Experimental Investigation on Mechanical Behaviour of Aluminium Metal Matrix Composites

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Abstract- *The main objective of this work isto produce Al6063 alloy and its composites reinforced with Al_2O_3 and B_4C particles by employing stir casting technique, using varying weight percentages of B_4Cas 2,4,6,8,10 wt. % while fixing Al_2O_3 particles at 5wt.%, to study the effect of B_4C particles on the mechanical andwear characteristics of thecomposites, to conduct dry sliding wear test, using pin-on-disc apparatus and to calculate the weight loss and wear rate.*

Keywords- Aluminium Matrix Composites, Stir Casting, Graphite, B_4C, Wear Test.

I. INTRODUCTION

Composite materials structurally contain two or more constituents that are combined together in such a way that they function mechanically as a single unit. One of the ingredient materials acts as matrix and the other as reinforcement in the composite. Depending upon the matrix materials, composites are classified as polymer matrix, metal matrix and ceramic matrix. In Polymer Matrix Composites, polymer resin is used as matrix and glass fibres are used as reinforcement. Metals and alloys are used as matrix in Metal Matrix Composites and ceramic particles or fibres as reinforcement , whereas in Ceramic Matrix , ceramic materials are used as matrix and fibres / short fibres/ particulates are used as reinforcement.

Reinforcing components in composites offer strength to them. The reinforcement materials should be stronger and stiffer than the matrix. Reinforcement for the composites may be fibres, particulates or whiskers (Sharma 2000). Fibres are characterized by very long axis with other two axes either often near circular or circular. Particles have no particular orientation and shape. Whiskers have proper shape, but are small in diameter and length, compared to fibres. In Metal Matrix Composites, often ceramic particulates are integrated with matrix as reinforcements. The selection criteria for ceramic particulates as reinforcements comprises of the following factors:

(i) density (ii) compatibility with the matrix (iii) elastic modulus (iv) tensile strength (v) melting point (vi) thermal stability (vii) size and shape of the reinforcing particle and (viii) cost. The most commonly used reinforcement in aluminium is B_4C andAl_2O_3.

Among these composites, Metal Matrix Composites have drawn substantial attention of industries, as they offer a large variety of microstructures and properties. In addition, Metal Matrix Composites allow tailoring of some useful properties that are not attainable in conventional metallic alloys. High specific strength, low thermal expansion, good thermal stability and improved wear resistance are some of the promising features of Metal Matrix Composites. Metal composites also offer better transverse properties and superior toughness compared to polymer composites.

1.1 Aluminium matrix composites

In most of the engineering applications, Aluminium and its alloys grabbed the attention most as matrix material in metal matrix composites due to their attractive mechanical properties, good ductility, excellent corrosion resistance. Aluminium alloys are used in advanced applications for the reason that the combination of factors such as durability, machinability, accessibility and price is more attractive than other competing materials. Aluminium matrix composites are very smart on account of their flexibility in processing. AMCs are well-known for their superior mechanical properties and attractive tribological properties. Due to their high strength-to-weight ratio, AMCs are the most appropriate materials for structural applications in aircraft, automotive and military industries, compared to other MMCs.

In AMCs, the major ingredient is either aluminium or aluminium alloy, which forms percolating network and is expressed as the matrix phase. AMCs generally have enhanced specific stiffness, elevated temperature strength, wear resistance and corrosion resistance with tailorable low thermal expansion coefficients. Another ingredient, a hard ceramic component, is dispersed in a matrix to obtain characteristics that are better than conventional monolithic metallic alloys. Based on the type of reinforcement, AMCs are classified into the following four types

a) Particulate-reinforced AMC(PAMC)
b) Whisker or Short Fibre reinforced AMC(SFAMC)
c) Continuous Fibre reinforced AMC(CFAMC)
d) Mono Filament reinforced(AMC)

Among metal matrix composites, particulate reinforced aluminium matrix composite is the most important one (Surappa 2003). Mechanical properties of PAMCs are better than unreinforced aluminium alloys. These composites normally contain equiaxed ceramic reinforcements with ratio of length-to-diameter less than about 5. Further, the properties of discontinuous ceramic reinforced composites are nearly isotropic, while those of continuously reinforced composites are highly anisotropic. Particulate metal matrix composites have high property of ductility and offer greater wear resistance. Fabrication methods of particulatereinforced composites are less expensive compared to continuous fibre reinforced composites. These particulate reinforced composites can be subjected to several secondary forming operations like rolling, forging and extrusion, to cite afew.

1.2 Fabrication techniques ofAMCs

The fabrication techniques used for manufacture of Aluminium matrix composites can be classified into two main groups: (i) Solid state processes (ii) Liquid state processes.

In solid-state processing, reinforcement is surrounded in the matrix all the way through diffusion at high temperatures and pressures. Powder metallurgy, diffusion bonding and vapour deposition techniques come under this category of solid state processing.

Powder metallurgy involves blending of aluminium alloy powder with ceramic particle which is a versatile technique for the production of AMCs. In diffusion bonding, matrix in the form of foils and reinforcement in the form of long fibres are stacked in a particular sequence and then pressed at elevated temperatures. This process is used to fabricate only simple plates and tubes. Vapour deposition techniques involve coating of reinforcement fibres with matrix materials needed to form the composite. Vapour deposition is the primary process wherein the matrix material is deposited from vapour phase on individual reinforcement elements of the ingredient.

A liquid state process involves incorporation of reinforcement particles into a molten matrix metal, followed by its solidification. There are different methods of liquid state process: stir casting, infiltration, spray deposition and in-situ processing. The selection of the production technique depends on various factors like type of reinforcement loading and degree of micro- structural integrity preferred. In the infiltration technique, a liquid matrix alloy is injected into a porous pre-form of reinforcement which may be either continuous and short fibre or whisker or particulate. Depending on the type of reinforcement and its quantity, preforms will be infiltrated, either with or without application of pressure or vacuum.

In Aluminium matrix composites, mostly ceramic particulates are used as reinforcements due to their enhanced mechanical properties irrespective of the orientation of the particulates and uniform distribution of particles is enough to achieve better mechanical properties. Particulate metal matrix composites have high ductility and low anisotropy compared to fibre reinforced MMCs. Particle-reinforced composites production technique is the most attractive economically. AMCs are familiar due to their easy availability, low-cost and attractive wear resistance. In addition to these four types, another type of AMC known as hybrid AMC has been developed recently and is in use in few areas. To cite an example, hybrid aluminium matrix composite which comprises of alumina particles and carbon fibres is used in cylindrical liner applications.

II. LITERATURE REVIEW

Pramanik et al. (2008) examined the effects of reinforcements on the machining of particulate reinforced MMCs and observed that the feed controlled the surface roughness and compressive residual stresses formed on the machined surface of MMC. The particles pullout influenced the surface roughness at low feed rate, particles facilitated chip breaking and affected residual stress generation, the shear and friction angles depended considerably on feed rate but were independent of speed.

Palanikumar and Muniraj (2014) investigated the thrust force and burr height on drilling of Al/15%SiC/4%Gr reinforced hybrid composites using tin-coated solid carbide drill tools at different spindle speeds and feed rates with three different diameters of the drills. The composite material produced by stir casting method with the average particle size of SiC was about 25 μm and the particle size of graphite was around 45 μm. Thrust force generated during drilling ofmetal matrix composite materials was calculated by means of Kistler piezo-electric- dynamometer. The drilling test results indicated that the thrust force increased with increase in feed rate. Because of increasing feed rate, load on the tool also increased which in turn raised the thrust force. Thrust force decreased with increase in cutting speed and vice-versa. The experimental result reported that increase in feed rate increased the burr height and increase in spindle speed reduced the burr height. Taguchi's orthogonal array and Response Surface Methodology (RSM) were used for conducting the experiments and for deriving the empirical relation. Analysis of Variance (ANOVA) was used to confirm the validity of the developed model. The results indicated that the empirical model can be effectively used to calculate the thrust force in drilling of hybrid composites within the ranges of parametersstudied.

Rajmohan et al. (2013) focused on finding the optimal drilling parameters to obtain minimum thrust force, surface roughness and burr height in drilling hybrid aluminium metal matrix composites using grey-fuzzy algorithm. Aluminium alloy Al 356 reinforced with 5–15 wt.% of SiC particles in steps of 5 wt.% and fixed quantity of 3 wt.% mica particles were used as second reinforcement. The composites were manufactured using stir casting technique at optimal speed, which confirmed uniform distribution of reinforcement particles in matrix alloy. The drilling experiments were carried out based on Taguchi's L27 orthogonal array with different spindle speed and feed rate using TiN coated HSS drill. They noted that the incorporation of 3% mica particles decreased thrust force drastically and it is attributed to the solid lubricating property of the mica particles. The drilling test results specified that low feed rate was desirable while drilling hybrid Al356/SiC/Mica MMC to obtain better hole quality. The rise in feed rate increased the thrust force and torque resulting in poor surface finish.

III. METHODOLOGY

From the literature review, the material for the metal matrix composite is chosen as Al6063 and the reinforcement is chosen as B_4C and Al_2O_3. The metal matrix composite is fabricated using stir casting. Then the final casted piece is machined using EDM for further testing. Various mechanical tests like tensile, wear, etc are calculated and the results are validated.

IV. STIR CASTING

According to the type of reinforcement, the fabrication techniques can vary considerably. From the contributions of several researchers, some of the techniques for the development of these composites are stir casting/ Compocasting (Y.H. Seo et al 1999), powder metallurgy (X. Yunsheng et al 1998), spray atomization and co-deposition (C.G. Kang et al 1997), plasma spraying (Y.H. Seo et al 1995) and squeeze-casting (S. Zhang et al 1998). The above processes are most important of which, liquid metallurgy technique has been explored much in these days. This involves incorporation of ceramic particulate into liquid aluminium melt and allowing the mixture to solidify. Here, the crucial thing is to create good wetting between the particulate reinforcement and the liquid aluminium alloy melt. The simplest and most commercially used technique is known as vortex technique or stir-casting technique. The vortex technique involves the introduction of pre-treated ceramic particles into the vortex of molten alloy created by the rotating impeller. Ceramic particles and ingot- grade aluminium are mixed and melted. The melt is stirred slightly above the liquidus temperature(600−700°C).

Stir casting offers better matrix-particle bonding due to stirring action of particles into the melts. The recent research studies reported that the homogeneous mixing and good wetting can be obtained by selecting appropriate processing parameters like stirring speed, time, and temperature of molten metal, preheating temperature of mould and uniform feed rate of particles. Disadvantages that may occur if process parameters are not adequately controlled include the fact that non-homogeneous particle distribution results in sedimentation and segregation.

V. EXPERIMENTAL METHODS

During processing of B_4C particle-reinforced aluminium matrix composites, the particles are preheated at 600–800^O C for 2 hours in order to remove the volatile substances and to maintain the particle temperature closer to melt temperature of 750^O C. The Al6063 billets were charged into the furnace and melting was allowed to progress until a uniform temperature of 750^O C(which is above the liquidus temperature) was attained, subsequently degassed by passing hexachloroethane (C2Cl6) solid degasser.

Fig 1

The melt was then allowed to cool to 600^{O} C (slightly below the liquidus temperature) to a semi-solid state. At this stage, the boron carbide and Al_2O_3 mixture was added to the melt and manual stirring of the slurry was performed for 20 minutes. An external temperature probe was utilized in all cases to monitor the temperature readings of the furnace. After the manual stirring, the composite slurry was reheated and maintained at a temperature of 750^{O} C ,10^{O} C (above the liquidus temperature) and then mechanical stirring was performed.

The stirring operation Wire Mesh particles is preheated at 200 ^{O}C in order to remove the volatile impurities on the surface and improve the wettability of reinforcement particle with the molten metal. The particles are washed in alkali solution to remove some of the surface contaminants present over boron carbide particles. The treated particulates are incorporated into the vortex of the melt created with the help of mechanical impeller with an average speed 400 rpm. The mechanical stirring suspends the particles in the melt and provides uniform distribution of reinforcement particles. The matrix material was loaded in a graphite crucible and it was placed inside a top loaded resistance furnace at different temperature level (700˚C, 750˚C, 800˚C, 850˚C, 900˚C). The B_4C reinforcement (average size 40 µm, supplied by universal carborendum Ltd, India) was preheated at 1000˚C for two hours before added in the matrixmelt.The10%byvolumeofpreheatedB_4Cpowderwasaddedintheliquidmeltand the slurry was consciously stirred using a stirring. The four blade Stirrer was designed in order to produce the adequate homogenous particle distribution throughout the matrix material. The axial and radial flows are provided to avoid different stagnant zones in the liquid melt by stirrer. Stirring of the mixture is carried out at different holding time (10, 20, and 30 minutes) to achieve homogeneity of particulates. The stainless steel stirrer blade was coated with zirconia to avoid the reaction between stainless steel and Al alloys at higher temperatures. The Argon gas was supplied into the near the crucible during the stirring to avoid the formation of oxide layer on the surface of matrix melt. The Stirring speed 450 rpm was maintained throughout work. The mixture is allowed to solidify in the preheated (300˚C) steeldie.

VI. RESULTS AND DISCUSSION

6.1 Tensile test

Tensile testing is a fundamental material science and engineering test in which the sample is subjected to controlled tension until failure.Properties measured directly via the tension test are Ultimate tensile strength, breaking load, maximum elongation and reduce in area. From these measurements the following values can be obtained young's modulus, yield strength and strain hardeningcharacteristics.

Universal testing machine (UTM)

It is also known as universal tester or material testing machine, is used to test the tensile strength and compressive strength of the material.

Fig 2.

The specimen chosen at the first is aluminium 6063. The tensile test was subjected to it and the tensile strength were obtained. Similarlythe samples with the reinforcements were also subjected to tensile strength using the UTM.

Table 1

SAMPLENO	COMBINATIONS	TENSILE STRENGTH(N/mm^2)
1	Al(100%)	185
2	Al(93%)+B_4C(2%)+Al2O3(5%)	198
3	Al(91%)+B_4C(4%)+ Al2O3(5%)	207
4	Al(89%)+ B_4C (6%)+ Al2O3(5%)	216
5	Al(87%)+B_4C(8%)+ Al2O3(5%)	238
6	Al(85%)+B_4C(10%)+ Al2O3(5%)	254

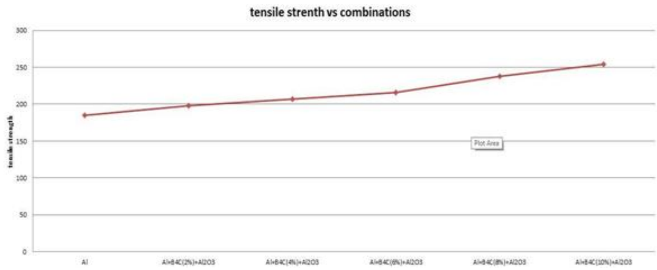

Fig 3.

6.2 Hardnesstest

Hardness is the measure of resistance to localized plastic deformation induced by either by mechanical indentation or abrasions.

$$BHN = \frac{2P}{3.14*D(D-(D-d)^{0.5})}$$

Table 2

SAMPLE NO	COMBINATIONS	HARDNESS(BHN)
1	Al(100%)	87
2	Al(93%)+B4C(2%)+Al2O3(5%)	102
3	Al(91%)+B4C(4%)+Al2O3(5%)	117
4	Al(89%)+B4C(6%)+Al2O3(5%)	128
5	Al(87%)+B4C(8%)+Al2O3(5%)	142
6	Al(85%)+B4C(10%)+Al2O3(5%)	153

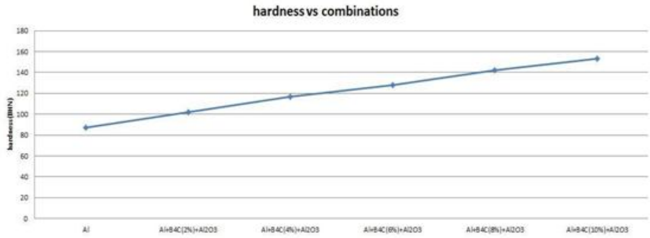

Fig 4.

6.3Wear test

Table 3

SAMPLE NO	COMBINATION	WEAR RATE (mm^3/Nm)
1	Al(100%)	0.1524
2	Al(93%)+B4C(2%)+Al2O3(5%)	0.1239
3	Al(91%)+B4C(4%)+Al2O3(5%)	0.1007
4	Al(89%)+B4C(6%)+Al2O3(5%)	0.0884
5	Al(87%)+B4C(8%)+Al2O3(5%)	0.0692
6	Al(85%)+B4C(10%)+Al2O3(5%)	0.0453

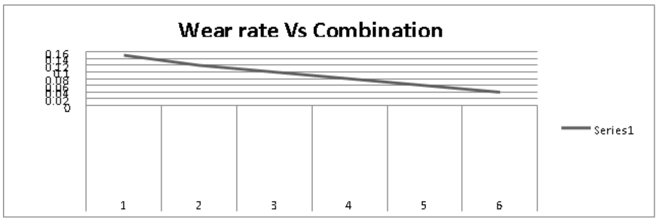

Fig. 5

VII. CONCLUSION

For a better reinforced materialit must have a higher tensile strength and hardness while the wear rate should be low from different compositions and combination of reinforcements used in the aluminium metal, we have tested for tensile strengthhardness and wear rate and the results were tabulated and plotted in graph for better understanding. From the results and graph we can clearly see that as the percentage of B4C is increased step by step of 2% the tensile strength and hardness increases gradually since the better sample is to have higher tensile strength and hardness while the were rate of the samples decreases as the percentage of B4C is increased as the sample is to have a lower wear rate and hence the better wear rate is also got. Therefore from the above conducted test it can be inferred that the material which was reinforced with 10% B4C and Al2O3 has the highest tensile strength, hardness and lowest wear rate when compared to pure aluminium metal and other aluminium reinforced samples.Thusmaking this sample with 10% B4C as reinforcement a better selection

REFERENCES

[1] D.P. Mondal, S. Das;" High stress abrasive wear behavior of aluminium hard particle composites: Effect of experimental parameters, particle size and volume fraction"; Tribol. Inter.,39 (2006) 470–478.

[2] J.P. Pathak, J.K. Singh. & S. Mohan "Synthesis and Characterization of Aluminium-SiliconSilicon Carbide Composite",Ind. J. Engg. &Mater.Sci., 13 (2006) 238-246.

[3] R.K. Uyyuru, M.K. Surappa and S. Brusethaug, "Tribological Behaviour of Al- Si-SiCp Composites/Automobile Brake Pad System under Dry Sliding Conidtions", Tribol. Inter. , 40 (2007)365-373.

[4] J. Rodriguez, P. Poza, M.A. Garrido and A. Rico, "Dry Sliding Wear Behaviour of Aluminium – Lithium Alloys Reinforced with SiC Particles", Wear, 262 (2007)292-300.

[5] Feng Tang, Xiaoling Wu, ShirongGe, Jichun Ye, Hua Zhu, Masuo Hagiwara and Julie M. Schoenung, "Dry Sliding Friction and Wear Properties of B4C Particulate-Reinforced Al 5083 Matrix Composites, Wear, 264 (2008)555-561.

[6] Sudarshan and M.K. Surappa, "Synthesis of Fly ash Particle Reinforced A356 Al Composites and their Characterization", Mater. Sci. & Engg.,480 (2008)117-124.

[7] S. Natarajan., R. Narayanasamy., S.P. KumareshBabu., G. Dinesh., B. Anil Kumar., K. Sivaprasad., "Sliding Wear Behavior of Al 6063/TiB2 in Situ Composites at Elevated Temperatures, Mater. & Dsg.,30 (2009) 2521-2531. [8] R.N. Rao and S. Das, "Effect of Heat Treatment on the Sliding Wear Behaviour of Aluminium Alloy (Al-Zn-Mg) Hard Particle Composite", Tribol. Inter. 43 (2010)330-339.

[8] Alaneme, K. K., &Bodunrin, M. O. (2013). Mechanical behaviour of alumina reinforced AA6063 metal matrix composites developed by two step-stir casting process.

Acta TechnicaCorviniensis-bulletin of engineering, 6(3),105.

[9] Sreenivasan, A., Paul Vizhian, S., Shivakumar, N. D., Muniraju, M., &Raguraman, M. (2011). A study of microstructure and wear behaviour of TiB2/Al metal matrix composites. Latin American Journal of Solids and Structures, 8(1),1-8.

[10] Skolianos, Stefanos. "Mechanical behavior of cast SiC p-reinforced Al-4.5% Cu-1.5% Mg alloy." Materials Science and Engineering: A 210.1 (1996):76-82.

[11] Singh, D., Singh, H., Kumar, S., & Singh, G. (2012). An Experimental investigation of Mechanical behavior of Aluminum by adding SiC and Alumina. International Journal on Emerging Technologies,178-184.

[12] Liang, Y. H., Wang, H. Y., Yang, Y. F., Wang, Y. Y., & Jiang, Q. C. (2008). Evolution process of the synthesis of TiC in the Cu–Ti–C system. Journal of Alloys and Compounds, 452(2),298-303.

[13] Min, S. O. N. G. (2009). Effects of volume fraction of SiC particles on mechanical properties of SiC/Al composites. Transactions of Nonferrous Metals Society of China, 19(6),1400-1404.

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

[15] Aruri, D., Adepu, K., Adepu, K., &Bazavada, K. (2013). Wear and mechanical properties of 6061-T6 aluminum alloy surface hybrid composites [(SiC+ Gr) and (SiC+ Al 2 O 3)] fabricated by friction stir processing. journal of materials research and technology, 2(4), 362-369.

[16] Preparation of Aluminum Based Metal Matrix Composite by Thermal Spraying Gagandeep Singh and ManpreetKaur

[17] Aluminium metal matrix composites - a reviewB. VijayaRamnath, C. Elanchezhian, RM. Annamalai, S.Aravind, T. Sri AnandaAtreya, V. Vignesh and C.Subramanian

[18] Study on Machinability of Aluminium Silicon Carbide Metal Matrix Composites-RabindraBehera a, S.Kayal b, N.R. Mohanta c,G.Sutradhard

[19] Corrosion of Metal-Matrix Composites with Aluminium Alloy substrateb.Bobić,
s. Mitrović, m. Babić, i. Bobić

[20] Fabrication and characterisation of Al2O3/aluminium alloy 6061 composites fabricated by Stir casting -Bhaskar Chandra Kandpal,*Jatinderkumar,HariSingh.