Journal of Advanced Engineering Research
ISSN: 2393-8447
Volume 3, Issue 2, 2016, pp.89-92

Investigation of Mechanical and Tribological Properties of A356 Alloy Al_2O_3 -SiC_p Hybrid Composites through Stir and Squeeze Casting

K. Sekar[1], M. Manohar[2], K. Jayakumar[3,*]

[1]Department of Mechanical Engineering, National Institute of Technology Calicut, Kerala-673601, India
[2]Materials and Mechanical Entity, Vikram Sarabhai Space Centre, Trivandrum, Kerala- 695022
[3]Department of Mechanical Engineering, SSN College of Engineering, Chennai-603110, India

*Corresponding author email: kjayakumar@ssn.edu.in, Tel.: +91 9176657710

ABSTRACT

Aluminum alloys are widely used in aerospace and automobile industries due to their low density and good mechanical properties, better corrosion and wear resistance, low thermal coefficient of thermal expansion (CTE) as compared to conventional metals and alloys. The present work consists of investigation on the microstructural characterization, mechanical properties and tribological properties of hybrid A356 alloy - Al_2O_3 –SiC_p metal matrix composites (MMCs) fabricated by the combined effect of stir and squeeze casting. The reinforcement is varied as 0.5 and 1.5 wt. % for alumina (Al_2O_3), while SiC reinforcement is varied for 1 and 4 wt. %. The double shear strength and hardness values are evaluated for all specimens having different weight percentage of reinforcement particles and compared with that of the matrix alloy. The dry sliding tribological tests are carried out using pin-on-disc tribometer by varying the load and the wear is measured in terms of weight loss. Coefficient of friction is obtained by the ratio of friction force to applied load. .

Keywords - Hybrid metal matrix composites, Stir and Squeeze casting, Microstructure analysis, Double shear strength, Hardness, Wear studies.

1. INTRODUCTION

The present need for light weight materials with high strength and high stiffness have attracted much interest in the development of processes for synthesizing metal-matrix composites. Hence, an attempt to go for A356 alloy reinforced with micro and nano Al_2O_3 particles by Squeeze casting with stirring is made here. As stir cast components are reported to have superior mechanical properties, fine microstructure and minimal porosity [1]. Influence of stirring speed and stirring time on distribution of particles in cast metal matrix composite was studied by [2] and reported that, high silicon content aluminum alloy–silicon carbide metal matrix composite material, with 10% SiC were successfully synthesized, using different stirring speeds and stirring times. Increase in stirring speed and stirring time resulted in better distribution of particles. The hardness test results also revealed that stirring speed and stirring time have their effect on the hardness of the composite. The uniform hardness values were achieved at 600 rpm with 10 min stirring. But beyond certain stir speed the properties degraded again.

Production and characterization of micro and nano Al_2O_3 particle-reinforced LM25 or A356 aluminum alloy composites were proposed by Suresh et al. [3] in 2006. They claimed that during the addition of Al_2O_3 micro and nano particles on LM25 alloy, the coarser particles were dispersed more uniformly while the finer particles lead to agglomeration and segregation. Nano Al_2O_3 particle reinforced MMC exhibit better hardness and strength compared with micro Al_2O_3. Since using appropriate stirring speed and time, uniform distribution of reinforcement particle has been achieved in both MMC produced have lower porosity and better strength. Shorowordi et al. [4] synthesized three types of aluminum metal matrix composites containing reinforcing particles of B4C, SiC and Al_2O_3 (0 - 20 vol.%). A clear interfacial reaction product was found at Al-SiC interface for composites. Aleksandar et al. [5] claimed that particulate composites with A356 aluminum alloy as a matrix were produced by compocasting process using ceramic particles (Al_2O_3, SiC) and graphite particles. Reinforcing particles (Al_2O_3, SiC) were arranged in clusters in the composite matrix. The arrangement of SiC particles in clusters was more favorable for mechanical and tribological properties of the composite in comparison to the arrangement of Al_2O_3 particles.

Tribological behaviour of stir-cast Al–Si/ SiCp composites against automobile brake pad material was studied by M.K. Surappa et al. [6] in 2007 using Pin-on-disc tribo tester and reported that both wear rate and friction coefficient varied with both applied normal load and sliding speed. With increase in the applied normal load, the wear rate was observed to increase whereas the friction coefficient decreases. However, both the wear rate and friction coefficients were observed to vary proportionally with the sliding speed.

The most important challenge during fabrication of MMCs by liquid phase processes are uniform mixing of reinforcement in the matrix without sinks and floats, wettability of ceramic particles in the base metal with less porosity and higher density. To overcome these challenges, especially during addition of nano particles combined stir with squeeze casting technique is adopted in this work. Moreover literature discusses the mechanical properties in terms of microstructure, hardness, tensile and compressive strength. However, the present work elaborates the micro - nano particulate composites behavior during double shear strength, hardness and tribological test.

2. EXPERIMENTATION

2.1 Materials and Manufacturing process

The matrix alloy for the study was A356 aluminum alloy. SiC particles of 1 µm (average size) and Al_2O_3 particles of 50 nm (average size) were added as the reinforcements in the matrix.

The furnace of the squeeze casting machine is set at a temperature of 800 °C. Since die capacity is only 1460 gram, weighed pieces of A356 alloy ingot was inserted into the furnace. The stirring of molten metal was carried out for 5 min. First casting is done without the reinforcement particles. Then 0.5 wt.% of zinc powder and 0.75 wt.% of magnesium was added to improve the shinning effect and wettability respectively. The nano alumina and micro silicon carbide powders were pre heated to the temperatures of 900 °C and 950 °C respectively and poured into the stirred melt using a hopper. The powders were added gradually into the melt while the stirring is done at 250 rpm. After completing powder addition, the stirring was continued for 5 minute. The different wt.% of reinforcement particles are added to the melt are (1) Al_2O_3 (0.5%) + SiC (4 %), (2) Al_2O_3 (0.5%) + SiC (1 %), (3) Al_2O_3 (1.5%) + SiC (1 %), (4) Al_2O_3 (1.5%) + SiC (4 %). Then the bottom pouring of the melt to the die is done. As soon as the melt is poured into the die, the squeeze pressure switch was pressed to squeeze the casting. The pressure applied is 100 Ton for 3 minutes during solidification of the casting. For easy removal of castings from the die, die coat is applied on the inner surface of the die. After solidification, the cast specimen of 46 mm diameter and 260 mm length is removed from the die.

2.2. Specimens preparation

Different samples were prepared for micro structural analysis, hardness test, double shear test and wear studies. SiC emery papers of various grades up to 1200 grit size in wet condition were used for initial polishing. Later the specimens were polished using Alumina paste and 1µm diamond paste. As per ASTM E3 standard, the fine polished samples were etched using Keller's reagent (2.5% HNO3 + 1.5% HCl + 1% HF + 95% H2O). The micro structural examination was carried using optical microscope with 500 X magnification. Double shear test was conducted using 200 kN capacities Universal Testing Machine (UTM) with the help of chuck arrangement. Sample sizes were 10 mm in diameter and 100 mm in length as per ASTM B769-11 standards. Hardness test was conducted on composite specimens using Rockwell hardness machine according to the ASTM E18 standards. The dry sliding tribological tests was carried out using pin-on-disc tribometer as per ASTM G-99 standards.

3. RESULTS AND DISCUSSIONS

3.1. Microstructure observation

Typical optical microscope images of hybrid A356-Al_2O_3-SiC metal matrix composites with 500 X magnification are shown in Fig. 1. In the images, white color particles are Al_2O_3 and SiC particles are in block color. From the Fig.1 the microstructure reveals that the composites have reinforcement with nearly uniform dispersion and dense structure without micro level cavities due to the combined stir and squeezing of the molten metal.

3.2. Double shear test

The double shear strength values of specimens were increased by the addition of reinforcement particles (Fig. 2). This strengthening effect is due to reasonably distribution of reinforcement particles and the Orowan strengthening. Due to thermal mismatch, i.e. difference in CTE of matrix (A356) and reinforcement particles dislocation occurred during cooling. Density of dislocation is very high in uniformly distributed samples due to high interfacial area. Also, addition of Al_2O_3 particle from 0 to 1.5% and SiC particles up to 4 wt % have increased double shear strength by 9.5% compared with matrix.

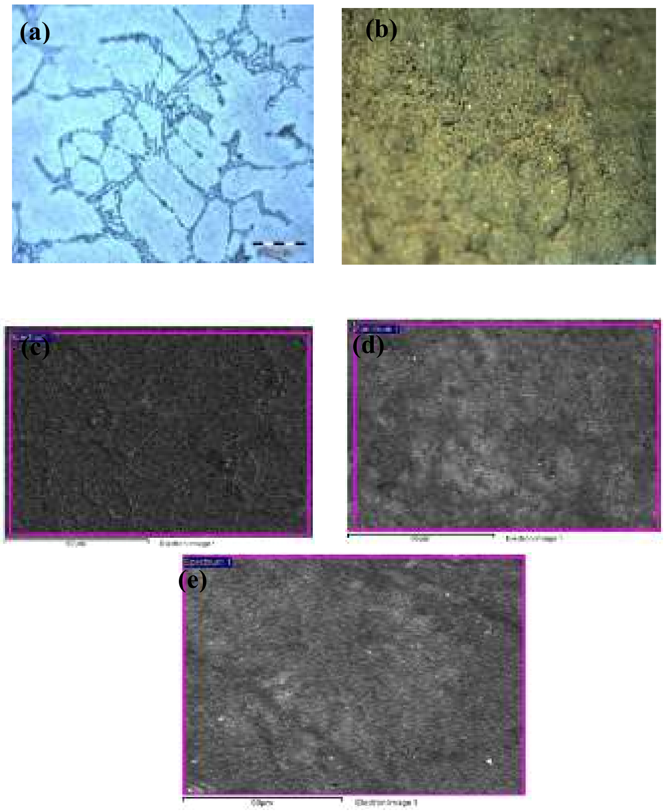

Fig. 1 Microstructure images: (a) A356 alloy (b) MMC - 0.5% Al_2O_3 + 1% SiC (c) MMC - 0.5% Al_2O_3 + 4% SiC (d) MMC - 1.5% Al_2O_3 + 1% SiC (e) MMC - 1.5% Al_2O_3 + 4% SiC

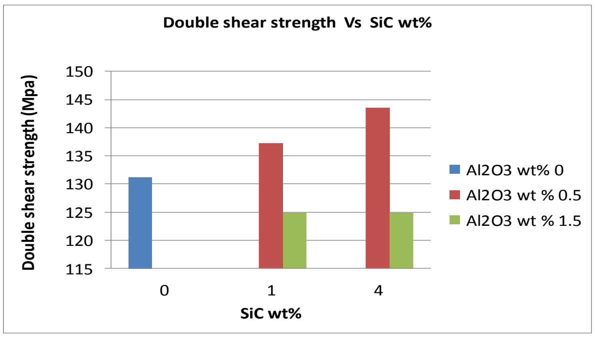

Fig. 2 Double shear strength of MMCs

3.3 Hardness test

Fig. 3 shows that uniformly increase in hardness for the composites. This is due to increase in resistance to deformation by adding SiC and Alumina as reinforcement in A356 alloy, existence of hard Al_2O_3 and SiC particles which act as obstacle to the motion of dislocation. The distribution of reinforcement particles in the specimens affects the hardness values obtained and the agglomerates also act as hard areas in the specimens. Increase in hardness with increase in the wt% of reinforcement particles is also due to reducing grain size by squeeze pressure. By adding 0.5 wt % of Al_2O_3 and 4 wt % of SiC particles, the hardness increases by 6.6%.

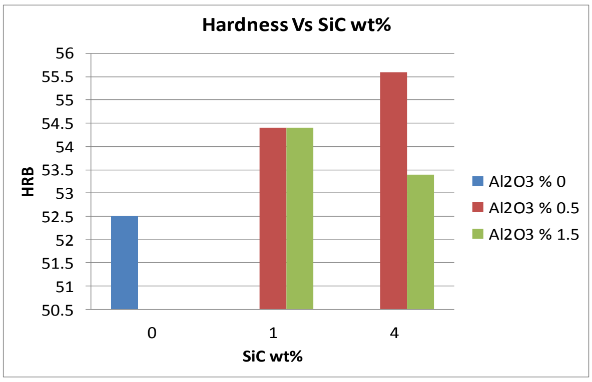

Fig. 3 Hardness of MMCs

3.4 Dry sliding wear

A pin-on-disc tribometer is used to perform the wear experiment. Before wear test, each composite specimen is then weighed using a digital balance having an accuracy of ± 0.0001 gm. After that the specimen is mounted on the pin holder of the tribometer ready for wear test. For all experiments, the sliding speed is adjusted to 1.308 m/s, track diameter 100 mm, sliding distance 1100m, and total time is 14 minute under room temperature. The above values are fixed based on various available literatures for MMCs. Fig. 4 shows the trend of wear rate (weight loss) performance of different MMCs and base alloy with varying loads of 10 N, 30 N and 50 N. When compared to the matrix alloy, all the composites exhibited increased wear resistance with increase in load. This could be attributed to the increase in contact pressure of the asperities which results in increased shearing at the sliding interface and thus contributing to wear. Specimen having 1.5% Al_2O_3, 4% SiC exhibited increased wear properties compared to the other specimens due to the poor wettability between the matrix and reinforcement particles owing to their higher concentration. Specimen having 0.5% Al_2O_3 and 4% SiC had shown less wear compared to the other entire specimen due to optimum wettability. The wear behavior of the specimen having 0.5% Al_2O_3 + 1% SiC and 1.5% Al_2O_3 + 1% SiC are lying in between that of 1.5% Al_2O_3 + 4% SiC and 0.5% Al_2O_3 + 4% SiC. This could be attributed to the variation of wt.% reinforcement addition to the matrix which exhibits different wettability and bonding characteristics.

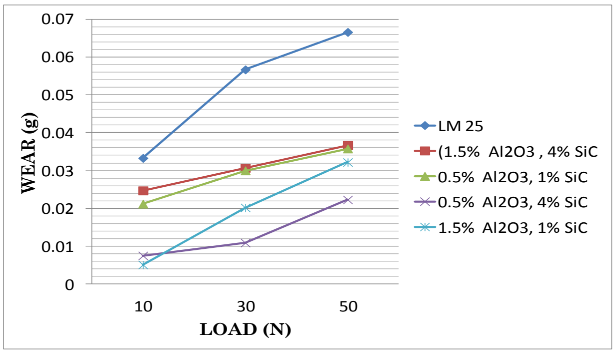

Fig. 4 Wear loss Vs Load

Fig 5 shows the trend of coefficient of friction of different MMCs and base alloy with varying load and keeping sliding distance: 1100 m, sliding speed: 1.308 m/s as constant. Compared to the matrix alloy all the other specimens exhibited reduced coefficient of friction with increase in load. MMC having 1.5% Al_2O_3 + 4% SiC exhibited increased coefficient of friction compared to the other specimens due to the poor wettability between the matrix and reinforcement particles owing to their higher concentration. Specimen having 0.5% Al_2O_3 + 4% SiC had shown less coefficient of friction compared to all other specimens due to optimum wettability and bonding characteristics.

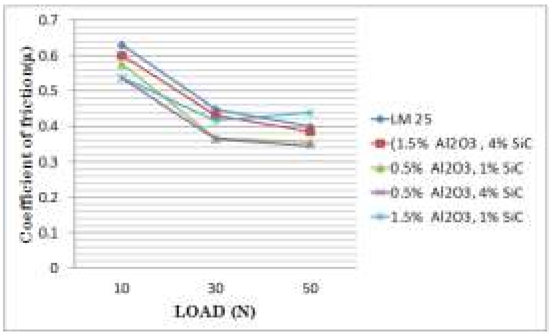

Fig. 5 Coefficient of friction Vs Load

The coefficient of friction of the specimen having 0.5% Al_2O_3 + 1% SiC and 1.5% Al_2O_3 + 1% SiC are lying in between that of 1.5% Al_2O_3 + 4% SiC and 0.5% Al_2O_3 + 4% SiC. This could be attributed to the variation of wt.% reinforcement addition to the matrix which exhibits different wettability and bonding characteristics. For the entire specimen tested it has been observed that coefficient of friction decreases with increase in load. This could be attributed to the formation of mechanically mixed layer (MML) which acts as a lubricant between the contact surfaces and thus consequently sliding occurs between pin specimen and the MML which contributes to reduction in coefficient of friction.

4. CONCLUSIONS

- MMCs have been successfully fabricated by combined effect of stir and squeeze casting technique with fairly uniform distribution of Al_2O_3 and SiC particles.
- The microstructure revealed that the composites have dense surface without micro level cavities due to squeezing of the molten metal.
- The maximum addition of both SiC (4%) and Al_2O_3 (1.5%) on the matrix slightly decreased the hardness and double shear strength due to clustering effect of nano particles within the aluminum alloy.
- By addition of 0.5 wt % of Al_2O_3 and 4 wt % of SiC, double shear strength and hardness increased.
- Dispersion of Al_2O_3 and SiC particles in aluminum matrix improves the wear resistance of the composites. Wear increase with increase in load.
- Specimen having 0.5% Al_2O_3+4% SiC exhibited high wear resistance compared to the other specimens. The coefficient of friction decreased with increase in load.

REFERENCES

[1] M R Ghomashchi and A Vikhrov A, Squeeze casting: an overview, *Journal of Material Processing Technology, 101(1-3)*, 2000, 1-9.

[2] S Balasivanandha Prabu, L Karunamoorthy, S Kathiresan and B Mohan, Influence of stirring speed and stirring time on distribution of particles in cast metal matrix composite, *Journal of Materials Processing Technology, 171(2),* 2006, 268-273.

[3] S M Suresh, D Mishra, A Srinivasan, R M Arunachalam and R Sasikumar, Production and characterization of micro and nano Al_2O_3 particle-reinforced LM25 aluminum alloy composites, *ARPN Journal of Engineering and Applied Sciences, 6(6),* 2006, 20-24.

[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, *Journal of Material Processing Technology, 142(3),* 2003, 738-743.

[5] V Aleksandar, B Ilija, A Saioa, B Biljana, M Aleksandar and B Miroslav, Structural, mechanical and tribological properties of A356 aluminum alloy reinforced with Al_2O_3, SiC and SiC + graphite particles, *Journal of Alloys and Compounds, 506(2),* 2010, 631-639.

[6] M K Surappa, R K Uyyuru and Brusethaug S, Tribological behavior of Al–Si–SiC composites/automobile brake pad system under dry sliding conditions, *Tribology International, 40(2), 2007,* 365-373.