TRIBOLOGICAL CHARACTERIZATION OF AL7075/$AL_2 0_3$/SIC REINFORCED HYBRID PARTICULATE METAL MATRIX COMPOSITE DEVELOPED BY STIR CASTING PROCESS

Raghavendra N[1] and V S Ramamurthy[2]

Department of Mechanical Engineering , B N M Institute of Technology, Bangalore.[1]
Department of Mechanical Engineering , Don Bosco Institute of Technology, Bangalore.[2]

ABSTRACT

In this work Hybrid Metal Matrix Composite have been developed using stir casting process for improving the Wear Behavior at lower cost. The silicon carbide (SiC) as one of the reinforcement used with 3% weight fraction and Alumina (Al_2O_3) as the major reinforcement in 3%,6%,9% &12% weight fraction. Al-7075 has been considered as the matrix material .The low cost stir casting process has been used for the development of the composite system. The matrix material was melted in electric furnace and the heat treated reinforcement in the desired weight fraction have been added followed by constant stirring the melt. The temperature of the melt held at 750°C. The pouring temperature was recorded which has relation to quality of the casting. The cast specimens have been obtained in the form of cylindrical rod of 20mm diameter and 200mm length for carrying out tribological tests. Microstructure analysis reveals the uniform distribution of reinforcements in the aluminum matrix. The density of the composite increases with the increase in weight fraction. The composite density found to lie in between the density range of matrix and the reinforcement. The pin on disc wear test has been carried on all the samples at various speeds of 300,600,900 and 1200 rpm, varying load of 1kg, 2kg, 3kg & 4kg and varying sliding distances of 1km, 2km, 3km & 4km. These test reveals that the wear resistance increases with the increase in the reinforcement weight fraction. The increase in the speed reduces the wear rate and wear rate increases in with increase in sliding distance. The wear rate and coefficient of the composite reduces for higher volume fraction. The addition of SiC apart from improving the wear rate reduces the noise and vibration at higher speed and load condition. The overall tribological property increases due to addition of the two reinforcement.

KEY WORDS

Hybrid composite, SiC, Al2O3, Stir casting, wear.

1. INTRODUCTION

Light weight, high strength and wear resistant material are the need for the automobile and aircraft industries. The regulations and norms related to environment impose less fuel consumption requirement in vehicles to reduce the pollution which ultimately requires light weight materials. The light weight alloys like aluminum, titanium, magnesium and copper can be used for automobile and aircraft parts. The alloy cannot be used alone due to its low strength and poor mechanical property. The ceramic materials are reinforced with the alloy for improved

DOI : 10.14810/ijmech.2015.4309

strength and wear resistance. The light weight metal alloy reinforced with hard ceramic material will improve the property of the material and at the same time light weight was retained.

The composite material have proven universally a saving of at least 20% of cost over metal counter parts. It has lower operational and maintaince cost. They are durable, resists fatigue loading, wear, dimensional integrity and easily maintainable and repairable. The cost of the composite depends on raw material cost and processing cost by 40% and 30%. By selecting the suitable process and reinforcement having low cost can reduce the final material cost. The stir casting process and the particulate form of reinforcement reduces the final material cost and suitable for mass production. The particulate composite fabricated by stir casting route will provide uniform distribution of the reinforcement. The stir casting process will be affected by stirring speed, melt temperature, pouring temperature, blade geometry and position of blade height. The melt temperature should be optimum to have the required viscosity thereby allowing the particles to be suspended in the matrix without sinking to bottom or floating at the top.The conventional ceramic material used in development of composite will not provide the desired property if used alone. The combination of oxides or borides or carbides of ceramics can effectively enhance the property. The graphite or MSO_2 used with the hard ceramics improves the lubricating effect of the composite. The ceramics used are soft and hard nature, the hard ceramics increases the wear resistance and strength where as the soft ceramics increases the lubrication effect, reduces the noise and vibration etc. The SiC ceramic reduces the noise and reduces the thermal expansion coefficient. It also conducts heat three times more effectively. These requirements of ceramics are used in developing the hybrid metal matrix composites.

The Al -7075 alloy has been selected as the matrix material due to its high strength and light weight property. It is also having good heat treatable and age hardenable response compared to 6061 and 2024 series alloys. The secondary process such as age hardening , solutionising and precipitation hardening can be carried out on this type of composite materials which further enhances the wear resistance and strength.Tribological characterization of the composite will be carried out to study the variation of the wear rate and its coefficient of friction. The wear is progressive loss of the material which alters the dimension and reduces the strength of the component. The coefficient of friction influences the noise, surface finish and vibration of the interacting parts. The automobile parts like disc brake, cylinder liner, piston and drive shaft are the some of the parts which experiences Sevier wear during its functioning. The high wear resistant materials like steel, cast iron or metal matrix composite to be used for such parts.

The composite material with proper weight fraction of the reinforcement, size, shape, coating and orientation will develop essential property. The Wettability of the melt, interface bond strength also influences the property. The microstructure of the composite was considered as the general parameter controlling the wear but with the availability of large variation in the materials, ceramics and composite materials the wear of material rather than system property it is of material characteristics. Over 300 equations for wear and friction can be found and these empirical equations are used for wear before 1970 .The contact mechanics based equations are used in 1970 to 1980.The wear map developed for the estimation of the wear of material over the range of parameter. The wear can also be evaluated on the basis of strength and hardness of the material. Considering all the above methods for determination of wear the experimental method of estimation of wear will be universally accepted and the established standards are included in ASTM. In this wok the essential parameter influencing the wear and friction behavior of material such as weight fraction, speed, load and sliding distance was evaluated for the developed hybrid metal matrix composites.

2. EXPERIMENT

Many interdependent variables has to be considered in design and development of the composite material. The performance of the composite material depends on the matrix and reinforcement hence careful selection of these materials is based on literature and the research data. The chemical compatibility of the reinforcement with matrix material has to be considered in designing the composite system. The excessive reaction of the reinforcement with the matrix will yield poor mechanical property. The composition and properties of the Al-7075 matrix is as shown in table 1.

Table 1. Composition and Properties of AL-7075

Element	Si	Fe	Mn	Mg	Cu	Zn	Ti	Cr	Al
Weight %	0.4	0.5	0.3	2.9	2	6.1	0.2	0.28	87.32

Mechanical properties	
Hardness –Brinell	150
Ultimate tensile strength	572MPa
Tensile yield strength	503MPa
Elongation at beak	11%
Modulus of Elasticity	71.7GPa
Poisson’s ratio	0.33
Fatigue strength	**159MPa**
Machinability	70%
Shear modulus	26.9GPa
Shear strength	331Mpa

The aluminum alloy Al-7075 has been selected as the matrix material is more compatible with the reinforcement and has good mechanical property and castability at the alloy level itself. The application of the alloy in automobile and aircraft application itself indicated that it is the proper selection. The material is also having good response to age hardening , heat treatment process and precipitation hardening.The reinforcement selected as alumina (Al_2O_3) in the form of particle size 50 micron to 150 micron. It is more stable with aluminum and withstands high temperature. It is an oxide ceramic having low affinity for the oxygen to form oxides. The particulate form of the reinforcement has better distribution in the matrix to provide isotropic property for the composite. The properties of the alumina is as shown in table 2. The Silicon carbide has been selected as the next ceramic which is a carbide type of ceramic. The SiC has good lubricating effect along with it reduces the noise and vibration during the relative motion. The properties of silicon carbide is shown in table 3.

Table 2. Properties of Alumina (Al_2O_3) Reinforcement

Property	values
Melting Point°C	2072
Hardness(kg/mm2)	1175
Density(g/cm3)	3.69
Coefficient of thermal expansion(micron/m °C)	8.1
Fracture Toughness	3.5
Poission's ratio	0.21
Colour	White

Table 3. Properties of Silicon Carbide (SiC) Reinforcement

Property	values
Melting Point °C	2200-2700
Hardness(kg/mm2)	2800
Density(g/cm3)	3.1
Coefficient of thermal expansion(micron/m °C)	4.0
Fracture Toughness	4.6
Poisson's ratio	0.14
Colour	Black

The matrix material Al-7075 obtained in the form of square rod of 20mm X 20mm and length 100mm.The bars are cleaned to remove the impurity, dust and oil and heated in graphite crucible in electric furnace. The quantity of alumina and the reinforcement are shown in table 4.The melting temperature was held at 750°C and the reinforcement heated separately at 450°C being added to the melt. The constant stirring of the melt carried out with alumina stirrer to get uniform distribution of the ceramic particles. The stirring was carried out for 10 minutes and the melt was poured in to sand mold. The stir casting process is shown in fig 1

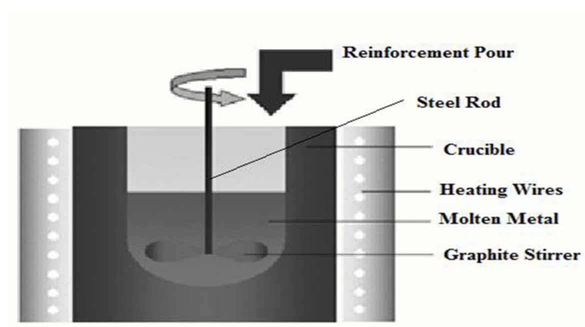

Figure 1. Stir casting process Set up

The composition percentage chosen is based on the literature and most common percentage used in most of the literature was selected and is given below. The SiC weight fraction is kept constant at 3% and the Alumina percentage is varied in steps of 3% till 12% of Alumina. The weight percentage is based on the weight of the reinforcements in relation to the matrix material.

Table 4. Specimen Composition for varying weight fraction.

Specimen Code	AL -7075	Al2O3	SiC
D	94% (940 gms)	3% (30 gms)	3%(30 gms)
E	91%(910 gms)	6%(60 gms)	3%(30 gms)
F	88%(880 gms)	9%(90 gms)	3%(30 gms)
C	85%(850 gms)	12%(120 gms)	3%(30 gms)

3. RESULTS AND DISCUSSION

The castings of circular cross section of 20mm diameter and 200mm length has been casted. The specimens were machined to reduce the diameter to 16 mm and length to 30 mm for microstructure characterization and hardness test. The specimen in the form of pin of diameter 12mm and length 25mm have been machined for wear and friction test. Microstructure analysis has been carried out as per ASTM E407 standards. The Specimens were grinded and polished with 300, 600, 900, 1000 and 1200 grit emery paper followed by polishing with diamond paste in polishing machine. The keller's etchant has been used for etching .The optical micrograph has been obtained at 100x and 50X.The optical micrographs are as shown in fig 2.

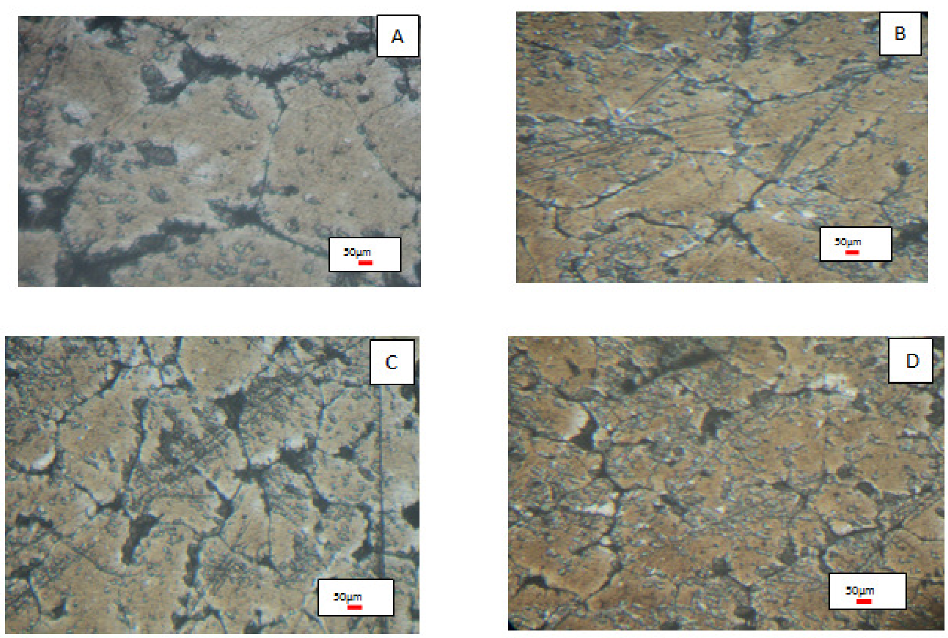

Figure 2. Optical micrograph of Hybrid composite at various weight fractions of reinforcement
a) Al7075 +3%Al_2O_3+3% SiC b) Al7075 + 6%Al_2O_3+3% SiC , c) Al7075 + 9%Al_2O_3+3% SiC , d) Al7075 +12%Al_2O_3+3% SiC

The density of the component was determined experimentally and theoretically by ruler of mixture .The micro hardness test carried out as per standards on Clumex digital micro hardness tester at CMTI, Bangalore. The precision diamond indentor with a load of 300gms was used to find the micro hardness. The image of the impression was grabbed on the CCD camera and the values are as shown in fig 3 with varying weight fraction.

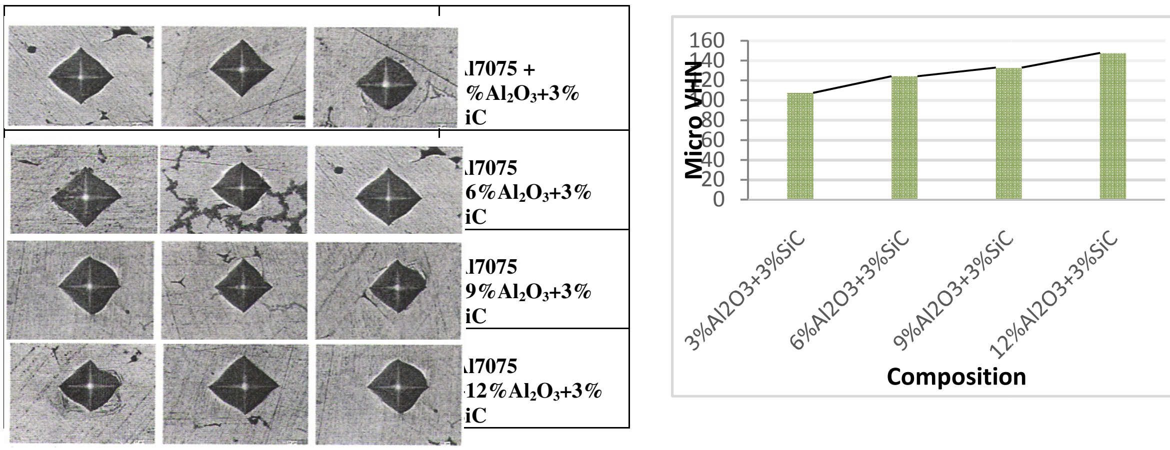

Figure 3.Indentation and Vickers micro hardness values

Wear test carried out on ‘wear and friction monitor TR-20 supplied by DUCOM, Bangalore. Rotating disc against the loaded pin was used to determine the wear loss of the material at various conditions. The wear simulations confirms to ASTM G99 standards. Tests are conducted in dry conditions and with rotating motion. The test parameter includes load, speed, temperature, roughness, shape and wear track etc. The variation of coefficient friction also noted during the wear test which will be influenced due to addition of the SiC. The wear and friction monitor is shown in fig 4.

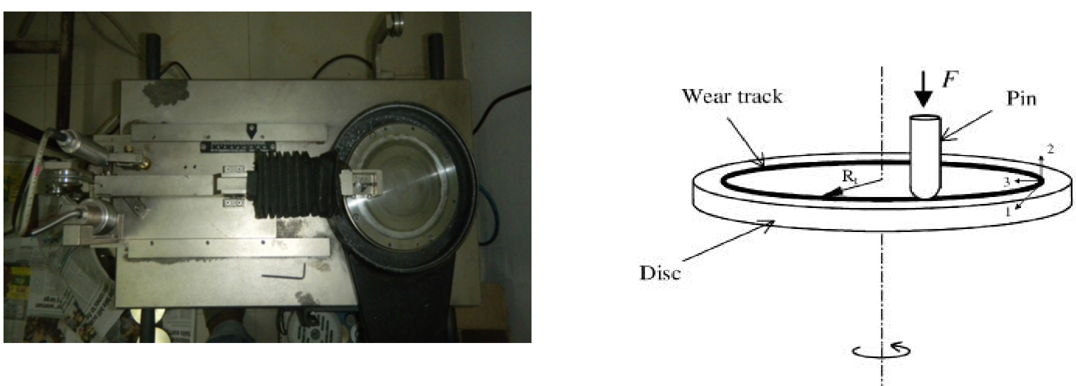

Figure 4 Wear and Friction Monitor and Pin on Disc geometry

The disc material includes EN32 Steel , hardened to 60HRc and roughness was 1.6Ra. The wear track diameter of 120mm was selected .The surface of the specimen used are flat and cleaned after each test. The wear test was carried out in three phases on all the four types of specimen having the varying weight percentage. The first phase involves the variation of load on the pin as 1kg, 2kg, 3kg and 4kg. The wear in micron and the average friction force were noted. In the second phase the speed of the disc were varied from 300, 600, 900, 1200 rpm. The corresponding wear and friction fore ware noted. In the third phase the sliding distance was varied as 1km, 2km, 3km and 4km.

The wear rate was estimated by Δv/w s, the change in volume is estimated by knowing the wear length in micron The coefficient of friction plot was obtained from winducom software. The variation of the speed load and sliding distance vs wear rate with respect to weight fraction are as shown in fig 5, 6, & 7.

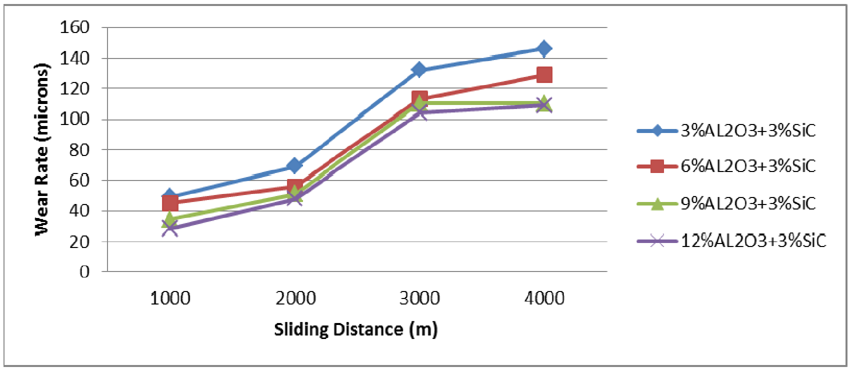

Figure 5.The variation of the sliding distance Vs wear with respect to weight fraction

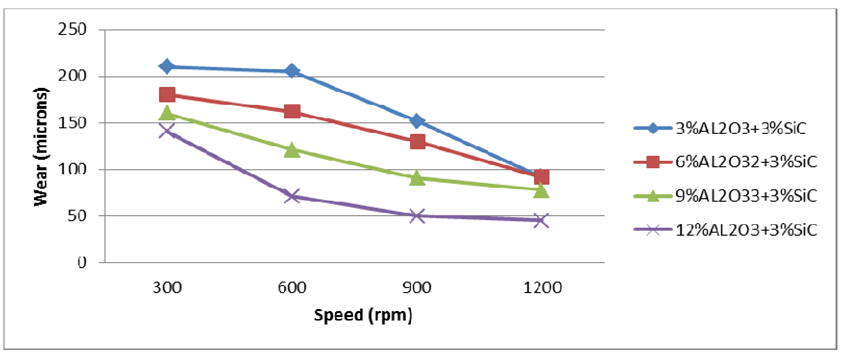

Figure 6.The variation of the speed vs wear with respect to weight fraction

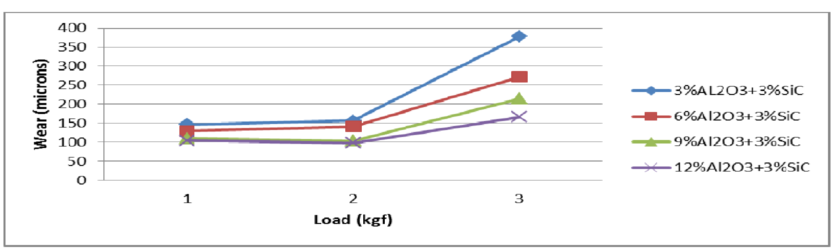

Figure 7.The variation of the load vs wear with respect to weight fraction

The wear length of the specimen in micron as recorded by the software with time is shown in fig8 for varying speed, load, weight fraction and sliding distance .

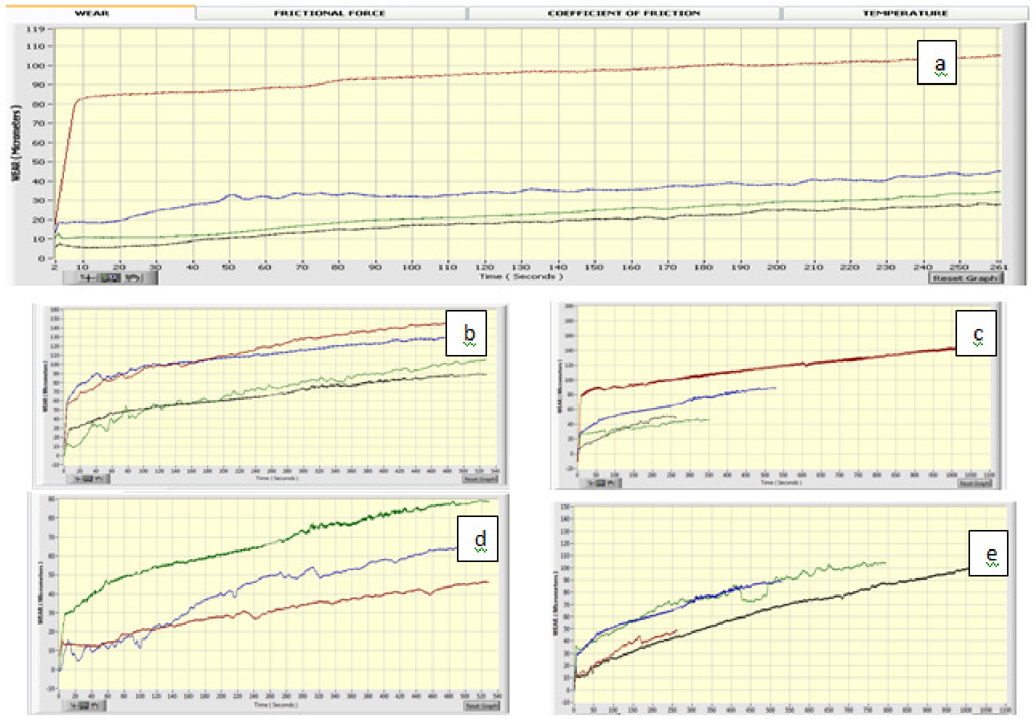

Figure 8. The variation of the linear wear as of specimen as recorded by winducom software . **a)**The linear wear at Sliding Distance 2000m, Speed 600rpm, Track diameter 120mm , Load 2kgf for the samples of pure Al7075, 3%Al2O3+3%SiC, 6%Al2O3+3%SiC, 9%Al2O3+3%SiC **b)**Sliding Distance 2000m, Speed 600rpm, Track diameter 120mm, Load 4 kgf for the samples D (3%AL_2O_3), E(6%AL_2O_3), F(9%AL_2O_3), G(12%AL_2O_3) **.c)** Speed variation, Load 2kgf, Sliding Distance 2000m, Track Diameter 120mm, and for the Sample G (12% AL2O3 + 3% SiC).**d**)Load Variation (kgf), Speed 600rpm, and Sliding Distance 2000m, Track Diameter for G (12%Al_2O_3+3%SiC). **e)** Sliding Distance Variation (m), Speed 600rpm, and Load 2kgf, Track Diameter 120mm, for the sample G (12% AL_2O_3).

The coefficient of friction recorded by the device are shown in fig 9,10 & 11.The consolidated parameter of all the test conducted on the specimen is given in table 6.

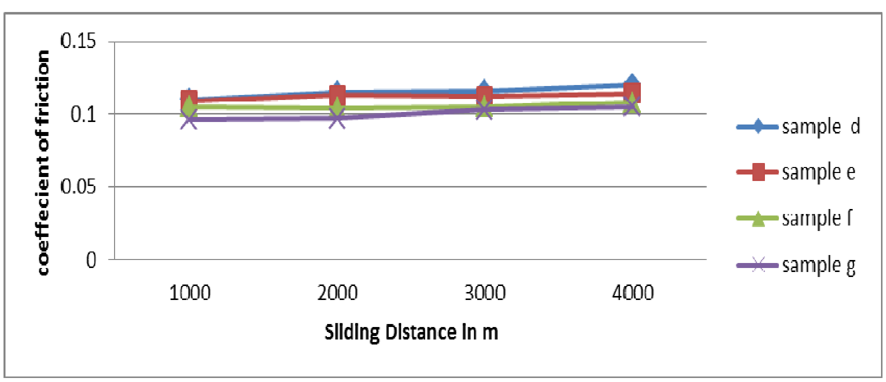

Figure 9.The variation of the coefficient of friction vs Sliding Distance Variation of 1000m,2000m,3000m& 4000m, Speed 600rpm, Load 2kgf, and Track Diameter 120mm.

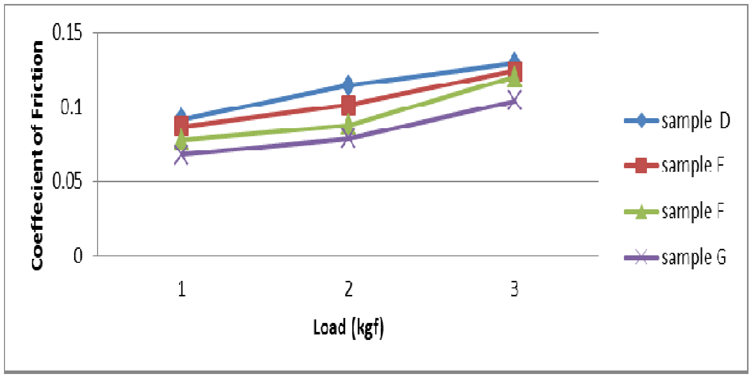

Figure 10.The variation of the coefficient of friction vs load of 1kg, 2kg, 3kg & 4kg for varying weight fractions , Sliding Distance 2000m, Speed 600rpm, and Track Diameter 120mm.

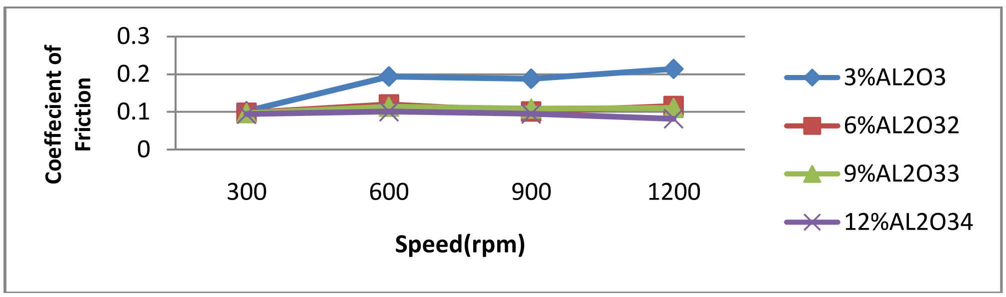

Figure 11. The variation of the coefficient of friction vs speed of 300rpm, 600rpm, 900 rpm & 1200rpm for varying weight fractions , Sliding Distance 2000m, load 2kg and Track Diameter 120mm.

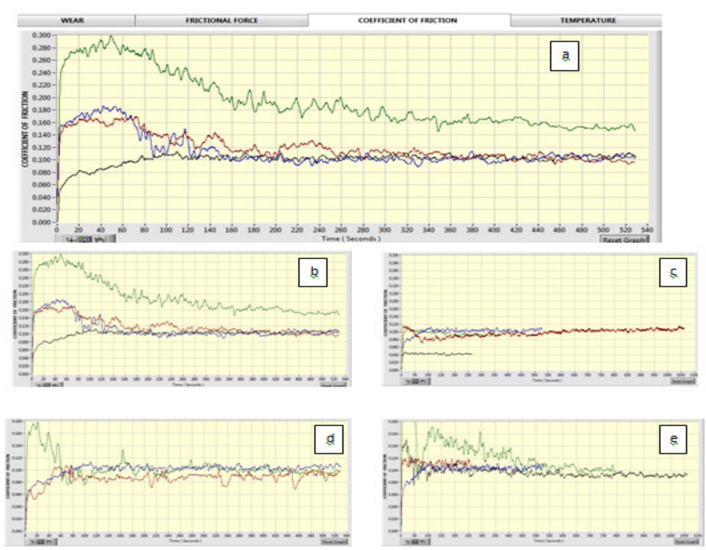

Figure 12 The variation of the coefficient of friction as of specimen as recorded by winducom software . **a)** The coefficient of friction at Sliding Distance 2000m, Speed 600rpm, Track diameter 120mm , Load 2kgf

for the samples of pure Al7075,3%Al2O3+3%SiC ,6%Al2O3+3%SiC , 9%Al2O3+3%SiC **b)**Sliding Distance 2000m, Speed 600rpm, Track diameter 120mm,Load 4kgf for the samples D (3%AL_2O_3),E(6%AL_2O_3),F(9%AL_2O_3),G(12%AL_2O_3). **c)** Speed variation, Load 2kgf, Sliding Distance 2000m, Track Diameter 120mm, and for the Sample G (12% AL2O3 + 3% SiC). **d)** Load Variation (kgf), Speed 600rpm, and Sliding Distance 2000m, Track Diameter for G (12%Al_2O_3+3%SiC). e) Sliding Distance Variation (m), Speed 600rpm, and Load 2kgf, Track Diameter 120mm, for the sample G (12% AL_2O_3).

The values of the mechanical and tribological parameter obtained from the various test carried out on all the casted specimens are presented in the form of table and graph so as to compare the weight fractions of the reinforced particles and its effect on the behavior of the composite. Similar to linear the Coefficient of friction plots are obtained from Ducom Software at various loads and speeds are shown in fig 12.

Wear Track Analysis was carried out by determining the optical micrograph and SEM on the wear test specimens. The fig 13& fig 14 indicates the wear track of specimens for varying weight fractions of reinforcements.

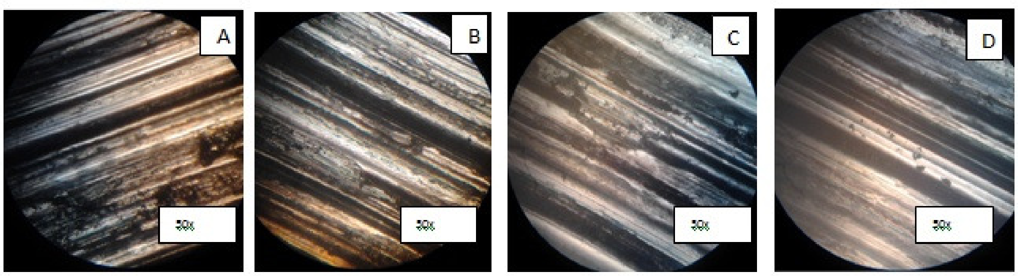

Fig 13 optical micrograph indicating the magnitude of delamination wear on the wear test specimens at a) Al7075 + 3%Al_2O_3+3% SiC b) Al7075 + 6%Al_2O_3+3% SiC , c) Al7075 + 9%Al_2O_3+3% SiC , d) Al7075 + 12%Al_2O_3+3% SiC

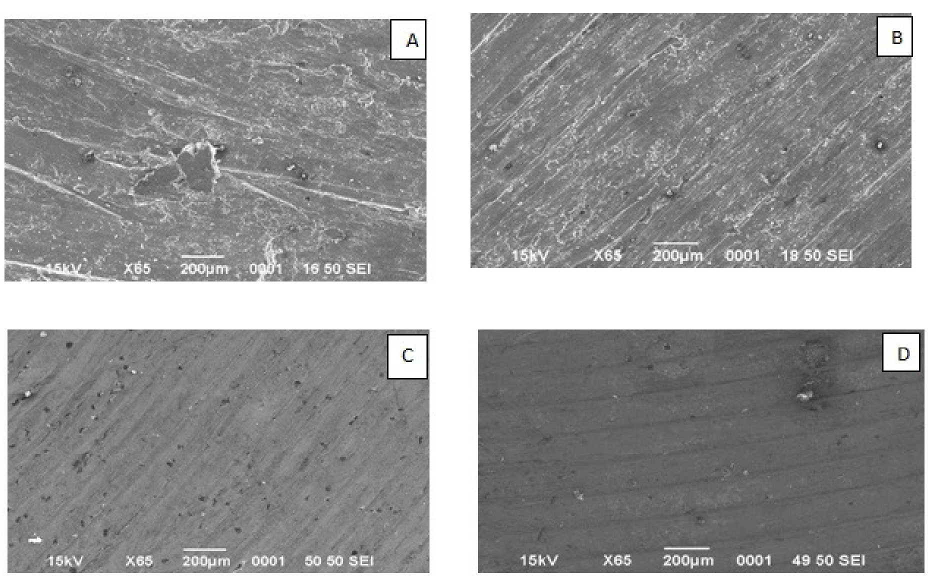

Fig 14 SEM indicating the magnitude of delamination wear on the wear test specimens at a) Al7075 + 3%Al_2O_3+3% SiC b) Al7075 + 6%Al_2O_3+3% SiC , c) Al7075 + 9%Al_2O_3+3% SiC , d) Al7075 + 12%Al_2O_3+3% SiC

Table 5 shows the various parameters of the test and fig 15 represents the data in the form of graph. By comparing the values it can be easily evaluated that the superiority of the reinforcement in the enhancement of the property. Also the advantage of reinforcing the two or more reinforcement in the matrix for multi level enhancement of property by each reinforcement.

Table 5. Consolidate Test results for varying weight fractions of reinforcement

Specimen code and weight fraction.	**Density Kg/m^3**	**Micro Hardness HV 300gmf/13 sec**	**Wear micron**	**Wear Rate $10^{-4}mm^3/N\ m$**	**Coefficients of friction**
Al7075 + 3%Al_2O_3+3% SiC	**2725**	107.58	152	3.629	0.0968
Al7075 + 6%Al_2O_3+3% SiC	**2730**	124.16	136	2.581	0.185
Al7075 + 9%Al_2O_3+3% SiC	**2745**	132.69	91	2.192	0.2076
Al7075 + 12%Al_2O_3+3% SiC	**2752**	147.51	71	1.269	0.3076

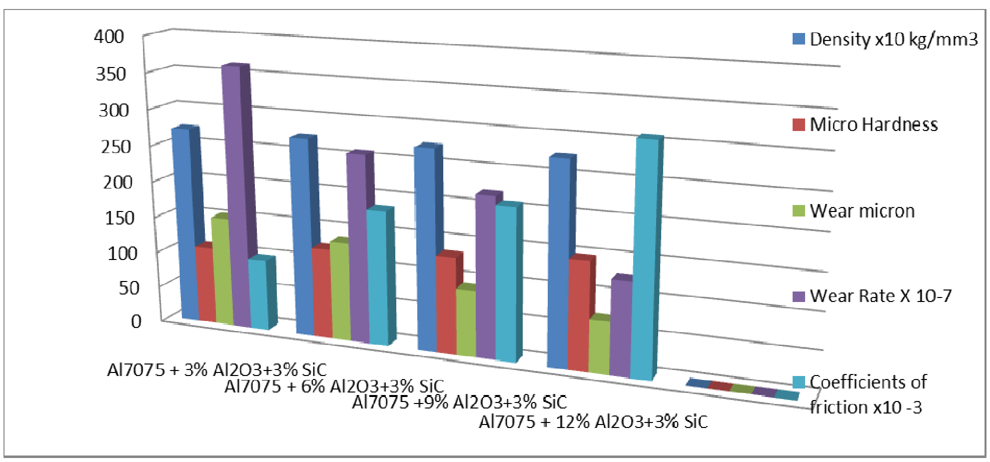

Fig 15 Consolidated test results for varying weight fraction of the composite materials with micro hardness, linear wear , wear rate , coefficient of friction

The hybrid metal matrix composite was developed using stir casting furnace satisfactorily .The distribution of the particles are uniform without any interface reaction. The particle dispersion in the melt was achieved through stirring and maintain the melting temperature at 750°C.

The density of the composite measured experimentally shows that 3% to 4% variation as compared to theoretical density. The density increases as the weight fraction increases. The density of the developed composite found to be less than the density of the conventional material like steel and cast iron. The porosity found to reduced to 3% due to sand casting.

The micro hardness values indicates that addition of reinforcement increases the hardness of the composite. This is due to more amount of ceramic particles in the vicinity of the indentation resists the deformation and induces hardness due to strong interface bonding.

Optical micrograph of unreinforced and reinforced composite shown in fig 1 indicates the presence of Al_2O_3 and SiC ceramic particles in the matrix. The amount of particles increases with increase in weight fraction. This gives the indication of the ceramic particles and their distribution in the composite.

The wear rate reduces with increase in speed , improved wear resistance of Al7075 / $Al_2O_{3/}$ SiC was observed at high speed. The transition from severe wear to mild wear was noticed as the speed varies from low to high value. The wear rate found to be inversely proportional to speed. With increase in speed the hardness increases and lower wear rate. Also at higher speed the temperature increases which will soften the material hence lower wear.

Wear rate was found to increase with increase in sliding distance and the highest percentage reinforcement of the composite possess the lowest wear rate at all sliding distance. The interfacial strength and the shape of the particulate will enhance the wear resistance at higher sliding distance. The improvement of the wear resistance is due to welding of the ferrous particle from the counter body at high sliding speed.

The wear rate increases with increase in load on the pin, this behavior is due to wear of the ceramic particle s at higher load or due to the fracture of the particles. The surface was covered with the transferred material layer which increases the wear. The detachment of the particles from the matrix was noticed at higher load and results in the increase in contact area of matrix and the disc which further increases the wear.

Tribological study involves the coefficient of friction and its effect of the wear of the material. It is essential to monitor the variation of the coefficient of friction along with the wear for a given speed, load and duration of experiment. The coefficient of friction was observed to be lower due to addition of SiC in the matrix . The coefficient of friction reduces for the composite with highest weight fraction. The reduction in the coefficient of friction is related to noise and vibration of during the test. It was noticed that considerable amount of noise level found to reduce for all the specimens as the SiC content in the matrix found responsible for this behavior. The graphite in the silicon carbide induces the lubrication effect for the composite.

4. CONCLUSION

- By stir casting process the hybrid metal matrix composite can be developed effectively.
- The porosity can be reduced by constant stirring ,maintaining the optimum melt temperature and using sand mold.
- Uniform distribution of the particulate and isotropic property of the composite can be obtained my melt temperature of 750°C and stirring by the alumina stirrer until pouring the melt.
- The density of the composite material is half of the conventional material and it increases with addition of ceramic material.

- Wear rate found to increase with increase in load and sliding distance . Amount of wear reduces at higher speed than at lower speed of the disc.
- The weight fraction of the composite influences the wear resistance as the weight fraction increases the wear reduces.
- The addition of SiC as secondary ceramic reduces the coefficient of friction there by reduction in the noise and vibration during the motion.
- The addition of SiC also influences the reduction in noise and vibration due to reduction in friction force.

REFERENCES

[1] R.L Deuis,C Subramanian , J M Yellup." Dry sliding wear of aluminum composites – A review ",Elsevier ,Composite society and Technology,57(1997),415-435.

[2] Koji kato "Wear in relation to friction – A review", Elsevier,Wear,241(2000),151- 157.

[3] S Naher, DBrabazon, Looney " Simulation of Stir casting process", Elsevier,Journal of material Processing technology,143-144(2003),567-571.

[4] K Gawdzinska, J Hajkowaski, BGlowcki ,"Impact of cooling rate on structure and tribological properties of Metal matrix Composites ",Proceedings of 18th international offshore and polar engineering conference', Canada, July 6-11-2008.

[5] S A Sajjadi,H R Ezatpour, H Beygi," Microstructure and mechanical properties of AL –Al2O3micro and nano composites fabricated by stir composites , Elsevier Material Science and Engineering A,528(2011),8765-8771.

[6] M Kok."Production and Mechanical properties of Al2O3 particle –reinforced 2024 aluminum alloy composites", Elsevier ,journal of material processing technology,16192005,381-387.

[7] L.J. Yang, "Wear coefficient equation foe aluminum –based matrix composites against steel disc",Elsevier , Wear,255(2003),579-592.

[8] Aluminum and Aluminum alloy, ASM International, Edited by J R Davis, Davis& Associates,1993.

[9] Florin Stefeneseu, GigelNeagu, AlexandriaMihai," Practical aspect concerning the solidification of cast metallic composites", U P D science Bulletein, series B ,vol 69,No -4,2007

[10] Shao.YunFu, Xi-QiaoFeng ,Bernd Lauke, Yia –wing Mai," Effect of Particle size ,Particle/Matrix Interface adhesion and particle loading on Mechanical properties of particulate polymer composites.',Composites,part-B-39,2008,933-961.

[11] A Al Qutqb,IAllam .A Al Ahmed and A S Elaiche," Elevated temperature wear of submicron Al2O3 reinforced with 6061 Aluminum composites, Advanced material search , vol 83-86,2010,p1288-1296.

[12] El-kaddah N E and Chang K E , "The Dispersion o f SiC-Al Slurries m Rotating Flows, Materials Science & Engineering A Structural Materials Properties, Microstructure and Processing", A144, Oct 1 1991, p 221-227

[13] C K Fang " Effect of aging time on wear resistance of alumina particulate reinforced MMCs ",Bulletin ,CIM ICM,china.2003.

[14] Namai T , Osawa Y and Kikuchi M , IMONO, "Journal of Japan Foundryman's Society", 56, 1984, pp 604-609

[15] Lignon R , "Research Aerospace", 1,1974, p 49

[16] S SRizam et al , " Effect of particle coating on Matrix –reinforcement Bonding", ICoSM ,2007,Malaysia.

[17] ZhiQia YU ,et al ," Microstructure and Tensile Properties of Yttria coated –Alumina particulates reinforced Aluminum matrix composites.

[18] S.A. Sajjadi, H.R. Ezatpour, H. Beygi "Microstructure and mechanical properties of Al–Al2O3 micro and nano composites fabricated by stir casting, Materials Science and Engineering A 528 (2011) 8765– 8771

[19] H. R. EZATPOUR1, M. TORABI-PARIZI2, S. A. SAJJADI , "Microstructure and mechanical properties of extruded Al/Al2O3 composites fabricated by stir-casting process", Trans. Nonferrous Met. Soc. China 23(2013) 1262−1268

[20] Ibrahim I A , Mohamad F A and Lavemia E J , "Particulate Reinforced Metal Matrix Composites - A Review, Journal of Materials Science", 1991, pp. 1137-1156

[21] A. Włodarczyk-Fligier, L.A. Dobrzański*, M. Kremzer, M. Adamiak, " Manufacturing of aluminium matrix composite materials reinforced by Al2O3 particles", Journal of Achievements in Materials and Manufacturing Engineering, Volume 27 Issue 1 March 2008

[22] L.J. Yang, "The effect of nominal specimen contact area on the wear coefficient of A6061 aluminium matrix composite reinforced with alumina particles" , Wear 263 (2007) 939–948

[23] Krzysztof Naplocha,Jacek W. Kaczmar , "Wear Behavior of Fiber-Reinforced Aluminum Alloy Composites" ,ADVANCED MATERIALS & PROCESSES • MARCH 2012

[24] Necat Altinkok," Use Of Artificial Neural Network For Prediction Of Mechanical Properties Of A-Al2o3 Particulate-Reinforced Al–Si10mg Alloy Composites Prepared By Using Stir Casting Process" , Journal Of Composite Materials, Vol. 40, No. 9/2006

[25] S.B. Venkata Siva, K.L. Sahoo, R.I. Ganguly, and R.R. Dash, "Effect of Hot Working on Structure and Tribological Properties of Aluminium Reinforced with Aluminium Oxide Particulates", ASM International, JMEPEG (2012) 21:1226–1231

[26] Khairel Rafezi Ahmad1*, Shamsul Baharin Jamaludin2, LuayBakir Hussain3, &Zainal Arifin Ahmad ," The Influence Of Alumina Particle Size On Sintered Density And Hardness Of Discontinuous Reinforced Aluminum Metal Matrix Composite" ,JurnalTeknologi, 42(A) Jun. 2005: 49–57.

[27] Katyrzyna Gawdzinska," Influence of cooling time on structure and tribological properties of MMC castings"

[28] Z. F. ZHANG, L. C. ZHANG*, Y.-W. MAI," Particle effects on friction and wear of aluminium matrix composites ",Journal of Materials Science 30 (1995) 5999-6004.

[29] Marcia M. Maru, Deniol K. Tanaka, "Influence of Loading, Contamination and Additive on the Wear of a Metallic Pair under Rotating and Reciprocating Lubricated Sliding" , Journal of the Braz. Soc. of Mech. Sci. & Eng. Copyright Ó 2006 by ABCM July-September 2006, Vol. XXVIII, No. 3 / 285

[30] L.A. Dobrzański, M. Kremzer, M. Adamiak, "The influence of reinforcement shape on wear behavior of aluminum matrix composite materials, Journal of Achievements in Materials and Manufacturing Engineering" 42/1-2 (2010) 26-32.

[31] Shao-Yun Fu a,*, Xi-QiaoFeng b, Bernd Lauke c, Yiu-Wing Mai d,"Effects of particle size, particle/matrix interface adhesion and particle loading on mechanical properties of particulate–polymer composites", Elsevier -composites, Composites: Part B 39 (2008) 933–961

[32] Hua-Tzu Fan',S. M. Wu," Case Studies on Modeling Manufacturing Processes Using Artificial Neural Networks", Transactions of the ASME, 412 / Vol. 117, AUGUST 1995.

[33] H. K. D. H. Bhadeshia," Neural Networks in Materials Science", ISIJ International, 1999.

[34] Rasit Kokera, Necat Altinkok b, Adem Demir b,"Neural network based prediction of mechanical properties of particulate reinforced metal matrix composites using various training algorithms" ,Materials and Design 28 (2007) 616–627.

[35] Mohammed Hayajneh∗, Adel Mahamood Hassan, Abdalla Alrashdan, Ahmad Turki Mayyas,"Prediction of tribological behavior of aluminum–copper based composite using artificial neural network", Journal of Alloys and Compounds 470 (2009) 584–588.

[36] Z. Zhang a,∗, K. Friedrich a, K. Veltenb," Prediction on tribological properties of short fibre composites using artificial neural networks", Wear 252 (2002) 668–675.

[37] W. Sha, Comment on "Modeling of tribological properties of alumina fiber reinforced zinc–aluminum composites using artificial neural network by K. Genel et al. [Mater. Sci. Eng. A 363 (2003) 203]" ,Materials Science and Engineering A 372 (2004) 334–335.

[38] Vivek Babu, Rajmohan, P A Abdul Samad , " Hardness Evaluation of LM6/Gr PMMC Prepared by Stir casting Method, International Journal of Emerging Technology and Advances Engineering, ISSN 2250-2459,Vol 3,Issue 7, July 2013.

[39] Z Zhou, ZFan,H X Peng,D X Li ,” High resolution electron microscope observation of interface microstructure of as cast Al-Mg-Si-Bi-Pb(6262)/Al2O3p composite, Journal of Microscopy ,vol 201,144-152,2001.

AUTHORS

Raghavendra.N working as associate professor at BNMIT, Bangalore. Having 16 years of Experience in academics. Currently carrying out research on Development and Tribology studies on PMMC for automobile applications.

Dr V.S. Ramamurthy is a Professor & HOD at Don Bosco I T, Bangalore, having 30 years of Academic experience in various capacity. Working on thermal analysis & of Chill casting of PMMC. Presently guiding 5 Ph D.