Effect of Silicon Carbide Reinforcement on the Characteristics of Aluminium Matrix Composites: A Review

Yathiraj K[1], M.H. Annaiah[2]
[1]Research Scholar, Acharya Institute of Technology, Bengaluru, Karnataka, India
[2]Acharya Institute of Technology, Bengaluru, Karnataka, India

Abstract— **Aluminium matrix composite are being used in various applications such as military, aerospace, electrical industries and automotive industries due to their superior physical and mechanical properties. The addition of reinforcements into the metallic matrix improves the stiffness, specific strength, wear resistance, creep and fatigue properties compared to the conventional engineering materials. This paper reports the effect of silicon carbide reinforcement in the aluminium alloy. Effect of silicon carbide reinforcement on AMCs on the various properties like tensile strength, strain, hardness, wear and fatigue are also studied in this paper.**

Keywords— **Aluminium matrix composites (AMC), Silicon Carbide, Reinforcement.**

I. INTRODUCTION

Aluminium matrix composites (AMCs) are proved to be better substitutes comparing with the conventional aluminium alloys because of their improved strength to weight ratio, energy saving, better wear resistance etc. AMCs reinforced with particles of Gr have been reported to be possessing better wear characteristics owing to the reduced wear because of formation of a thin layer of Gr particles, which prevents metal to metal contact of the sliding surfaces.

Different types of reinforcement play a vital role in the various characteristics of the MMCs. The most commonly used reinforcements are Silicon Carbide (SiC) and Aluminium Oxide (Al2O3). SiC reinforcement improves the tensile strength, hardness, density and wear resistance of Al and its alloys while the Al2O3 reinforcement increases compressive strength and wear resistance. Boron Carbide (B4C) is one of the hardest known elements which have high elastic modulus and fracture toughness. The addition of B4C in Al matrix increases the hardness, but does not significantly improve the wear resistance. Zircon is usually used as hybrid reinforcement. It significantly improves the wear resistance. The use of fly ash reinforcements has been increased in the last decade due to their low cost and availability as by-product in thermal power plants. Fly Ash improves the electromagnetic effect of the Al-MMC significantly. Based on the various benefits of MMCs, this paper studies the behaviour of Silicon Carbide reinforcement materials on the Aluminium based MMCs.

II. SILICON CARBIDE REINFORCED AMC

Naveen G et al.[1] developed the aluminum based silicon carbide composite in order to study the effect of silicon carbide particles on mechanical and tribological properties of A357 metal matrix composites. SiC (100 grit) was selected and experiments were conducted for varying percentage of SiC (from 0%-12% in the steps of 3%). The experimental results showed that tensile and hardnes increased with increase in SiC weight percentage and also 12% SiC with Aluminium will give the maximum value among the matrix mixture composites.

Narinder Kaushik and **Sandeep Singhal** [2] fabricated aluminum alloy AlMg0.7Si-SiC metal matrix composites and used taguchi optimization approach for inspection of wear performances. The AMCs are fabricated (having 37µm SiC particle size) in four different wt. fractions (0 wt%, 3.5 wt%, 7 wt% and 10.5 wt%). Effect of three control variables, viz,. % wt. of SiC, Load (N) and Sliding distance (m) on the wear rate and frictional force of the casted composites in unlubricated dry slippery conditions is examined by using pin-on-disc wear and friction monitor apparatus. And analyzed that sliding distance is the most significant factor influencing wear rate.

Smrutiranjan Pradhan et al.[3] prepared Al-SiC metal matrix composites using stir casting technique with 5 wt.%, 10 wt.%, 15wt.% SiC. Tribological behavior of the MMC's were investigated in acidic environment and found out that Coefficient of friction decreases with increase in normal load while it fluctuates with sliding speed also with increase in load and speed wear also increases.

K.R.Padmavathi and **R. Ramakrishnan** [4] studied the tribological properties of Al 6061- micro SiC (5, 10 and 15 wt.%) and Al 6061- nano SiC (0.5, 1.0 and 1.5 wt.%) which were produced by stir casting technique and concluded that aluminium based composite with 1.0% by weight nano SiC reinforcement possess better wear resistance properties compared to micro SiC reinforced aluminium metal matrix composites.

Ajith Arul Daniel et al.[5] investigated the dry sliding wear behaviour of aluminium 5059/SiC/MoS_2 hybrid metal matrix composites using silicon carbide (SiC) (5,10%, 15%) and particle size (10,20,40µm) of SiC and constant 2% of Molybdenum disulphide(MoS_2) is reinforced with aluminium matrix. The experiments were conducted by varying the sliding speed of (1.5,2.5 &3.5 m/s), loads (30,50&70N) with sliding distance ranges from (500, 1000& 1500m) under dry sliding conditions. Taguchi method and ANOVA method was used to find out the outcome which showed that load and sliding distance are the most influencing factors for friction coefficient also Load and percentage of SiC indicates the most affecting factor for wear rate. It was also concluded that 15% weight percentage of SiC at 10µm offers better wear resistance and friction coefficient.

Sachin Mohal [6] investigated the microstructure of as-cast plates fabricated by Al6061/SiCp MMC by a low cost stir casting technique using SiC particles in a varying weight percentage of 5,10,15%. The microstructure investigation carried out using Optical microscopy, X-ray diffraction (XRD) analysis and Wavelength dispersive X-ray fluorescence spectroscopy (WD-XRF) showed excellent distribution of SiCp in to 6061Al alloy matrix. Moreover, XRD analysis reveals the uniform presence of SiC particles into matrix.

Rajesh Agnihotri and **Santosh Dagar** [7] studied the mechanical properties of Al-6061/SiC (Silicon carbide) MMCs by STIR casting process. The composite plates were prepared with varying the reinforced particles by weight fraction of 5%, 10% and 15%. The average reinforced particles size of SiC was 325 mesh respectively. The stirring process was carried out at 200rev/min rotating speed. The results showed that addition of silicon carbide particles to the matrix alloy improves the mechanical properties such as hardness and tensile strength of the matrix alloy. But the wear rate tends to decrease with increasing particles wt. percentage.

Avinash. L et al. [8] studied the dry sliding wear behavior of A357 (Al-7%Si) alloy reinforced with the bimodal sizes (~250µm (L) and ~38 µm (S)) of 6wt% SiCp prepared by permanent mould die casting method. In the study three different combinations of bimodal distributions were considered: (3% L + 3% S, 4% L + 2% S, and 2% L + 4% S) and the wear behavior of the alloy and the composites was studied for the speed of 1 m/s and load conditions of 10-30 N with an interval of 5 N in a pin on disc apparatus. The hardness and microstructure of the composites were also characteristised. The results showed that the addition of bimodal size of particles significantly improves the hardness and wear resistance of the alloy. Among the different combinations, the 4% L + 2% S bimodal distribution combination provides the highest wear resistance and the hardness. This result indicates that the higher amount of large size particles are more important than that of small size particles to improve the wear resistance.The wear morphology studies showed that the abrasive wear is the main wear mechanism in the bimodal size composites whereas the delamination wear is predominant in the alloy.

Poornesh M. et al. [9] studied the mechanical and tribological properties of composites made using Al-18wt%Si as the base alloy and SiC particles as the reinforcement. The composite was prepared using stir casting with bottom pouring technique and centrifugal casting. Various mechanical and tribological properties were checked and were then compared with results of the base alloy produced using centrifugal casting. It was found that, the introductions of the SiC particles have improved the mechanical and tribological properties of the base alloy.

A. O. Inegbenebor et al. [10] investigated conventional simple methods of producing MMC with attained properties through the dispersion of silicon carbide in the matrix. Two-step mixing method of stir casting technique was employed. Aluminum (99.66 %C.P) and SiC (320 and 1200 grits) were chosen as matrix and reinforcement materials. Experiments were conducted by varying the weight fraction of SiC for 2.5 %, 5.0 %, 7.5 % and 10 %. The result showed that the stir casting method was quite successful to obtain uniform dispersion of reinforcement in the matrix. This was indicated by the improvement of properties of composites over the base metal. Young's modulus (E) and hardness increased in reinforced Aluminum Silicon Carbide composites above the unreinforced case and marginal reduction of electrical conductivity was recorded for the composites. The silicon carbide of 1200 grits (3 µm) showed increased Young's modulus (E) and hardness of 1517.6 Mpa and 26.1 Hv values at 7.5%volume fraction silicon carbide; when compared with the silicon carbide 320 grit (29 µm).

A. O. Inegbenebor et al. [11] studied the influence of the grit size of silicon carbide particles on the mechanical and electrical properties of stir cast aluminum matrix composites. 1170AL and silicon carbide particles of 45 µm, 29 µm, 9 µm and 3 µm were used along with 2.5 %, 5 %, 7.5 % and 10 % weight fraction of SiC. Mechanical properties, Microstructures, MicroHardness and Electrical properties were determined which showed that the modulus, yield strength and hardness of the composite increase at lower grit sizes of silicon carbide of 3 micron. The maximum hardness of 26.1 HVN and maximum modulus elasticity of 1517.6 N/mm^{-2} was obtained at 7.5 % weight fraction of SiC. The mechanical and electrical property of the produced alloys was increased by changing the grit size of the silicon carbide.

Pranjal Bordoloi et al. [12] studied the mechanical properties and microstructure of aluminum alloy 63401 metal matrix composite reinforced with silicon carbide powder of different wt% i.e. 3%, 6% and 9% and different grain size of 177 µm, 149 µm and 74 µm. From the experiments conducted it was concluded that the hardness and impact strength of the Al alloy increased with the increase in percentage of SiC and with the decrease in grain size of SiC. The tensile strength increased by increasing wt % of SiC whereas % elongation decreases with the increase in weight percent of SiC and increases by decreasing grain size of SiC.

Smrutiranjan Pradhan et al. [13] studied the friction and wear performances of Ai-SiC composite for varying applied load and sliding speed parameters under acidic environment. The composite was developed by reinforcing 5 wt % SiC particle with LM6 aluminium alloy using stir casting method. It was found that wear is directly proportional to the applied normal load and sliding speed also Coefficient of friction value decreases with increase in load but remains almost constant with variation of sliding speed.

Amir Hussain Idrisi et al. [14] fabricated Nano sic /Al 5083 composites using stir casting process with varying composition one for AA5083/10% micron SiC one for AA5083/1% nano SiC and one for AA5083/2% nano SiC. It was investigated that hardness, rigidity and compressive quality at 2% sic nano composites might have been higher in comparison of all other compositions whereas hardness of Al-alloy with 10% SiC composite was more than Al alloy with 1% SiC nano composite.

Pavan Kumar et al. [15] studied the mechanical behavior and sliding wear response of Al-Si alloy and Al-Si-SiC particulate composite developed by reinforcing 10 wt% and 15 wt% SiC particles of size 2μm in the Al matrix. Mechanical properties such as Tensile strength, Compressive strength, Impact strength, Hardness and Wear resistance of the composites were compared with the matrix alloy. The results showed a large improvement in mechanical properties and wear resistance of the Al-Si-SiC particulate composite with 10wt% reinforcement and on further increase of reinforcement the properties tends to decrease due to high brittleness.

Mohd. Suhail et al.[16] produced a composite material with balanced Al + 4% Cu as matrix phase and 5% SiC with different grit sizes 400, 600 and 800 mesh and observed the mechanical properties with varying pouring temperatures 700, 725 and 750°C. The results showed that the mechanical properties as hardness, impact and tensile strength were enhanced with increasing grit size of reinforcement SiC particles and the best value of BHN, Impact and UTS has been obtained at optimum pouring temperature 725°C.

Aykut Canakci and **Temel Varol** [17] produced SiC particle (2.5, 5 and 10 wt.%) and Al powder (10, 20, 30 and 50 wt.%) reinforced AA7075 alloy matrix composites by the combination of powder metallurgy and hot pressing techniques. The effects of the amounts of SiC particles and Al powder on the microstructure, density, porosity and hardness of the composites were observed. The green density of the AA7075/Al–SiC composites increased with increasing amounts of Al powder, while SiC showed the opposite effect. The hot pressed density of the composites decreased with increasing amounts of Al powders and SiC content. An increase in the weight percentage of the SiC particles (from 0 to 10 wt.%) in the AA7075/Al–SiC composites improved the hardness of the recycled composites due to the high hardness of the SiC particles.

Amir Hussain Idrisi et al.[18] studied the behaviour of Aluminium 5083 with SiC as reinforcement produced by stir casting method and ultrasonic assisted stir casting method and concluded that the mechanical properties increased by increasing wt. % of SiC in stir casting and also with ultrasonic assisted stir casting. Whereas ultrasonic stir casting proved to be the prominent route for fabrication of composites.

J.Jebeen Moses et al. [19] prepared Aluminum alloy AA6061reinforced with 0,5,10 and 15 wt.% SiC particles using stir casting method. The microstructures were studied using SEM and optical microscopy. The results showed that the 15 wt.% SiC AMC exhibited higher microhardness compared to unreinforced AA6061 alloy.Also increase in SiC content shifted the fracture mode from ductile to brittle.

Shiming Hao et al. [20] fabricated SiC reinforced Al-30Si matrix composite using vaccum hot pressing technique. Mechanical properties of the composite were measured and Microstructure was observed using SEM,TEM,XRD. The results showed that the SiC particles were dispersed uniformly in the matrix and the Matrix composite was dense and free from porosity. The composite with SiC particles possessed high tensile properties.

Dr.Govind Nandipati et al. [21] studied the effect of uniformly dispersed SiC nano particles of various weight percentage in AA7075 matrix. The study showed that the hardness and impact strength increased by 10% and 75% respectively also the metal matrix nano composites had fine and more homogeneous microstructure with the increase of weight percentage of nano SiC content.

Salim Sahin et al. [22] studied the wear behavior of Al/SiC/Graphite and Al/FeB/Graphite hybrid composites. Aluminium composites were produced with 10 % and 20 % silicon-carbide and ferroboron reinforcements and (0, 0.5, 1 and 1.5) % graphite additions using powder metallurgy.The investigation showed that minimum wear rate was found in the sample having 0% graphite and 20% FeB reinforcement. The increase in graphite increased the wear rate also increase in reinforcement increased the porosity in the composite.

Ghauri, K.M. et al. [23] prepared the SiC/Al composite which was produced by reinforcing the various proportions of SiC (5, 10, 15, 25 and 30%) in using stir casting technique. Mechanical properties of test specimens have been observed using metallographic and mechanical testing techniques. It was found that as the volume fraction of SiC in the composite is gradually increased, the hardness and toughness increase. Whereas beyond a level of 25-30 percent SiC, the results are not very consistent, and depend largely on the uniformity of distribution of SiC in the aluminum matrix.

N. Altinkok et al. [24] Produced Al2O3/SiC particulate reinforced metal matrix composites using stir casting process. The Al2O3/SiC powder mix was prepared by reaction of aqueous solution of aluminium sulphate, ammonium sulphate and water containing SiC particles at 1200_C. 10 wt% of this hybrid ceramic powder with different sized SiC particles was added to a liquid matrix alloy during a mechanical stirring between solidus and liquidus under inert conditions. Pin-on-disk friction and wear tester was used to conduct dry sliding wear tests. The worn surfaces were examined using a scanning electron microscope to observe the wear characteristics and investigate the wear mechanism. It was observed that hybrid and bimodal particle reinforcement decreased weight loss when SiC powder with larger grain size was used. Microstructural examination showed that besides occurring coarse SiC particle reinforcement, a fine alumina particle reinforcement phase was observed within the aluminium matrix (A332). Wear resistance of the hybrid ceramic reinforced metal matrix composites increased due to the larger SiC particles. Also hardness of the composites increased with small sized particles.

III. CONCLUSIONS

The literature survey presented above shows that extensive work has been done to improve mechanical and wear properties of Aluminium based Metal Matrix Composites. It reveals that when aluminium alloy treated with different reinforcements like Silicon carbide, Al_2O_3, Boron and fly ash are tested resulting in improved mechanical and wear properties.

The SiC reinforced AMCs have been studied extensively in this review:

a) The increase in reinforcement ratio and decrease in reinforcement particle size significantly improves the mechanical and fatigue properties of AMCs.
b) SiC reinforced AMCs have higher wear resistance than Al_2O_3 and B_4C reinforced AMCs.
c) Incorporation of graphite in aluminium increases its tensile strength and elastic modulus, but hardness is reduced. Also friction coefficient is reduced in case of tribological behavior.
d) Hybrid reinforcements have given better mechanical properties than composites in most of the cases.
e) A simple designed conventional method of stir casting was used to produce an aluminum silicon carbide composite.
f) The metal matrix composite (MMC) materials produced show that modulus and hardness had higher values than the unreinforced base metal aluminum.
g) The study found that with the increase in SiC reinforcement ratio, tensile strength, hardness and density of AMC material increased, but impact toughness decreased.
h) Also more the weight percentage of SiC powder, impact strength, tensile strength and hardness increases but the percentage elongation decreases with increase in weight percentage of SiC and increases with decrease in grain size of SiC.

ACKNOWLEDGMENT

The author thank Dr. M.H. Annaiah, Principal, Dr. SMCE, Bengaluru, India for guiding to carry out the study. The authors thank Mr. Harendra Kumar, Mr. Chandraiah M.T, for their kind assistance.

REFERENCES

[1] Naveen, G., Chethan, N., Gururaja, R., Lokesh, K., and Chetan Kumar, B. M., "Effect of Silicon Carbide on Mechanical Properties of Aluminium Alloy (A357) Composite (Al Sic)", International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE), 2, pp 1061-1064, 2017.
[2] Narinder Kaushik., and Sandeep Singhal., " Examination of Wear Properties in Dry-Sliding States of SIC Strengthened Al-Alloy Metal Matrix Composites by Using Taguchi Optimization Approach", International Journal of Applied Engineering Research, 12, pp 9708-9716, 2017.
[3] Smrutiranjan Pradhan., Tapan K. Barman., Prasanta Sahoo., and Goutam Sutradhar., "Effect of SiC weight percentage on tribological properties of Al-SiC metal matrix composites under acid environment", Jurnal Tribologi, 13, pp 21-35, 2017.
[4] K.R.Padmavathi1., and R. Ramakrishnan., "Tribological properties of micro and nano SiC reinforced Aluminium metal matrix composites", International Journal of ChemTech Research, 10, pp 367-372, 2017.
[5] Ajith Arul Daniela., Sakthivel Murugesana., Manojkumara., and Sudhagar Sukkasamya., " Dry Sliding Wear Behaviour of Aluminium 5059/SiC/MoS2 Hybrid Metal Matrix Composites", Materials Research, 20(6), pp 1697-1706, 2017.
[6] Sachin Mohal., "Microstructural Investigation of Aluminium-Silicon Carbide Particulate Metal Matrix Composite Fabricated by Stir Casting", IJIRST –International Journal for Innovative Research in Science & Technology, 3(11), pp 26-30, 2017.
[7] Rajesh Agnihotri., and Santosh Dagar., "Mechanical Properties of Al-SiC Metal Matrix Composites Fabricated by Stir Casting Route", Research in Medical & Engineering Sciences, 2(5), pp 1-6, 2017.
[8] L. Avinash, T. Ram Prabhu, and Srikanth Bontha, "The Effect on the Dry Sliding Wear Behavior of Gravity Cast A357 Reinforced with Dual Size Silicon Carbide Particles", Applied Mechanics and Materials. 829, pp 83-89, 2016.
[9] Poornesh, M., Harish, N., and Kiran Aithal, "Mechanical and Tribological Properties of Centrifugally Cast Al-Si-SiC Composites", American Journal of Materials Science., 6(4A), pp 31-35, 2016.
[10] A. O. Inegbenebor, C. A. Bolu, P. O. Babalola, A. I. Inegbenebor, and O. S. I. Fayomi, "Aluminum Silicon Carbide Particulate Metal Matrix Composite Development Via Stir Casting Processing", Silicon., 10, pp 343-347, 2016.
[11] A. O. Inegbenebor, C. A. Bolu, P. O. Babalola, A. I. Inegbenebor, and O. S. I. Fayomi, "Influence of the grit size of silicon carbide particles on the mechanical and electrical properties of stir casting aluminium matrix composite material", Silicon., 8, pp 573-578, 2016.

[12] Pranjal Bordoloi., Amit Singla., and Amit Chauhan., "Study on Mechanical Properties and Microstructure of Aluminum Alloy 63401 Metal Matrix Composite Reinforced with Silicon Carbide Powder", Indian Journal of Science and Technology, 9(36), pp 1-6, 2016.

[13] Smrutiranjan Pradhan., Tapan Kr. Barman., Prasanta Sahoo., Goutam Sutradhar., and Shouvik Ghosh., "Tribological Behavior of Al-SiC Metal Matrix Composite in Acidic Medium", International Journal of Engineering and Technologies, 8, pp 24-31, 2016.

[14] Amir Hussain Idrisi., Gaurang Deep., and Vijay Sharma., "Fabrication of aluminum matrix composite reinforced by SiC Nano particles for enhancing its mechanical characteristics", International Journal for Research in Applied Science & Engineering Technology (IJRASET), 4(10), pp 89-96, 2016.

[15] Pavan Kumar., Sanjay Soni., R. S. Rana., and Alok Singh., "Mechanical Behavior And Dry Sliding Wear Response of Al-Si-Sic Particulate Composite", Proceedings of The IRES 9th International Conference, Hong Kong, pp 40-48, 2015.

[16] Mohd. Suhail., Mahmood Alam., and Reyaz Ur Rahim., "The Effect of Process Parameter on Metal Matrix Composite (Al+4%Cu+5%Sic) By Stir Casting", International Journal of Engineering Trends and Applications (IJETA), 2(1), pp 28-33, 2015.

[17] Aykut Canakci., and Temel Varol., "Microstructure and Properties of AA7075/Al-SiC composites fabricated using powder metallurgy and hot pressing", Powder Technology, 268, pp 72-79, 2014.

[18] Amir Hussain Idrisi., Vikas Dev Singh., and Vipul Saxena., "Development and testing of Al5083 alloy reinforced by SiC particles", International Journal of Scientific Research Engineering & Technology (IJSRET), 2(11), pp 697-704, 2014.

[19] J. Jebeen Moses., I. Dinaheran., and S. Joseph Sekhar., "Characterization of Silicon Carbide Particulate Reinforced AA6061 Aluminium Alloy composites produced via stir casting", Procedia Materials Science, 5, pp 106-112, 2014.

[20] Shiming Hao., Jingpei Xie., Aiqin Wang., and Ming Fang., "Preparation, Properties and Microstructure of SiC Particle Reinforced Al-Si Matrix Composite", Materials Transactions, 55, pp 750-753, 2014.

[21] Dr.Govind Nandipati., Dr.Ravindra Kommineni., and Dr. Nageswara Rao Damera., "Study on Processing and Mechanical Properties of nano SiCp reinforced AA7075", The International Journal of Engineering And Science (IJES), 3(12), pp 29-34, 2014.

[22] Salim Sahin., Nilay Yuksel., Hulya Durmus., and Simge Gencalp Irizalp., "Wear Behavior of Al/Sic/Graphite and Al/Feb/Graphite Hybrid Composites", Materials and technology, 48(5), pp 639-646, 2014.

[23] Ghauri,K.M., Ahmad, A., Ahmad, R., Din, K.M., and Chaudhry, J.A., " Synthesises and Characterization of Al-SiC composite made by stir casting method", Pakistan Journal of Engineering and Applied Science, 12, pp 102-110, 2013.

[24] N. Altinkok., I. Ozsert., and F. Findik., " Dry sliding wear behavior of Al_2O_3/ SiC particles reinforced aluminium based MMCs fabricated by stir casting method", Acta Physica Polonica A, 124, pp 11-19, 2013