Investigation of Wear and Mechanical Properties of A356-SiC_p-Al_2O_3 Hybrid Composite by Stir and Squeeze casting

K. Sekar[1], M. Ravi[2], K. Jayakumar[3]
[1]Department of Mechanical Engineering, National Institute of Technology, Calicut, Kerala 673601.
[2]CSIR- National Institute for Interdisciplinary Science and Technology, Thiruvananthapuram, Kerala -695019.
[3]Department of Mechanical Engineering, SSN College of Engineering, Kelambakkam, Chennai-603110.
***Corresponding author: E-Mail: sekar@nitc.ac.in**

ABSTRACT

In this present work, the effects of addition of micro and nano particles on double shear strength, hardness and tribological properties of A356 alloy reinforced with SiCp micro particles of size ~37 µm and Al_2O_3 nano particles of size ~30 nm is investigated. The percentage of SiCp micro particles were diversed from 1 to 4 wt% and Al_2O_3 were ranged from 0.5 to 1.5 wt%. The particles were mixed with stirring at 350 rpm and casting at 800 °C and pressure of 43 MPa in the squeeze casting machine. By addition of 0.5 wt % of Al_2O_3 and 4 wt % of SiC_p the double shear strength is increased by 9.5% and hardness is increased by 6.6%. The addition of both SiC_p (4 wt%) and Al_2O_3 (1.5 wt%) decreased the hardness. Wet sliding test was carried on the composites using coconut oil and SAE20W40 lubricant ad coconut oil has shown better tribological performances.

KEY WORDS: A356-SiC_p-Al_2O_3 metal matrix composite, Stir-squeeze casting, Microstructure, Double shear strength, Wet wear analysis**.**

1. INTRODUCTION

For the past three decade, mechanical characterization studies on stir cast Al based MMCs were carried. Balasivanandha Prabu (2006) did the analyses the particles distribution of cast MMC for the impact of stirring speed and stirring time. They showed that, higher silicon content in Al–SiC MMC material, with 10% SiC was effectively synthesized by various stirring speeds and stirring times.

Shorowordi (2003) conducted comparative study on interface and microstructure characteristics of Al_2O_3, SiC and B_4C reinforced Al matrix composites. In that work, aluminum metal matrix composites that contain the reinforcement particles Al_2O_3, SiC and B_4C (0–20 vol. %) was synthesized successfully. A product of clear interfacial reaction was found at Al–SiC interface for composites. Synthesis and characterization of micro and nano Al_2O_3 particle-reinforced LM25 aluminum alloy composites was analyzed by Suresh (2011). They claimed that adding Al_2O_3 on LM25 alloy, the coarser particles was dispersed more uniformly whereas the finer particles lead to agglomeration and segregation of particles. Nano Al_2O_3 particle reinforced MMC exhibit good hardness and strength compared with micro Al_2O_3.

Sajjadi (2012) presented fabrication of A356 composite mixed with Al_2O_3 particles and reported that to improve the wettability; the ceramic particles were heated at 300 °C in the presence of argon gas. The porosity and hardness % increased with rising the Al_2O_3 wt% and lessening particle size. By increasing the stirring time, better uniform distribution of Al_2O_3 in the aluminum matrix was found.

Impacts of thermal cyclic loading on cast aluminium composite reinforced with SiC and fly ash particles were studied by Sanjeev Kumar (2010). In this study, dry fly ash was used with aluminum reinforced with SiC and a composite was made by stir casting process with less quantity of SiC. Wear, mechanical and structural analysis of A356 alloy strengthened with SiC + graphite particles and Al_2O_3, SiC was proposed by Aleksandar (2010). They showed that particulate A356 composites alloy matrix were synthesizes from compo casting using SiC, Al_2O_3, and graphite particles. Reinforcing particles (SiC, Al_2O_3) were arranged in clusters in the matrix composite. The array of SiC particles in clusters was more favorable for tribological and mechanical properties of the composite as compared to the regular arrangement of Al_2O_3.

Tribological properties of MMCs are important while considering their application in brake drum, cylinder liners, cam, etc. Uyyuru (2007), presented a study on the behavior of tribological stir-cast Al–Si/ SiC composites applied in automobile brake pad material. Friction coefficient and wear rate varied with sliding speed and normal load. With increasing the applied load, the wear rate was in increase while the coefficient of friction decreased. Prasad (2004), explained the Al MMCs reinforced tribological behavior with particles, short fibers, and solid lubricants and techniques for producing automotive parts from these novel materials. The importance from the work was on making affordable Al MMCs, reinforced with SiC and Al_2O_3 which decreases the weight and considerable reduction in wear and friction.

2. EXPERIMENTATION

Materials and Manufacturing Process: The chemical composition of A356 alloy which was used in this study is listed in Table.1. A356 alloy reinforced with SiC micro particles of size 37µm and Al_2O_3 nano particles of size 30 nm is investigated. The percentage inclusions of SiC micro particles were varied from 1 to 4 wt% and Al_2O_3 were

varied from 0.5 to 1.5 wt%. The particles were added with stirring at 350 rpm and squeeze casting at 800 °C and pressure of 43 MPa in the squeeze casting machine.

Table.1. Chemical composition of A356 alloy

Composition (Wt%)										
A356 alloy	Cu	Si	Mg	Mn	Fe	Ti	Ni	Zn	Tin	Al
	0.09	6.65	0.55	0.06	0.32	0.06	0.04	0.004	0.001	Remaining

SiC micro particles of size 37µm and Al_2O_3 particles of 30 nm size were added as the reinforcements in the metal matrix composites. The chemical composition analysis was carried out as per ASTM E1251-07 OES standards. The A356 alloy billets were melted in electric furnace up to 800 °C. The stirring was continued for 10 min to improve uniform distribution of the SiC micro particles and Al_2O_3 nano particles. After melting, bottom pouring valve of the furnace was operated using automatic control to pour the molten metal into the die steel mold. At this moment, squeeze piston was simultaneously activated to squeeze the molten nano composite metal and the complete stir-squeeze casting machine setup is shown in figure 1. The tribological properties of the samples were also investigated by pin-on-disk wear tester at 10, 30 and 50 N loads, sliding speed 1.308 m/s and sliding distance 1100 m in wet condition.

Figure.1. Stir and squeeze casting set-up

Specimens Preparation: After casting, different samples from 'as cast' alloy and MMCs were prepared for micro structural analysis, double shear, hardenss and wear test. As per ASTM E3 standards, the fine polished samples were etched using Keller's etchant. The sample size was ∅ 8mm and h = 27 mm as per ASTM G-99 standards.

3. RESULTS AND DISCUSSIONS

Microstructure analysis: In order to check the uniform distribution of reinforcement in the matrix, surface morphology was examined to identify micrographs and surface texture of the cast A356 alloy and hybrid composites and are presented in Figs. 2 ((a) to (e)) which were taken at 1000X.

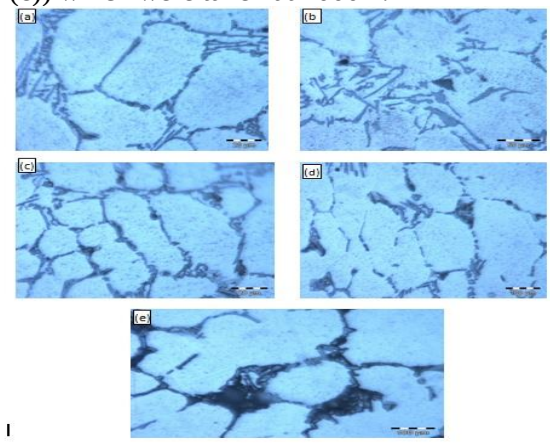

Figure.2. Optical micrographs (a) A356 alloy (b) MMC with Al_2O_3 (0.5%) + SiC (4 %) (c) MMC with Al_2O_3 (0.5%) + SiC (1 %) (d) MMC with Al_2O_3 (1.5%) + SiC (1 %) (e) MMC with Al_2O_3 (1.5%) + SiC (4 %)

Reinforcement particles are uniformly distributed across the grain boundary, the grain size reduces because the particles act as nucleation sites. The particle size reduces due to the good wettability of the particles with the melt. So it gives better property when compared to other composites and also observed that fine grain structure is obtained for the squeeze + stir cast specimen due to the application of pressure. By effective squeezing process, breaking up of the agglomerates and redistribution of the reinforcement particles occurs. This occurs when the amount of liquid inside the slurry is large enough and the particles slide over each other and breaking up occurs.

The white region in the microstructure is the matrix and the gray region is the silicon. The large size of silicon phase will degrade the strength of the castings. The silicon phase is brittle so the crack will first generate in the silicon and propagate rapidly through the Al_2O_3 nano particles or matrix leading to failure. In figure 3.(e) Al_2O_3 (1.5%), SiC (4 %), the reinforce particles have formed as a agglomeration in grain bounty.

Energy Dispersive Spectroscopy: Figure.3 shows the Energy Dispersive Spectroscopy (EDS) spectra and elements of the A356 with the addition of SiC micro particles and Al_2O_3 nano particles hybrid composite specimen indicating the presence and distribution of the different elements. The oxygen content in specimens with 1.5 wt% of Al_2O_3 and 4 wt.% of SiC particles are less, implies that the addition of Al_2O_3 nano particles is not properly obtained in this sample. For samples with 0.5wt% of Al_2O_3 and 4 wt. % of SiC particles shows better oxygen and carbon content and better distribution are shown in figure. 3.

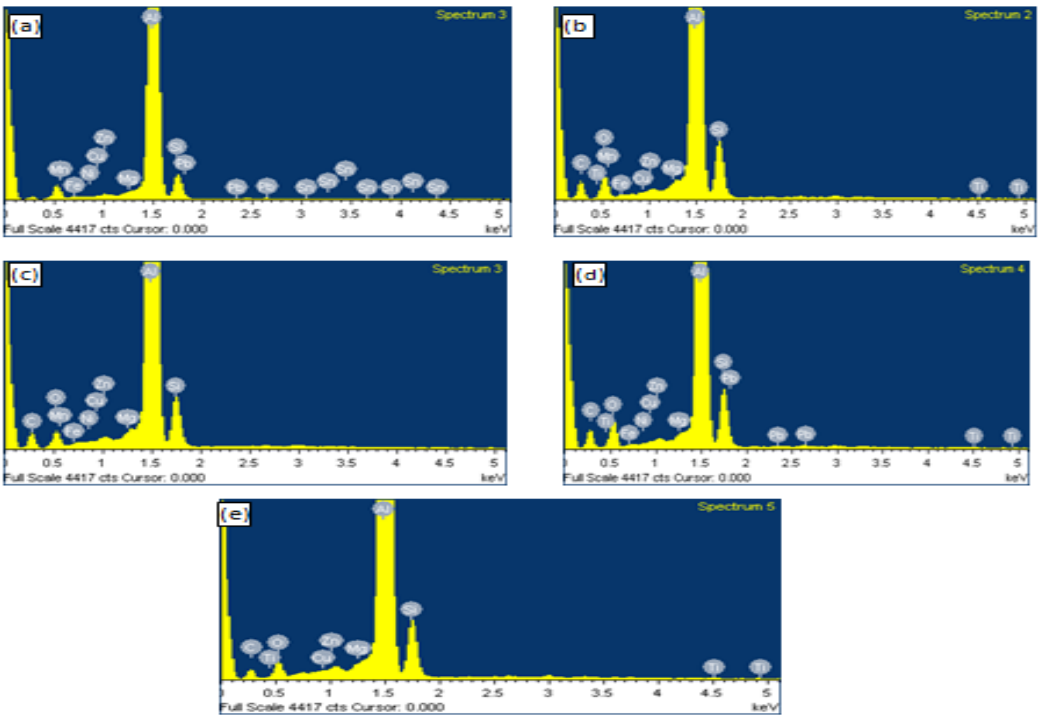

Figure.3. EDS images (a) A356 Alloy (b) MMC with Al_2O_3 (0.5%) + SiC (4%) (c) MMC with Al_2O_3 (0.5%) + SiC (1%) (d) MMC with Al_2O_3 (1.5%) + SiC (1%) (e) MMC with Al_2O_3 (1.5%) + SiC (4%)

Double shear test: The shear strength values of all samples are shown in Figure. 4. In MMC with 0.5 wt % of Al_2O_3 and 4 wt % of SiC particles, the double shear strength is increased by 9.5%. The increase in double shear strength is due to more uniform distribution of nano and micro ceramic particles in the matrix and the resistance offered by the hard ceramic particles against the applied load during shearing. Also, dislocation density is high in uniformly distributed samples due to high interfacial area (Sekar, 2016). Above 1% of Al_2O_3 nano particle addition, the double shear strength started to decrease due to clustering effect of particles on the base material which weakens the strength of the composite.

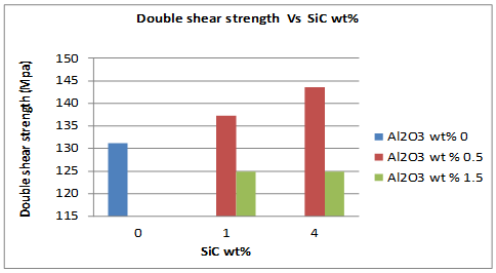

Figure.4. Double shear strength for different samples

Fracture surface study of double shear: To study the nature of fracture of MMCs, fractured surfaces were examined and figure.5 (a-e) shows the SEM fractographs of double shear fractured surface of all samples. There was a large difference in the appearance of fracture surfaces. For the monolithic Al specimens, larger size dimples were found (Fig. 5 (a)). Thus the void formation was concentrated on some inclusions in the matrix, and they were allowed to grow considerably and coalesce. For the composites, dispersed shallow dimples of varying sizes were found in the matrix.

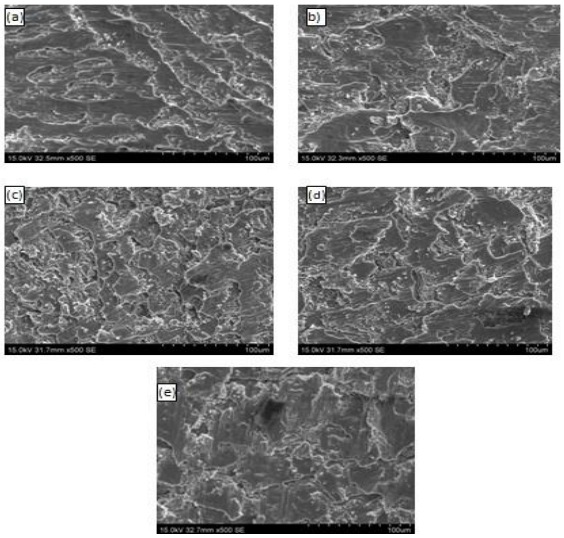

Figure.5. SEM -fracture surface (a) A356 Alloy (b) MMC with Al_2O_3 (0.5%) + SiC (4%) (c) MMC with Al_2O_3 (0.5%) + SiC (1%) (d) MMC with Al_2O_3 (1.5%) + SiC (1%) (e) MMC with Al_2O_3 (1.5%) + SiC (4%) [at 500X]

As the amount of particulate increased, some dimples linked together along the boundaries. These dimples are observed in the form of numerous cup-like depressions. This shape of the dimples is strongly influenced by stresses; dimples are developed in fracture surfaces and as shown in Figure. 5(d).

Figure 5(e). Illustrates the formation of large voids were on the fracture surface of the Al_2O_3 (1.5%), SiC (1%). The large amount of Al_2O_3 particulates in the void shows that the agglomeration of the particles provided sites for crack initiation. Due to this agglomeration, energy absorption and ductility of the composite decreased with an increase in the amount of reinforcement particles.

Hardness: Figure 6 shows the variation of Rockwell hardness of the hybrid composite with increase in wt% of Al_2O_3 nano and SiC micro particles. It was observed that addition of hybrid composites of 0.5 and 4 wt% resulted in higher hardness than the A356 monolithic alloy, because of uniform distribution of reinforcement and resistance to deformation from the ceramic phases. Hardness increases due to increase in wt% of reinforcement and decreasing particle size because of more stress required to dislocation movement in A356 alloy due to increase in the particle concentration and decrease in grain size of A356 alloy. Increase in hardness with increase in the wt% of reinforcement particles is also due to reducing grain size. By adding 0.5 wt % of Al_2O_3 and 4 wt % of SiC particles, the hardness increases by 6.6%.

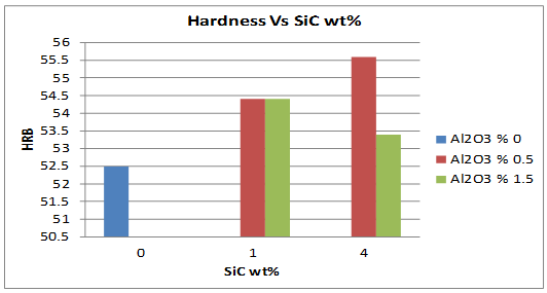

Figure.6. Hardness for different samples

Wet Sliding Wear: The study was conducted under wet condition. Initially coconut oil was used as the lubricant and the test was conducted at different load 10 N, 30 N and 50 N. Then for comparison, the same was repeated using to SAE20W40 as lubricant. SAE20W40 is a shear-stable, multi grade gasoline engine oil having special combination of additives which exhibits effective corrosion inhibitors that protect against rust and corrosion

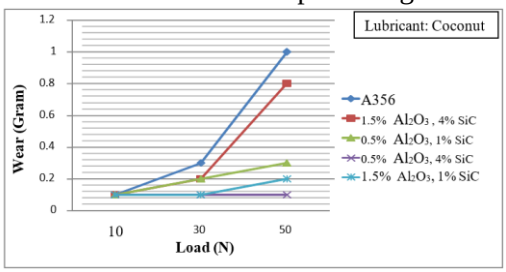

Figure.7. Variation of wear for different samples

Figure.7 shows the trend of wear rate performance of different hybrid MMCs and base alloy with against load by keeping sliding distance: 1100 m and sliding speed: 1.308 m/s as constant in coconut lubricant. Compared

to the matrix alloy all the other specimen has exhibited less wear with increase in load. The wear produced in wet sliding test is relatively less for the entire load range. This is due to the presence of liquid coconut lubricant which reduces the contact pressure at the asperities and when sliding occurs the shearing of asperities gets neutralized and significantly reducing the amount of wear.

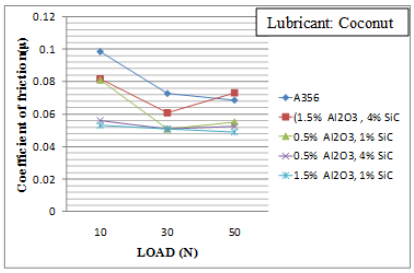

Figure.8. Variation of coefficient of friction for different samples

Figure.8, shows the trend of coefficient of friction of different hybrid MMCs and base alloy with load, keeping sliding distance: 1100 m and sliding speed: 1.308 m/s as constant. From all specimens tested, the matrix alloy had shown increased coefficient of friction with increase in load. The coefficient of friction produced in wet sliding test is relatively less for the entire load range. This could be attributed to the liquid lubricant (coconut oil) present in between the contact surfaces and consequently the sliding occurs between the pin specimen and the liquid lubricant.

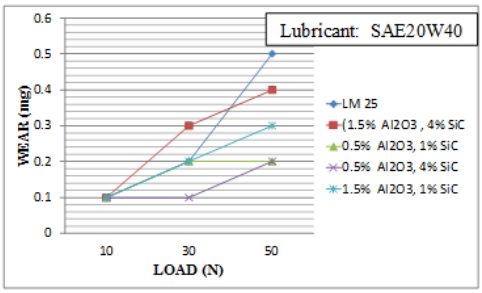

Figure.9. Variation of wear for different samples

Figure.9 shows the trend of wear rate performance of different MMCs and base alloy with Load, keeping sliding distance: 1100 m and sliding speed: 1.308 m/s as constant using SAE20W40 as lubricant. Compared to the wear characterizing obtained by using coconut oil as lubricant, the wear characteristics of SAE20W40 are less for all the specimen tested using same parameter. The additives presents in the SAE20W40 imparts more lubricity compared to the pure coconut oil which doesn't have any additives. Compared to the matrix alloy all the other specimen has exhibited less wear with increase in load. Wear is low in MMC with 0.5% Al_2O_3 and 4% SiC.

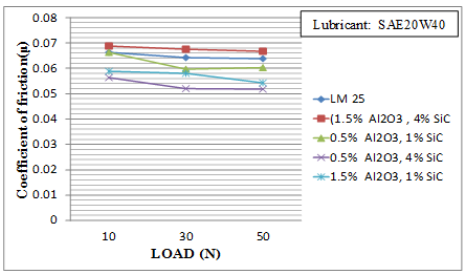

Figure.10. Variation of coefficient of friction for different samples

Figure.10, shows the trend of coefficient of friction (COF) of different MMCs and base alloy with load, keeping sliding distance: 1100 m and sliding speed: 1.308 m/s as constant. For all the specimens tested the matrix alloy had shown increased Coefficient of friction with increase in load. The friction coefficient of SAE20W40 is less compared to the pure coconut oil, this phenomenon could be related to stable SAE20W40 lubricating layer formed in between the sliding couple compared to the unstable lubricating layer of coconut oil. The instability of coconut layer is induced by frictional heating of the sliding couple. Absence of additives in the pure coconut oil enhances the frictional heating. From the graph, it was observed that, COF was low in MMC with 0.5% Al_2O_3 and 4% SiC.

4. CONCLUSIONS

Based on the results obtained in this work the following conclusions were drawn:

- The microstructure images revealed that the composites have uniform distribution of reinforcements and dense surface without micro level cavities due to stir combined squeeze casting. From the microstructure images and EDS, uniform distribution and better wettability of reinforcements is observed in the case of 0.5 wt. % Al_2O_3 and 4 wt. % of SiC particles added in A356 alloy.

- By addition of 0.5 wt % of Al_2O_3 and 4 wt % of SiC, double shear strength increases by 9.5% and hardness increases by 6.6%. MMC with higher SiC (4 wt %) and Al_2O_3 (1.5 wt %) showed lower hardness, double shear strength due to clustering effect of micro and nano particles within the matrix alloy.
- Wet sliding wear and coefficient of friction was relatively less for SAE20W40 lubricant than coconut oil during the entire load range due to the presence of liquid lubricant.

REFERENCES

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

Balasivanandha Prabu S, Karunamoorthy L, Kathiresan S, Mohan B, 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.

Prasad S.V and Asthana R, Aluminum Metal-Matrix Composites for Automotive Applications, Tribological Considerations, Tribology Letters, 17 (3), 2004, 445-453.

Sajjadi S.A, Torabi Parizi M, Ezatpour H.R, Sedghi A, Fabrication of A356 composite reinforced with micro and nano Al_2O_3 particles by a developed compocasting method and study of its properties, J. alloys and compounds, 511 (1), 2012, 226-231.

Sanjeev kumar and Bikramjit Sharma, Effects of thermal cyclic loading on cast aluminium composite reinforced with silicon carbide and fly ash particles, M.E.Thesis, Thapar University, Patiala, India, 2010.

Sekar. K, Manohar. M, Jayakumar. K, Investigation of Mechanical and Tribological Properties of A356 Alloy-Al_2O_3-SiC_p Hybrid Composites through Stir and Squeeze Casting, Journal of Advanced Engineering Research, 3 (2), 2016, 89-92.

Shorowordi K.M, Laoui T, Haseeb A.S.M.A, Celis J.P, Froyen L, Microstructure and interface characteristics of B4C, SiC and Al_2O_3 reinforced Al matrix composites: a comparative study, J. of Materials Processing Technology, 142 (3), 2003, 738-743.

Suresh S.M, Mishra D, Srinivasan A, Arunachalam R.M, Sasikumar R, Production and characterization of micro and nano Al_2O_3 particle-reinforced LM25 aluminum alloy composites, ARPN J.Engg. and Applied Sciences, 6 (6), 2011, 94-98.

Uyyuru R.K, Surappa M.K, Brusethaug S, Tribological behavior of Al–Si–SiCp composites/automobile brake pad system under dry sliding conditions, 40 (2), 2007, 365-373.