum-metal matrix composites (Al-MMC). Strong interfacial bond affects mechanical and wear properties of Al-MMC. The purpose of this work is to investigate the effect of Mg on wear characteristics of silicon carbide (SiC) and alumina (Al_2O_3) reinforced Al-MMC. Al-MMC reinforced with varying wt. % of SiC and Al_2O_3 were prepared using stir casting fabrication technique. Hardness and wear characteristics of prepared composites were evaluated. Microstructural observation revealed random dispersion of reinforcing particles in Al matrix. Hardness test results indicated that hardness of both unreinforced Al and Al-MMC increased after Mg addition. Heat treatment increased the hardness of Al-MMC further. Pin-on-disc wear test results showed that Mg addition increased wear resistance of Al-MMC. Heat treated Al-MMC showed better wear resistance compared to as cast Al-MMC.

Keywords— Al-MMC, wettability, interfacial bond, hardness, wear

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1 INTRODUCTION

Al-MMC have become an important engineering materials due to its wide applications. In Al-MMC, Al or Al alloy forms continuous phase termed as matrix in which reinforcements are dispersed randomly. Stir casting is commonly used and inexpensive process to manufacture Al-MMC. It offers wide range of process conditions through which properties of Al-MMC can be controlled. In stir casting fabrication technique, wettability of reinforcing particles in molten Al is required to form strong interfacial bond between reinforcing particles and Al by chemical reactions. Mg addition improves wettability by increasing surface energy of reinforcing particles and decreasing the surface tension of molten matrix metal during casting. This results in strong interfacial bond formation which enhances strength and wear resistance of Al-MMC [1-5].

K.M. Shorowordi, T. Laoui, A.S.M.A. Haseeb, J.P. Celis, L. Froyen [4] studied microstructure and interface characteristics of B_4C, SiC and Al_2O_3 reinforced Al matrix composites. Al-SiC, Al-Al_2O_3 and Al-B_4C composites containing varying volume fractions of reinforcing particles were prepared using stir casting manufacturing technique. In microstructural observation, Al-B_4C composites showed better particles distribution while a clear interfacial reaction product layer was found in Al-SiC composites. From fracture surface analysis, it was seemed that Al-B_4C composites showed strongest interfacial bonding compared to Al-SiC and Al-Al_2O_3 composites.

GENG Lin, ZHANG Hong-wei, LI Hao-ze, GUAN Li-na, HUANG Lu-jun [5] investigated the effects of Mg content on the microstructure and mechanical properties of SiC_p/Al-Mg composites. Composites containing 10 % SiC particles by volume fraction with varying Mg content were prepared using semi-solid stirring techniques. Microstructural observation revealed that SiC particles were distributed homogeneously in matrix. Composites with high magnesium content showed more homogeneous distribution of SiC particles in matrix. Increased Mg content improved wettability and promoted good interfacial bond formation during solidification. Tensile test results showed that SiC_p/Al-Mg composites had higher tensile strength compared to Al-Mg alloys and tensile strength of composites increased with the increase of Mg content.

The aim of this work is to investigate the effect of Mg on wear characteristics of SiC and Al_2O_3 reinforced Al-MMC.

2 EXPERIMENTAL

Al was used as matrix base metal. The composition of Al used in this work is shown in table 1. Both SiC and Al_2O_3 particles were used as reinforcements on varying wt. %. They were sieve analyzed and particles of mesh number -200/+270 (particle size 53-74 µm) were used as reinforcements. Mg was added in ribbon form.

TABLE 1
COMPOSITION OF ALUMINUM USED AS MATRIX BASE METAL (WT. %)

Elements	Fe	Si	Mn	Cu	Mg	Al
%	0.16	0.19	0.01	0.01	0.01	Balance

Liquid metallurgy fabrication technique called stir casting was used to prepare Al-MMC. Al was cleaned and melted in a graphite crucible in natural gas fired pit furnace. When the temperature of molten Al reached at 750 °C, Mg wrapped with Al foil paper was added. Molten alloy was then transferred to

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electrical resistance heating stirring furnace. At temperature 730 °C, preheated SiC and Al_2O_3 particles were added to molten metal through sheet metal funnel. To increase surface reactivity and reduce temperature difference between reinforcing particles and molten metal, SiC and Al_2O_3 particles were preheated for about two hours at 800 °C in separate ceramic crucibles. The mixture was then stirred for 5 minutes at 400 rpm with a graphite stirrer followed by pouring in preheated metal mould at 670 °C. The dimensions of as cast composites were 19.5 cm × 7 cm × 2 cm. Nomenclature of prepared Al-MMC is shown in table 2.

To evaluate the effect of heat treatment, prepared Al-MMC were heat treated by three steps - solution treatment, quenching and age hardening. Composites were heated at 500 °C for 4 hours followed by quenching in water. Then composites were age hardened at 170 °C for 1.5 hours and finally air cooled.

Microstructures were observed in unetched condition using optical microscope. Samples were first polished with different grades of emery papers. Then they were cloth polished using fine alumina powder. All microstructures were observed at 500X magnification. Hardness was measured using Vickers hardness testing machine. Samples were mounted with bakelite and a load of 5 kg was applied for 10 seconds on samples. Considering the effect of segregation, 4 readings for each sample were taken.

Wear tests were conducted using pin-on-disc method at room temperatures under dry sliding conditions. Cylindrical samples of diameter 8 mm. and height 10 mm. were used. Cast iron discs of diameter of 9 cm. and hardness HRC-47 were used as counter discs. All tests were conducted applying a fixed load of 20 N at 300 rpm of revolving counter disc.

TABLE 2
NOMENCLATURE OF SIC AND AL_2O_3 REINFORCED AL-MMC

Base metal	Mg (wt. %)	Reinforcements (wt. %)	Al-MMC nomenclature
Al	0	No reinforcements	A1
		5% Al_2O_3 + 10% SiC	A2
		10% Al_2O_3 + 5% SiC	A3
	2	No reinforcements	B1
		5% Al_2O_3 + 10% SiC	B2
		10% Al_2O_3 + 5% SiC	B3

3 RESULTS AND DISCUSSION

3.1 Microstructures

Microstructural observation revealed the distribution of reinforcing particles in Al matrix. Fig. 1 shows optical microstructures of as cast and heat treated Al-MMC.

In microstructures, randomly dispersed SiC particles were observed in Al matrix. Non-homogeneous distribution of SiC particles was observed in some areas in Al matrix. After heat treatment, microstructure became more homogeneous. Agglomeration of SiC particles and porosities due to entrapped air were also observed in microstructures.

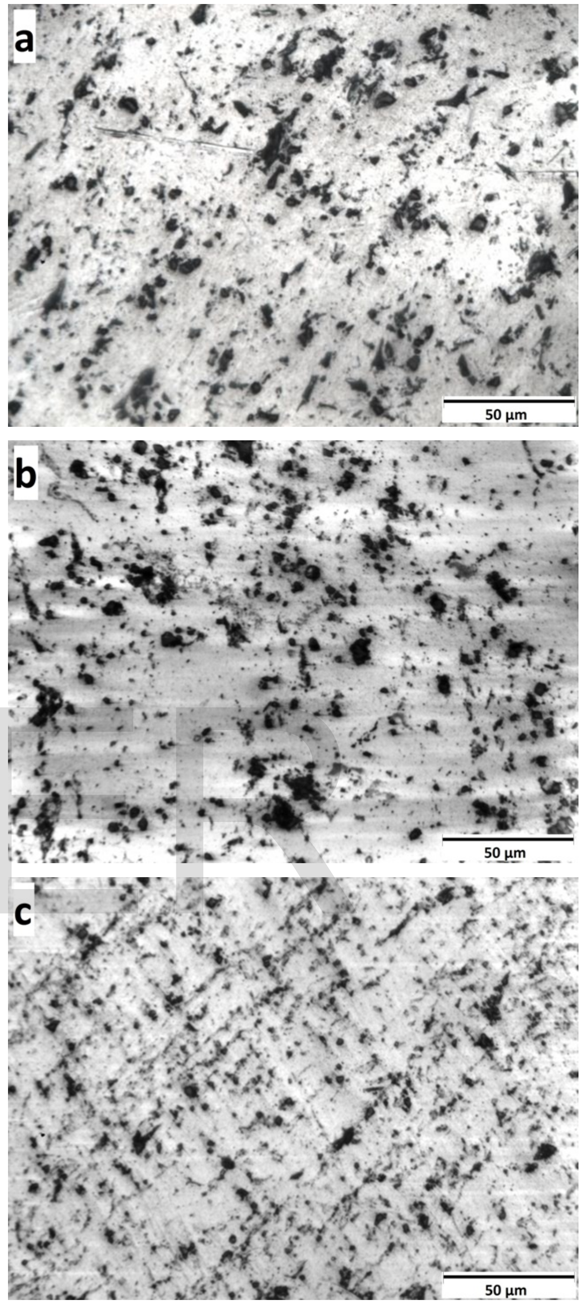

Fig. 1. Microstructures of Al-MMC (a) as cast B2 (b) as cast B3 (c) heat treated B3

3.2 Hardness

Table 3 shows the Vickers hardness values of as cast Al-MMC. It is seen from Fig. 2 that Mg addition increases the hardness of both unreinforced Al and Al-MMC. When hardness value of unreinforced Al was found (29.2 ± 2.62), 2 wt. % Mg addition increased its hardness value to (42.8 ± 1.01). Addition of 2 wt. % Mg enhanced hardness values of A2 and A3 from (21.6 ± 0.66) and (22.7 ± 0.93) to (45.0 ± 1.97) and (48.4 ± 2.17) respectively. This can be attributed due to enhanced matrix hardness

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and strong interfacial bond formation between reinforcing particles and Al matrix caused by Mg addition [6-8].

TABLE 3

VICKERS HARDNESS VALUES OF AS CAST AL-MMC

Al-MMC	Vickers hardness number, HV
A1	29.2 ± 2.62
A2	21.6 ± 0.66
A3	22.7 ± 0.93
B1	42.8 ± 1.01
B2	45.0 ± 1.97
B3	48.4 ± 2.17

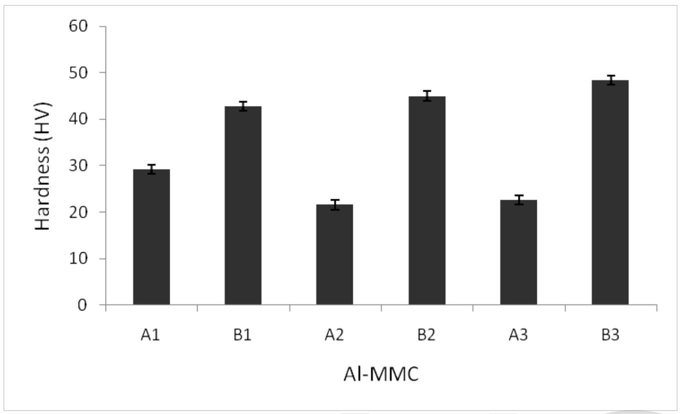

Fig. 2. Variation of Vickers hardness values of as cast Al-MMC

Fig. 3 shows the effect of heat treatment on hardness of Al-MMC. It is seen from the graph that heat treatment increased hardness values of Al-MMC and reduced the effect of segregation on hardness. As cast B2 and B3 had Vickers hardness values of (45.0 ± 1.97) and (48.4 ± 2.17) respectively. But after heat treatment, Vickers hardness values increased to (49.2 ± 0.88) and (50.9 ± 0.65) respectively. Homogenization by heat treatment enhanced the hardness values of Al-MMC.

TABLE 4

VICKERS HARDNESS VALUES OF AS CAST AND HEAT TREATED AL-MMC

Al-MMC	Vickers hardness number, HV	
	As cast	Heat treated
B2	45.0 ± 1.97	49.2 ± 0.88
B3	48.4 ± 2.17	50.9 ± 0.65

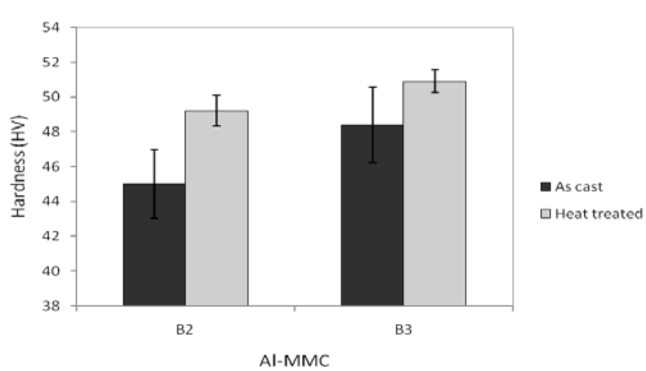

Fig. 3. Effect of heat treatment on hardness of Al-MMC

3.3 Wear characteristics

Fig. 4 shows a comparison of cumulative mass loss from worn surfaces of A2 and B2 as a function of time during wear test. It is observed from the graph that B2 showed lower mass loss compared to A2. Both Al-MMC had equal wt. % of SiC and Al_2O_3 reinforcements, but 2 wt. % Mg addition made B2 more wear resistant.

During wear test, relatively soft Al matrix is removed preferentially. Then exposed SiC and Al_2O_3 particles on worn surface oppose further material removal [9]. Mg addition to Al-MMC enhances the hardness of Al matrix and improves interfacial bond strength. These contribute to reduce the mass loss.

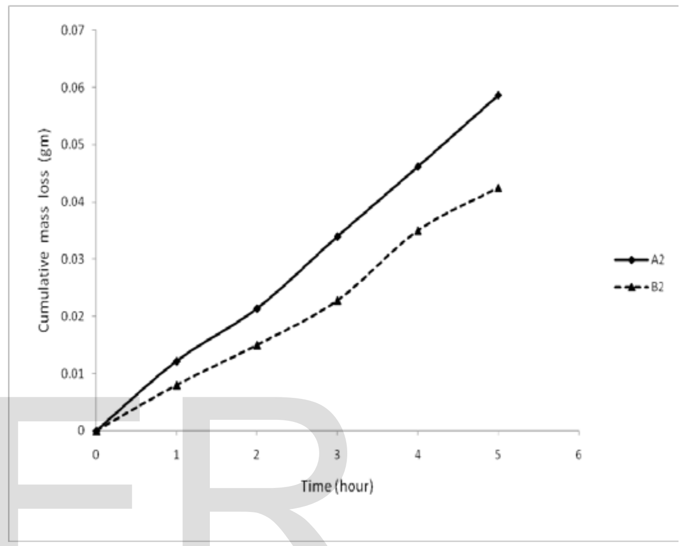

Fig. 4. Cumulative mass loss of A2 and B2 as a function of time

Fig. 5 shows the effect of heat treatment on wear properties of Al-MMC. It is observed that heat treated B3 showed better wear resistance compared to as cast B3. This can be attributed due to the high hardness value of heat treated Al-MMC [10].

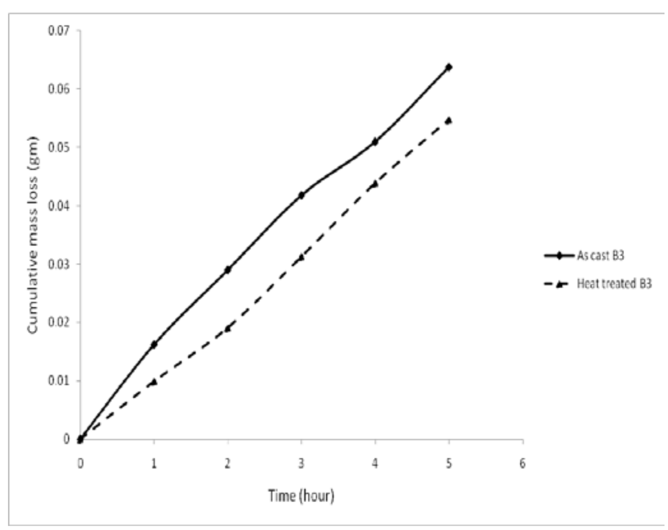

Fig. 5. Cumulative mass loss of as cast B3 and heat treated B3 as a function of time

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4 Conclusion

Al-MMC reinforced with varying wt. % of SiC and Al_2O_3 were successfully prepared using stir casting fabrication technique. Microstructural observation revealed random dispersion of reinforcing particles in Al matrix. 2 wt. % Mg addition increased hardness of both unreinforced Al and Al-MMC. Heat treated Al-MMC showed higher hardness values compared to as cast Al-MMC. Wear test results showed that Mg addition increased wear resistance of Al-MMC. Heat treated Al-MMC showed lower mass loss compared to as cast Al-MMC.

References

[1] M K Surappa, "Aluminium matrix composites: Challenges and opportunities," *Sadhana*, vol. 28, no. 1 & 2, pp. 319-334, Feb. /Apr. 2003.

[2] S. Vaucher and O. Beffort, "Bonding and interface formation in metal matrix composites," vol. 9, MMC- Assess Thematic Network, 2001.

[3] B. C. Pai, Geetha Ramani, R. M. Pillai and K. G. Satyanarayana, "Role of magnesium in cast aluminium alloy matrix composites," *J. Materials Science,* vol. 30, no. 8, pp. 1903-1911, Apr. 1995.

[4] K.M. Shorowordi, T. Laoui, A.S.M.A. Haseeb, J.P. Celis and L. Froyen, "Microstructure and interface characteristics of B_4C, SiC and Al_2O_3 reinforced Al matrix composites: a comparative study," *J. Materials Processing Technology,* vol. 142, pp. 738-743, 2003.

[5] GENG Lin, ZHANG Hong-wei, LI Hao-ze, GUAN Li-na and HUANG Lu-jun, "Effects of Mg content on microstructure and mechanical properties of SiC_P/Al-Mg composites fabricated by semi-solid stirring technique", *Trans. nonferrous metals society of China,* vol. 20, pp. 1851-1855, 2010.

[6] G. B. Veeresh Kumar, C. S. P. Rao and N. Selvaraj, "Mechanical and tribological behavior of particulate reinforced aluminum metal matrix composites - a review," *J. Minerals & Materials Characterization & Engineering,* vol. 10, no. 1, pp. 59-91, 2011.

[7] R. S. Rana and Rajesh Purohit, "Effect of magnesium enhancement on mechanical property and wear behaviour of LM6 aluminum alloy," *Int. J. Scientific and Engineering Research,* vol. 3, no. 7, pp. 1-5, July 2012.

[8] Hayrettin Ahlatci, Tolga Koc¸er, Ercan Candan and Huseyin C¸imenog˘lu, "Wear behaviour of Al/(Al_2O_{3p} + SiC_P) hybrid composites," *Tribology Int.*, vol. 39, pp. 213–220, 2006.

[9] A. Vencl, A. Rac and I. Bobić, "Tribological behaviour of Al-based MMCs and their application in automotive industry", *Tribology in industry*, vol. 26, no. 3 & 4, pp. 31-38, 2004.

[10] S. Das, D.P. Mondal, S. Sawla and N. Ramakrishnan, "Synergic effect of reinforcement and heat treatment on the two body abrasive wear of an Al-Si alloy under varying loads and abrasive sizes," *Wear,* vol. 264, pp. 47-59, 2008.

[11] C.Neelima Devi, N.Selvaraj and V.Mahesh, "Micro structural aspects of aluminium silicon carbide metal matrix composites," *Int. J. Applied Sciences and Engineering Research,* vol. 1, no. 2, pp. 250-254, 2012.

[12] Vinayak Janiwarad, Shadakshari R, M.H. Annaiah, Dr. Mahesha K and Harendra kumar H.V, "The effect of heat treatment on microstructure, mechanical properties and damping behaviour of hybrid composite of A356.0", *Int. J. Innovative Research in Science, Engineering and Technology,* vol. 2, no. 4, pp. 1026-1032, Apr. 2013.

[13] Dunia Abdul Saheb, "Aluminum silicon carbide and aluminum graphite particulate composites," *ARPN J. Engineering and Applied Sciences,* vol. 6, no. 10, pp. 41-46, Oct. 2011.

[14] William D. Callister,Jr., *Materials Science and Engineering An Introduction,* John Wiley & Sons, Inc., 7th edition, 2007.

[15] Sourav Kayal, R. Behera and G.Sutradhar, "Mechanical properties of as–cast silicon carbide particulate reinforced aluminum alloy metal matrix composites," *Int. J. Current Engineering and Technology,* vol. 2, no. 3, pp. 318-322, Sept. 2012.