Vol. 39, No. 2 (2017) 145-151, DOI: 10.24874/ti.2017.39.02.01

Tribology in Industry

www.tribology.fink.rs

RESEARCH

Studies on Mechanical Behaviour of Aluminium/Nickel Coated Silicon Carbide Reinforced Functionally Graded Composite

A. Mohandas[a], N. Radhika[a]

[a] *Department of Mechanical Engineering, Amrita School of Engineering, Coimbatore , Amrita Vishwa Vidhyapeetham, Amrita University, India. Pincode- 641 112.*

Keywords:

Liquid metallurgy
Electroless nickel coating
Scanning Electron Microscope
Centrifugal casting
Microstructure
Hardness

Corresponding author:

N. Radhika,
Department of Mechanical Engineering, Amrita School of Engineering, Coimbatore ,
Amrita Vishwa Vidhyapeetham,
Amrita University,
India.
Pincode-641 112.
E-mail: n_radhika1@cb.amrita.edu

A B S T R A C T

The aim of the work is to fabricate functionally graded aluminium (Al-Si6Cu)/ nickel coated SiC metal matrix composite using centrifugal casting route. SiC particles (53-80 µm) were coated with nickel using electroless coating technique to enhance the wettability with aluminium matrix. Several attempts were made to coat nickel on SiC by varying the process temperature (65 °C, 75 °C, and 85 °C) to obtain a uniform coating. Silicon particles coated with nickel were characterised using EDS enabled Field Emission Scanning Electron Microscope and it was found that the maximum nickel coating on SiC occurred at a process temperature of 75°C. This nickel coated SiC particles were used as the reinforcement for the manufacture of functionally graded metal matrix composite and a cast specimen of dimensions 150×90×15 mm was obtained. To ensure the graded properties in the fabricated composites, microstructure (at a distance of 1, 7 and 14 mm) and hardness (at a distance of 1, 3, 7, 10 and 14 mm) from outer periphery taken in the radial direction was analysed using Zeiss Axiovert metallurgical microscope and Vickers micro hardness tester respectively. The microstructure reveals presence of more SiC particles at the outer periphery compared to inner periphery and the hardness test shows that the hardness also decreased from outer periphery (90 HV) to inner periphery (78 HV).Tensile strength of specimen from outer zone (1-7mm) and inner zone (8-14 mm) of casting was also tested and found out a value of 153.3 Mpa and 123.3 Mpa for the outer zone and inner zone respectively. An important observation made was that the outer periphery of casting was particle rich and the inner periphery was particle deficient because of centrifugal force and variation in density between aluminium matrix and reinforcement. Functionally graded Al/SiC metal matrix composite could be extensively used in automotive industry especially in the manufacture of liners and brake drums.

1. INTRODUCTION

Composite materials are a type of advanced materials constituting one or more insoluble micro or macro constituents which differ in their physical or chemical composition [1]. Composite materials show material properties that could not be met by the conventional materials and are utilized where materials with unconventional blends of properties such as high strength, modulus, wear resistance, elongation, corrosion resistance and low density are required [2-4]. Metal matrix composites (MMCs) are materials with a base metal and reinforcement, most commonly ceramics fabricated for attaining noticeable qualities like high specific modulus, hardness and wear resistance in its applications. Corrosion behaviour of titanium diboride reinforced cast and forged aluminium 6061 alloy was studied and relatively higher corrosion resistance was observed for composite fabricated with forged alloy than the cast one [5].

Wettability refers to the interaction between fluid and solid phases. In MMCs, the interaction between molten aluminium matrix and reinforcement was determined by wettability [6]. Coating techniques improve the interfacial interaction between matrix and reinforcement instead of matrix-matrix interaction. Proper coating over reinforcement could improve the wettability, protect the reinforcement from damage, improves distribution capacity of particles in aluminium matrix, and prevents interfacial reaction between reinforcement and matrix alloy [7,8].

A functionally graded metal matrix composite (FGMMC) is characterized as a composite in which the reinforcement molecule's volume division fluctuates constantly from inward to the external areas of the part, accordingly its properties shift from internal to external region [9]. Among various methods for fabrication of FGMMC such as chemical vapour deposition, physical vapour deposition, sol-gel technique, plasma spraying, molten metal infiltration, centrifugal casting etc, the one which adopt solidification method was preferred because of its economic and ability to fabricate large castings [10,11]. Creation of functionally graded materials utilizing centrifugal casting was a viable strategy. The principle point of interest of centrifugal casting was appropriate mold filling ability joined with greater control over its microstructure. The materials could be designed for specific function and applications as wear resistant lining for handling large heavy abrasive ore particles, rocket heat shields, heat exchanger tubes, thermoelectric generators, heat engine components etc.

During the study of mechanical characteristics of functionally graded aluminium diboride (AlB_2) reinforced Al-4%Mg composite, it was identified that with the increase in the reinforcement phase in external zones, increase in the hardness up to 20 % has been achieved. During the microstructure analysis it was found out that more number of AlB_2 reinforcement particles were embedded in the outer zone of the aluminium matrix, whereas, there was considerably lesser number of AlB_2 particles within the Al-Mg matrix at the internal zone [12]. Since the reinforcement particles volume varies from inner periphery to outer periphery, its mechanical properties also vary accordingly [13,14]. Wear characteristics of fabricated LM13/boron carbide MMCs was determined by varying percentage of reinforcement, load applied, sliding velocity and distance. From results it was inferred that load was a highly influential parameter followed by weight percentage of reinforcement, velocity and sliding distance [15]. The influence of parameters such as, applied load, sliding velocity and temperature on the wear rate of fabricated AlSi10Mg alloy with 3wt% of graphite and 9wt% of alumina was studied. It was found out that load was more influential parameter followed by temperature and sliding velocity [16].

The important aspect noted from the literature survey was that the influence of coating on the mechanical properties of a composite was not clearly understood. Hence in this study, an attempt has been made to identify the temperature at which maximum nickel coating over silicon carbide (SiC) particle was obtained and the mechanical properties of nickel coated SiC reinforced functionally graded metal matrix composite were studied.

2. MATERIAL SELECTION

In the present investigation, Al-Si6Cu alloy was chosen as the base metal matrix as it is suitable for applications like crank cases of diesel engines, clutch cases and gear boxes. The reinforcement chosen was SiC (10wt%) with an average size of 53-80 microns. The SiC particles have very high abrasive property and addition of SiC to aluminium matrix can increase the hardness further. The density of the aluminium alloy and reinforcement were 2.81 gm/cm^3 and 3.21 gm/cm^3 respectively. The constituent element of alloy is shown in Table 1.

Table 1. Constituent elements of alloy.

Element	Cu	Mg	Si	Fe	Mn	Ni	Ti	Al
Wt%	4.28	0.027	5.878	0.473	0.078	0.006	0.108	Balance

3. ELECTROLESS COATING PROCESS

Electroless process was adopted for coating nickel over SiC particles in order to improve the wettability between aluminium matrix and reinforcement during the fabrication of composite. SiC particles were taken in a vessel and were cleaned in acetone for 15 minutes and then washed with water. SiC were now taken for sensitization in a solution containing Tin chloride ($SnCl_2$) and concentrated hydrochloric acid (HCl) for 15 min, then washing with water. Enactment was done in a solution of Palladium chloride ($PdCl_2$) and concentrated HCl for 15 min, later washed with water and dried. The dried SiC powders were delicately scattered in an electroless bath constituting of nickel chloride, sodium hypophosphite, sodium citrate and ammonium chloride and was stirred using magnetic stirrer with simultaneous heating. The nickel deposition over SiC began with hydrogen issuing at 60–90 °C. Three trials were directed to find the advanced temperature at which more nickel coating was to be obtained over SiC particles. Coating was carried out at different temperatures of 65 °C, 75 °C and 85 °C individually.

4. FIELD EMISSION SCANNING ELECTRON MICROSCOPE AND ENERGY DISPERSIVE X-RAY SPECTROSCOPY ANALYSIS

After electroless coating of nickel over SiC particles was done by varying the temperature (65 °C, 75 °C, 85 °C), SEM analysis was carried out to find the optimum coating temperature in order to obtain uniform nickel coating over SiC particles. Figures 1(a) and 1(c) shows non homogenous nickel coating over SiC at 65 ˚C and 85 ˚C respectively. It was clearly understood from Fig. 1(b) that a homogenous nickel coating over SiC has happened at the temperature 75 ˚C.

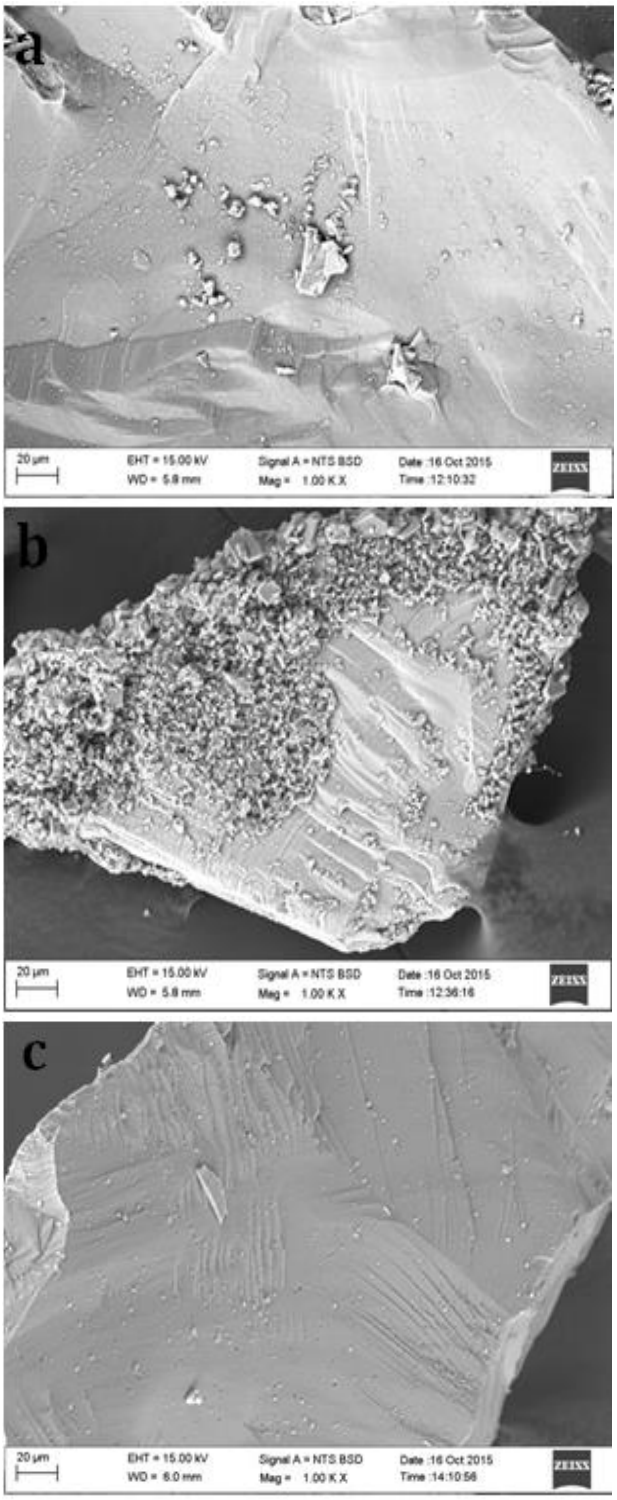

Fig.1. SEM images of electroless nickel coating over SiC particles a) 65 ˚C, b) 75 ˚C, c) 85 ˚C.

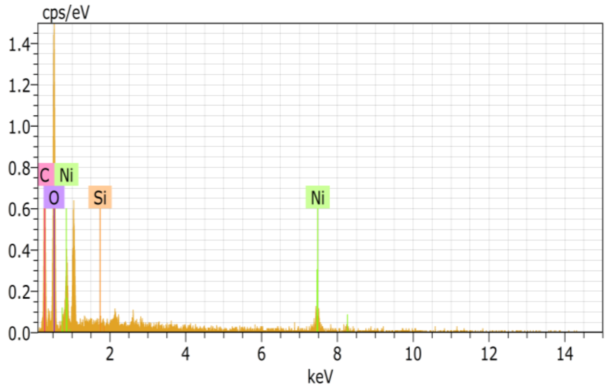

Fig. 2. EDX spectra on nickel coated silicon carbide at 75 °C.

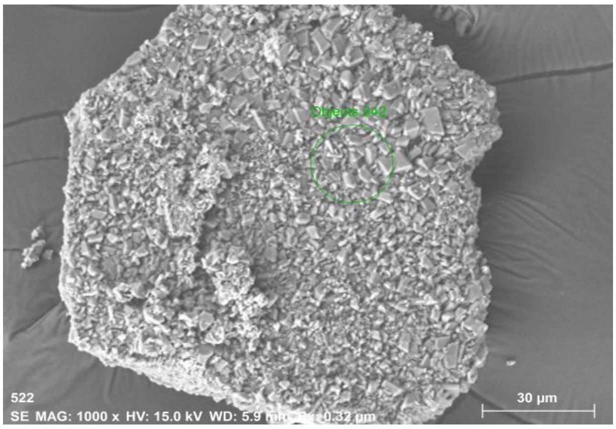

Fig. 2a EDAX image of the nickel coated SiC particle at 75°C.

From the EDX analysis (Fig. 2) of Ni coated SiC particles, the peak ratio of the elements was obtained. It shows the presence of nickel. Also, the presence of elements such as Ni, Si, C, and O in the particle was understood from the EDX spectrum which ensures the coating of Ni over SiC particles. EDAX image of nickel coated SiC particle was shown in Fig. 2a.

5. SYNTHESIS OF FUNCTIONALLY GRADED METAL MATRIX COMPOSITE

The liquid metallurgy technique was employed to fabricate the FGMMC required for this study. It includes the stir casting process which was used for the homogenous mixing of SiC in aluminium matrix followed by centrifugal casting process which was one of the economical methods for fabrication of FGM. A graphite crucible containing the Al-Si6Cu aluminium matrix was kept inside the melting furnace for melting purpose (Fig.3). An Argon gas atmosphere was maintained inside the furnace to prevent the presence of impurities and formation of imperfections in the casting. The nickel coated SiC particles were preheated to a temperature of 350 °C and were added to the liquid metal in the furnace. The furnace has a stirrer setup which provides the mechanical stirring for liquid metal and the reinforcement. The stirrer was permitted to rotate at 300 rpm which accomplishes the uniform scattering of nickel covered SiC particles in the liquid metal. The molten metal maintained at a temperature of 760°C was poured into metallic mould of the horizontal centrifugal casting machine which was preheated to a temperature of 350 °C (Fig. 4) rotating at an rpm of 1250. The die rotates until the molten metal solidifies and the cast segment (Fig. 4a) was removed from the die.

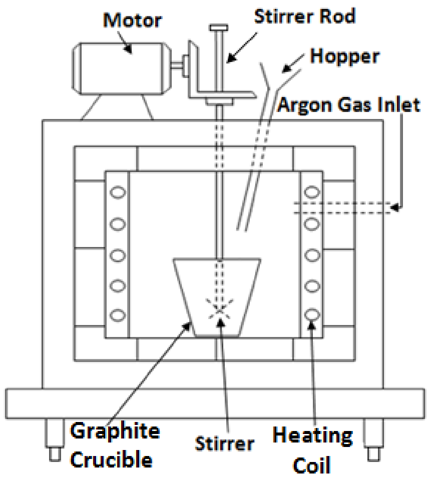

Fig. 3. Furnace with stirrer set up.

Fig. 4. Centrifugal Casting Machine.

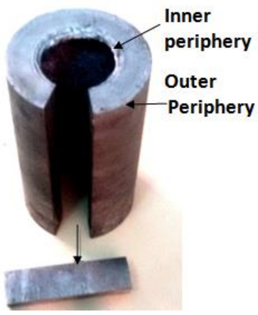

Fig. 4a. FGMMC specimen after casting.

5.1 Microstructure evaluation

Microstructural characterization was carried out using Zeiss Axiovert metallurgical microscope. Cast specimen obtained was cut into standard size of 20x20 mm and then polished using emery sheets with 1/0 and 2/0 grades and the specimen was finally polished with a velvet disc polisher in the presence of alumina. The polished specimen was etched using Keller's reagent and then the microstructure was observed. To observe the microstructure of the internal layers of FGMMC, the specimens were ground to a depth of 1 mm initially and then to 7 and 14 mm from the outer periphery.

5.2 Hardness evaluation

Vickers hardness tester was used for the measurement of hardness. A specimen was cut from casting for hardness measurement. Specimen was polished before measurement to get the accurate results using emery sheets of different grades 1/0 and 2/0 and then later with velvet polisher. The specimen was secured on the holder and an indentation was made using the diamond indenter of the machine. The load applied was 100 gf for a period of 15 seconds. The hardness values were calculated by the machine by capturing the size of the indentation made by the diamond indenter. Mean of the three hardness values measured on the surface was taken as the hardness value of that particular surface. Likewise, hardness value was taken from outer periphery to inner periphery in the radial direction at a distance of 1, 3,7,10 and 14 mm.

5.3 Tensile strength evaluation

Tensile specimen was machined according to the ASTM standard E-8. Two specimens were prepared from the casting i.e from the inner (8-14 mm) and outer zone (1-7 mm). The specimen specifications of gauge length 25 mm and thickness 6 mm was loaded into the machine and then the specimen was placed in the holder of universal testing machine. A maximum load value of 10,000 N was given as an input to the machine. The machine records continuous values of load and deformation. Load was applied till it breaks and the same procedure was followed for both specimen.

6. RESULTS AND DISCUSSIONS

Microstructure analysis, hardness measurement and tensile characteristics are discussed in detail below.

6.1 Microstructural Analysis

Microstructure was observed under Zeiss Axiovert inverted metallurgical microscope (Fig. 5a-c). More number of SiC particles was seen at the outer periphery (1 mm) (Fig. 5a) of casting. On moving in the radial direction at a distance of 7 mm (Fig. 5b) and 14 mm (Fig. 5c) towards inner periphery, it was observed that the SiC particles reduce in number. This was due to the movement of less dense gas bubbles from outer periphery to inner periphery during the centrifugal casting process. During this time, the less dense gas bubbles take away some SiC particles towards the inner periphery and therefore, few SiC particles were observed near inner periphery (Fig. 5c). The graded properties in the cast specimen depends on parameters like the variation in the densities of particle and matrix, melt temperature, centrifugal force, metal viscosity, particle size, cooling rate and also influenced by proper stirring of the molten metal before it was poured into the preheated die. Similar scenario was seen here [17,18]. Based on these factors two different zones were formed during solidification i.e particle rich and particle depleted zone.

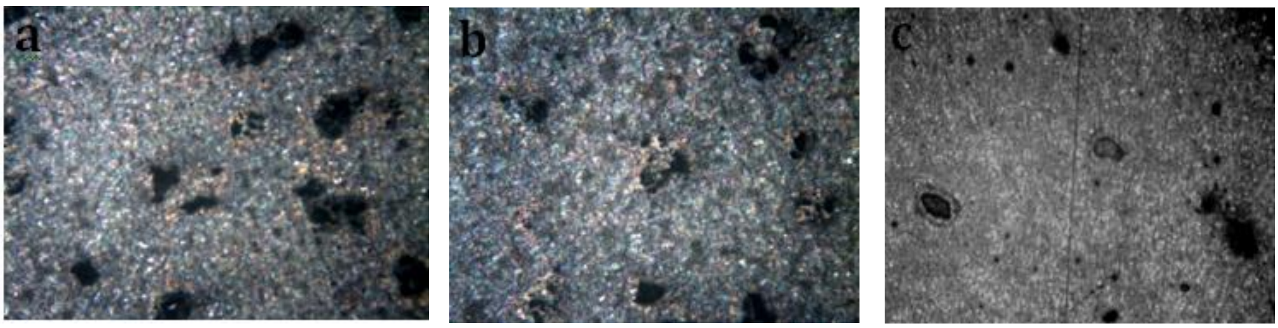

Fig. 5. Microstructure variation from outer periphery a) 1mm b) 7mm c) 14mm.

6.2 Hardness Measurement

The hardness of FGMMC (at the distance 1, 3, 7, 10, 14 mm) from outer periphery was measured. Figure 6 shows the variation in hardness from the outer periphery to the inner periphery in the radial direction. The increase in the hardness value from the inner periphery to outer periphery reveals that more number of SiC particles was dispersed at the outer periphery compared to the inner periphery. The centrifugal force allows more number of high density nickel coated SiC particles to be dispersed to the outer periphery. With the increased uniform distribution and high volume fraction of SiC particles, the hardness near the outer periphery was more and similar phenomenon was studied here [19,20]. The solidification occurred from outer periphery towards inner periphery of casting, while the pressure force acts from inner to outer in an opposing radial direction producing a squeeze effect. Due to this phenomenon, less dense gas porosities, slag inclusions and agglomerates were observed at the inner periphery. So hardness was reduced from outer periphery to inner periphery with lesser SiC particles at the inner periphery.

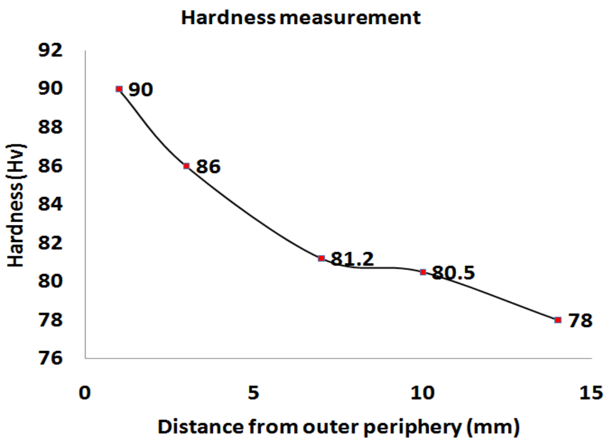

Fig. 6. Hardness variation from outer to inner periphery.

6.3 Tensile Test

Tensile test was conducted on specimens of outer zone (1-7 mm) and inner zone (8-14 mm) of the FGMMC casting. It was found out that specimen of inner zone has an ultimate tensile strength of 123.3 MPa and specimen of outer zone has an ultimate tensile strength of 153.3 MPa. The centrifugal force and density difference between aluminium matrix and SiC particles were responsible for the dispersion of more number of SiC particles at the outer periphery. Due to this particle rich outer zone, a much greater bonding was formed between the Al alloy and nickel coated SiC particles. Therefore during the tensile test, load applied was transferred from aluminium matrix to SiC particles on which SiC shows higher load withstanding property as the presence of nickel enhances better bonding. Thereby it delays the breaking of the specimen. While in the inner zone due to lesser number of SiC particles, it shows low tensile strength and thereby it could not withstand greater load.

7. CONCLUSION

Nickel was successfully coated on SiC particles using electroless coating technique. The maximum uniform nickel coating on SiC particles was found to be at a temperature of 75°C. The microstructure of the fabricated FGMMC of Al reinforced with Ni coated SiC was observed, showing more number of SiC particles at the outer periphery of casting compared to the inner periphery. Hardness measurements and tensile test showed the graded property of FGMMC from outer periphery to inner periphery. This nickel coated SiC reinforced aluminium FGMMC could be used in automotive applications like pulleys, pistons, cylinder head etc wherever a combination of high rigidity and bulk mechanical properties are necessary.

REFERENCES

[1] F. Kretz, Z. Gacsi, J. Kovacs and T. Pieczonka, 'The electroless deposition of nickel on SiC particles for aluminium matrix composites', *Surf. Coat. Technol.,* vol. 180, pp. 575–579, 2004.

[2] A. Vencl, A. Rac, I. Bobić and Z. Mišković, 'Tribological properties of Al-Si alloy A356 reinforced with Al_2O_3 particles', *Tribol. Ind.,* vol. 28, no. 1, pp. 27-31, 2006.

[3] S. Mitrović, M. Babić, B. Stojanović, N. Miloradović, M. Pantić, and D. Džunić, 'Tribological potential of hybrid composites based on zinc and aluminium alloys reinforced with SiC and graphite particles', *Tribol. Ind.,* vol. 34, no. 4, pp. 177-185, 2012.

[4] D.B. Miracle, 'Metal matrix composites – From science to technological significance', *Compos. Sci. Technol.*, vol. 65, pp. 2526–2540, 2005.

[5] G.S. Pradeep Kumar, R. Keshava Murthy, P. Kumari and C. Dubey, 'Corrosion behaviour of TiB_2 reinforced aluminium based in-situ metal matrix composites', *Perspect. Sci.,* 2016.

[6] V. Umasankar, S. Karthikeyan and M. Anthony Xavior, 'The influence of electroless nickel coated SiC on the interface strength and microhardness of aluminium composites', *J. Mater. Environ. Sci.,* vol. 5, no. 1, pp. 153-158, 2014.

[7] J. Hashim, L. Looney and M.S.J. Hashmi, 'Metal matrix composites: production by the stir casting method', *J. Mater. Process. Technol.*, vol. 92, pp. 1-7, 1999.

[8] T.P.D. Rajan, R.M. Pillai and B.C. Pai, 'Review reinforcement coatings and interfaces in aluminium metal matrix composites', *J. Mater. Sci.,* vol. 3, pp. 3491 - 3503, 1998.

[9] E. Jayakumar, J.C. Jacob, T.P.D. Rajan, M.A. Joseph and B.C. Pai, 'Processing and characterization of hypoeutectic functionally graded aluminum – SiC metal matrix composites', *Mater. Sci. Forum,* vol. 830, pp. 456-459, 2015.

[10] T.P.D. Rajan, E. Jayakumar and B.C. Pai, 'Developments in solidification processing of functionally graded aluminium alloys and composites by centrifugal casting technique', *Trans. Indian. Inst. Met.*, vol. 65, no. 6, pp. 531–537, 2012.

[11] Y. Watanabe and S. Oike, 'Formation mechanism of graded composition in Al–Al_2Cu functionally graded materials fabricated by a centrifugal in situ method', *Acta. Mater.*, vol. 53, pp. 1631–1641, 2005.

[12] O. Savas, R. Kayikci, F. Ficici and S. Koksal, 'Production of functionally graded AlB_2/Al-4%Mg composite by centrifugal casting', *Period. Eng. Nat. Sci.,* vol. 1, no. 2, pp.1-6, 2013.

[13] A.N. Attia, 'New phase reinforcement for composite materials', *Mater. Des.,* vol. 22, no. 6, pp. 459-466, 2001.

[14] L.L. Mishnaevskyjr, 'Functionally gradient metal matrix composites: numerical analysis of the microstructure–strength relationships', *Compos. Sci. Technol.*, vol. 66, pp. 1873–1887, 2006.

[15] N. Radhika and R. Raghu, 'Evaluation of dry sliding wear characteristics of LM13/B_4C composites', *Tribology in Industry,* vol. 37, no. 1, pp. 20-28, 2015.

[16] N. Radhika, A. Vaishnavi and G.K. Chandran, 'Optimisation of dry sliding wear process paramaters for aluminium hybrid metal matrix composites', *Tribolology in Industry,* vol. 36, no. 2, pp. 188-194, 2014.

[17] R. Rodríguez-Castro, R.C. Wetherhold and M. H. Kelestemur, 'Microstructure and mechanical behavior of functionally graded Al A359/SiCp composite', *Mater. Sci. Eng.*, vol. 323, no. 1, pp. 445-456, 2002.

[18] J. Hashim, L. Looney and M.S.J. Hashmi, 'The enhancement of wettability of SiC particles in cast aluminium matrix composites', *J. Mater. Process. Technol.,* vol. 19, no. 1, pp. 329-335, 2001.

[19] N. Radhika and R. Raghu, 'Mechanical and tribological properties of functionally graded aluminium/zirconia metal matrix composite synthesized by centrifugal casting', *Int. J. Mater. Res.*, vol. 106, pp. 1174-1181, 2015.

[20] N. Radhika and R. Raghu, 'Experimental investigation on abrasive wear behaviour of functionally graded aluminium composite', *J. Tribol.*, vol. 137, no. 3, pp. 1-7, 2015.