Vol. 40, No. 1 (2018) 81-91, DOI: 10.24874/ti.2018.40.01.07

Tribology in Industry

www.tribology.rs

RESEARCH

Analysis of Three Body Abrasive Wear Behaviour of Centrifugally Cast Aluminium Composite Reinforced with Ni Coated SiC using Taguchi Technique

N. Radhika[a]

[a]*Department of Mechanical Engineering, Amrita School of Engineering, Coimbatore , Amrita Vishwa Vidyapeetham, India.*

Keywords:

Aluminium Composite
Abrasive wear
Analysis of Variance
Linear Regression analysis
Scanning Electron Microscope

Corresponding author:

N. Radhika
Department of Mechanical Engineering, Amrita School of Engineering, Coimbatore , Amrita Vishwa Vidyapeetham, Tamilnadu, India.
E-mail: n_radhika1@cb.amrita.edu

A B S T R A C T

The aim of the present research is to determine the abrasive wear behavior of functionally graded Al LM21/10wt.% Ni coated SiC composite fabricated by centrifugal casting route. The centrifugal cast hollow cylindrical part has the dimensions of $Ø_{out}$150 mm x $Ø_{in}$135 mm x 160 mm. Ni was coated over SiC reinforcement particles by electroless coating process and the presence of Ni content on reinforcement particles were confirmed by Energy Dispersive Spectroscopy analysis (EDS). Abrasive wear test was conducted as per Taguchi's L_{27} orthogonal array design. The parameters selected for wear experiments were: load (29, 34 and 41 N), rotational speed (100, 150 and 200 rpm) and radial distance (1, 6 and 11 mm) from outer periphery. The wear characteristics of the composite were analyzed using signal-to-noise and analysis of variance. Results showed that the radial distance had major impact on the wear rate (40.59 %), followed by the applied load (29.7 %) and rotational speed (14.85 %). The regression equation was developed and validated with confirmatory experiments and the error was found to be less than 10 %. Scanning Electron Microscope (SEM) analysis was done on the worn specimens and observed lesser wear rate at the radial distance of 1 mm.

1. INTRODUCTION

In modern world, the main aim of material development is to meet the requirement of properties for industrial applications. Aluminium Metal Matrix Composites (AMMCs) are one such material to provide combination of properties such as high strength, high stiffness, higher thermal conductivity, higher young's modulus and better tribological properties over unreinforced alloys. These AMMCs are mostly used in applications such as automobile, marine and aerospace industries [1,2]. Further attempts have been made to improve the mechanical and tribological properties of AMMCs by introducing new concepts called Functionally Graded Material (FGM). FGM is a new class of an advanced material which consists of two or more phases with continuous changes in composition and/or microstructure across the dimension and result of this variation causes a property change in the material [3]. The functionally graded AMMCs are increased its potential towards the application in the field of wear and tear [4].

FGM has been grouped into many categories such as liquid phase technique, solid phase technique and vapour phase technique. For Al based alloys, liquid phase centrifugal casting is one of the most economical and effective methods for fabrication of FGM composites [5,6]. Aluminium matrix composite reinforced with Mg_2Si fabricated by centrifugal casting have been studied and results showed that the outer region of cylindrical casting has more Mg_2Si particles than the inner region due to density difference between the matrix and reinforcement particles [7]. Al-Mg/in-situ AlB_2 composite fabricated by centrifugal casting is investigated and observed higher in-situ AlB_2 particle concentration towards outer region of the composite which results in higher hardness [8]. Al/Al-Cu FGM fabricated by powder metallurgy technique have been investigated and found continuous change in composition and hardness property along their graded direction due to diffusional effect [9]. Two body abrasive wear behavior of Al 1100 composites reinforced by varying the composition, e.g. vol.% (5, 10 and 20) of SiC are studied and found that abrasive wear resistance of composites increases with increase in vol.% of SiC particles [10]. The abrasive wear mechanism on Al AA6061 matrix reinforced with varying wt.% (5, 10 and 15) of SiC produced by powder metallurgy method is analysed. It is found that at low speed, abrasive wear rate is dominated whereas at high speed, delamination is the dominant wear mechanism [11].

The effect of particle size on abrasive wear behavior of Al 2024/10wt.% B_4C composite has been studied and results reveals that the smaller particles (29 μm) has higher abrasive wear resistance if compared to larger particles (71 μm) [12]. Effect of both electroless copper coated and uncoated basalt short fiber in Al 7075 MMC have been investigated and composite with copper coated reinforcement particles shows improved mechanical properties [13]. Two body abrasive wear behavior of Al 6061/Ni-P coated Si_3N_4 composite have been studied and result shows that composites with coated reinforcement particles have better wear resistanceif compared to uncoated reinforcement particles [14]. Two body abrasive wear behavior of Al 6063 composites reinforced with varying wt.% (5 and 10) of TiB_2 have been studied and observed that, wear resistance of the composites effectively increases with TiB_2 particles [15]. Two body abrasive wear behavior of both Al/10wt.% sillimanite composite and unreinforced aluminium alloy is investigated and found that sillimanite composite has superior wear resistance than aluminium alloy [16].

The effect of different parameters on wear behavior of the materials is effectively analyzed by Taguchi technique. The best process design parameters are analyzed by signal-to-noise (S/N) and analysis of variance (ANOVA). Taguchi creates standard orthogonal array data to accommodate several factors on the targeted value and defines the plan of experiment [17,18]. Analysis of wear behavior and optimization of parameters of Al 2025 reinforced with 3wt.% Al_2O_3, 3wt.% graphite and 1wt.% B_4C hybrid MMCs have been investigated using Taguchi technique. Result reveals the applied load as the most influencing parameter on the wear rate followed by the sliding distance [19].Two body abrasive wear behavior of Al 2124/10wt.% SiC composite is analyzed and abrasive size exerts greater impact on wear rate followed by the applied load and sliding distance [20]. The effect of applied load and sliding distance on abrasive wear behaviour of A 356 Al composite reinforced with 1.8 vol.% Al_2O_3 (size-100 μm) particle fabricated by compo casting is analysed. Result revealed that wear rate increases with both applied load and sliding distance [21].An artificial neural network (ANN) is also an optimization technique used to predict tribological properties. The wear behavior of A356 Al alloy with varying vol.% (0, 5, 10 and 15) of B_4C particle is investigated by using this technique and found reasonable correletation between experimental and predicted values [22,23].

From the literature review it is observed that AMMCs reinforced with Ni coated SiC composite has not fully been explored. Hence, the present aim of this research work is to fabricate LM21 aluminium composite reinforced with Ni coated SiC by centrifugal casting method and to investigate its three body abrasive wear characteristics using Taguchi's Design of Experiment (DOE). The fabricated FGM with improved wear properties can be suggested for suitable automotive applications.

2. MATERIAL SELECTION

LM21 aluminium alloy is chosen as the matrix material due to their properties such as excellent casting characteristics, better machinability and higher proof strength. The elemental composition of Al LM 21 alloy is shown in Table 1. Silicon Carbide (SiC)(10 wt%) with particle size of 33 μm is chosen as reinforcement particle and this has properties such as good wettability due to lesser contact angle with Al matrix, higher hardness and higher load bearing ability. SiC is also used as abrasives and cutting tools in industrial application.

Table 1. Elemental composition of Al LM21 alloy.

Element	Cu	Mg	Si	Fe	Mn	Ni	Ti	Al
Wt.%	4.3	0.27	5.9	0.47	0.08	0.006	0.108	Bal.

In this work, Ni is coated over SiC particles and the coating was produced by electroless coating process. The purpose of coating Ni over SiC particles is to enhance the wettability between the matrix and SiC and also to attain better bonding characteristics. This process is done by the sequence of sensitizing, activation, metallization, rinsing and drying stages. The important coating parameters considered during coating Ni on SiC reinforcements are the concentrations of sodium hypophosphite (10 g), sodium citrate (100 g), nickel chloride (50 g), ammonium chloride (50 g), bath temperature (75 °C) and bath pH(8).The energy dispersive X-ray spectroscopy is performed in the Ni coated SiC particles, as a confirmatory test for observing the presence of Ni over SiC. As observed from the Fig. 1, peaks are observed for Ni, Si and C. The peaks of Si and C corresponded to SiC particles. The presence of Ni is confirmed at two peaks (one at 0.8 keV and the other at 7.4 keV).

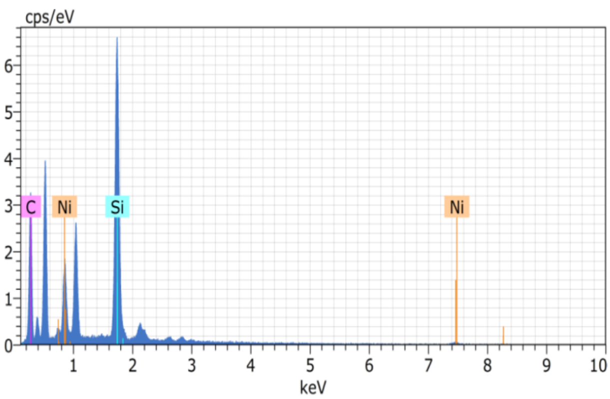


Fig. 1. EDX plot for Ni coated SiC particle.

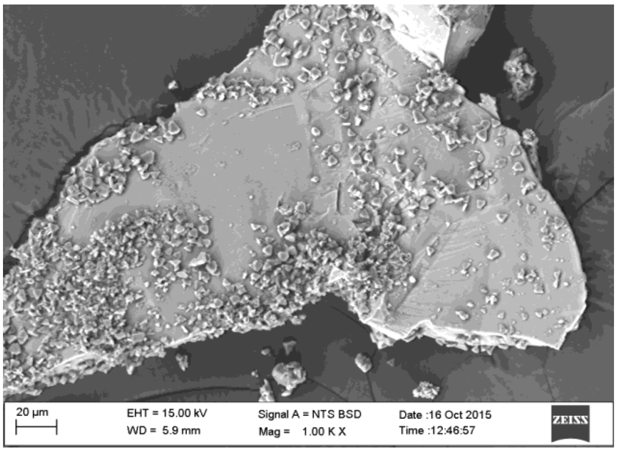
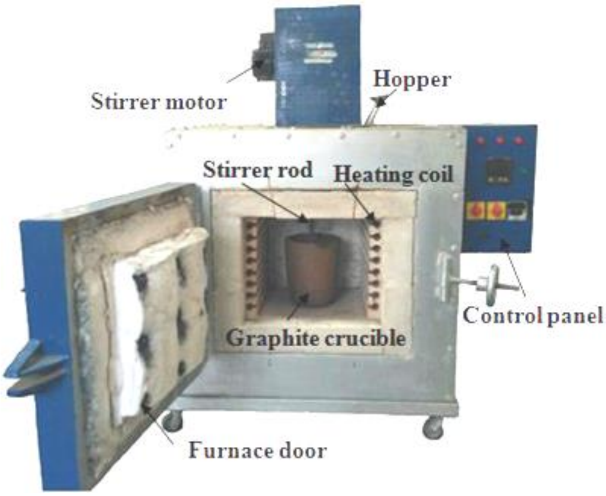


Fig. 2. SEM image of Ni coated SiC particles.

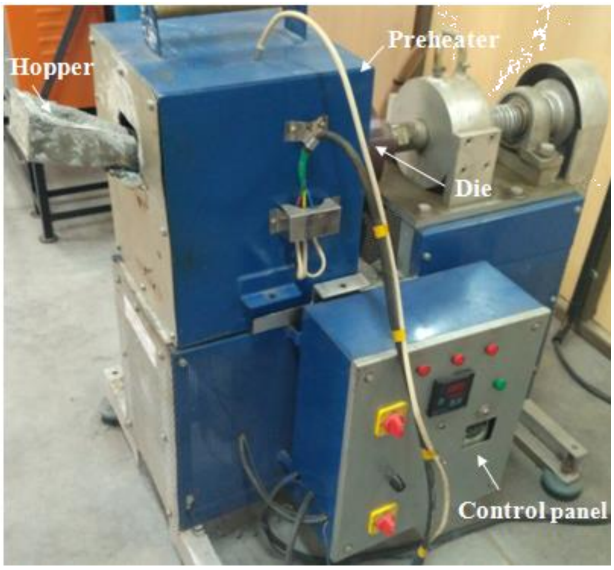
The SEM image of Ni coated SiC particle is shown in Fig. 2, where it can be seen proper coating of Ni content over SiC particles and also inferred that Ni content has good bonding characteristics with SiC particles.

3. FABRICATION OF COMPOSITE

The Al LM21/10 wt.% Ni coated SiC composite is fabricated by stir casting technique followed by centrifugal casting. The aluminium ingot is cut into small solid pieces and kept inside the resistance type electric furnace (Fig. 3a) through graphite crucible. The melting of aluminium alloy occurs at a temperature between 660 to 720 °C. This melting process is carried out under argon gas atmosphere to prevent unwanted chemical reactions. After getting complete molten state, the preheated (300 °C) Ni coated SiC reinforcement particles are gradually added to the melt and stirring is carried out at a speed of 300 rpm for 5 minutes. Then the molten mixture is carefully taken out from the furnace and poured into the horizontal centrifugal mould (Fig. 3b) which is rotated at 1000 rpm. Before pouring, the centrifugal mold is preheated at 350 °C to prevent the occurrence of temperature gradients which may cause defects during solidification. During rotation of the mould, the centrifugal force is created which distributes the reinforcement particles acrossthe matrix in radial direction. The centrifugal mould is rotated till to get complete solidification of the molten metal. Finally, casting is removed from the centrifugal die through ejector and hollow cast component is obtained with the dimensions of $Ø_{out}$150 mm x $Ø_{in}$135 mm x 160 mm (Fig. 3c).



a)



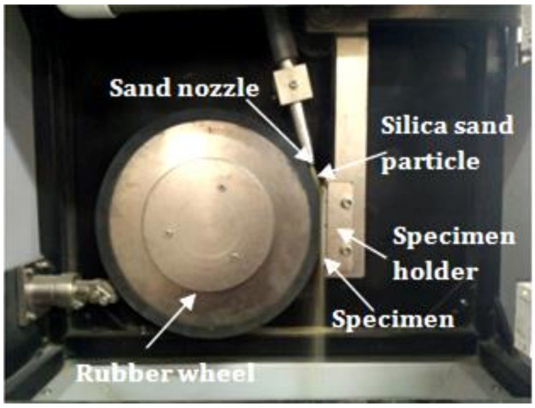
b)

c)

Fig. 3. a) Aluminium melting furnace; b) Centrifucal casting machine; and c) Hollow cylindrical cast component.

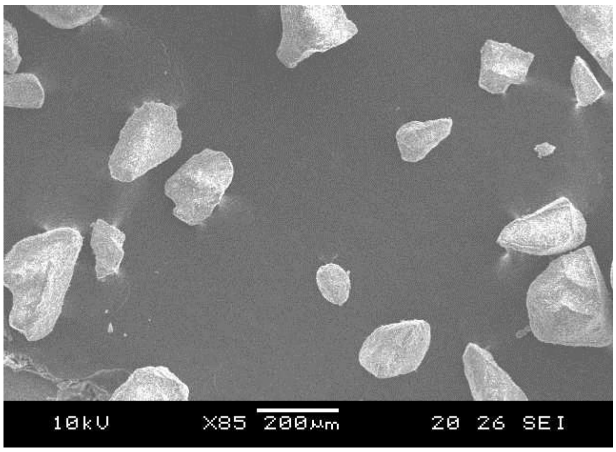
4. ABRASIVE WEAR TEST

The abrasive wear test is conducted on the composite using dry abrasion tester (Fig. 4a). This test has been carried out (~30 °C temperature, 22 % humidity) according to standard ASTM G65.The rectangular test specimen is machined (1.4 Ra surface roughness) from fabricated composite with the dimensions of 75x25x12 mm. The composite specimen before and after wear test is shown in Fig. 4b. The silica sand particles (Fig. 4c) are used as abrasives.



a)

b)



c)

Fig. 4. a) Abrasive wear tester; b) Specimen before and after wear test; and c) SEM image of silica sand particle.

The specimen is mounted on the specimen holder. The silica sand flows between the rotating wheel and the test specimen at the flow rate of 354 g/min. The wheel is made up of chlorobutyl rubber (A-60 Durometer hardness and specific gravity of 0.93) material which has the dimension of Ø228 x 13 mm. The specimen is pressed against the rotating rubber wheel with different applied loads where the abrasives are fed continuously between the rubber wheel and the specimen and results in three body abrasive wear. The load is applied on the specimen by means of a lever arm which is located on side of the machine. This test has been carried out along the radial direction of the composite at different radial distances (1, 6 and 11 mm) from outer periphery and also at constant time (5 min) with different rotational speeds (100, 150 and 200 rpm) and different applied loads (29, 34 and 41 N). Fresh contact of specimen with the abrasive material is ensured by dressing the abrasive wheel for before each experiment. After the test, specimen is properly cleaned with acetone, rinsed with water and dried. The wear loss of the specimen is determined by weight loss method. The weight loss of the specimen is measured using an electronic weighing balance which gives up to the accuracy of 0.0001 g. Each experiment is conducted for 3 times and their average value is taken for analysis. The wear rate of the composite is calculated by the following equation (1):

$$W = \frac{\Delta M}{(\rho \times L \times D)} \tag{1}$$

where, W is the wear rate (mm^3/Nm), ΔM is the mass loss of the specimen (g), ρ is the density (g/mm^3), L is the applied load (N) and D is the sliding distance (m).

4.1 Taguchi's plan of experiments

Influence of process parameters are analyzed by plan of experiment using Taguchi method. It is used to reduce the number of experiments and is also an effective tool to get high quality products with minimum cost. The best level of quality characteristics with minimum variation is also obtained from Taguchi. Based on the degree of freedom, a L_{27} orthogonal array is chosen for this investigation (see Table 3). According to this condition, the degree of freedom should be equal to or greater than the sum of variables. There are three independent variables such as applied load, rotational speed and radial distance of the casting which are taken into this analysis. The process parameters and their levels are shown in Table 2.

Table 2. Process parameters and their levels.

Levels	Load, L (N)	Rotational speed, S (rpm)	Radial distance, D (mm)
1	29	100	1
2	34	150	6
3	41	200	11

5. RESULTS AND DISCUSSION

The microstructure, abrasive wear behavior, signal-to-noise ratio, analysis of variance, linear regression analysis model and scanning electron microscopy analysis are discussed in the following subsections.

5.1 Microstructure of composite

Microstructure of aluminium functionally graded composite observed at outer region (1 mm) using metallurgical microscope is shown in Fig. 5. The fact that the outer region of aluminium composite has higher reinforcement particles due to the creation of centrifugal force and the density difference between the reinforcements and matrix. This invoke the interest to observe the microstructure only at outer surface of the composite. The microstructure (Fig. 5) reveales that the reinforcement concentration is higher at the outer region of the composite. It is also confirmed that the bonding between reinforcement and matrix is superior due to the coating of Ni over SiC reinforcements.

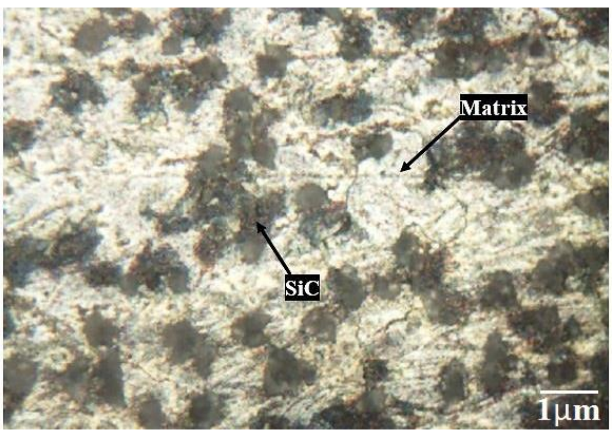


Fig. 5. Microstructure of functionally graded aluminium composite at outer region.

5.2 Effect of process parameters on wear behavior of composite

The abrasive wear rate (W) of the aluminum composite is calculated as per L_{27} orthogonal array and the wear experiment results are shown in Table 3.

Table 3. Wear experimental results.

S. No	L (N)	S (rpm)	D (mm)	Wx10^{-3} (mm^3/Nm)	S/N ratio (db)
1	29	100	1	3.44	49.27
2	29	100	6	4.81	46.36
3	29	100	11	4.23	47.47
4	29	150	1	3.12	50.12
5	29	150	6	4.38	47.17
6	29	150	11	4.21	47.51
7	29	200	1	3.23	49.82
8	29	200	6	3.48	49.17
9	29	200	11	3.96	48.05
10	34	100	1	4.41	47.11
11	34	100	6	5.23	45.63
12	34	100	11	5.20	45.68
13	34	150	1	3.83	48.34
14	34	150	6	4.16	47.62
15	34	150	11	4.48	46.97
16	34	200	1	3.66	48.73
17	34	200	6	4.18	47.58
18	34	200	11	4.59	46.76
19	41	100	1	4.20	47.54
20	41	100	6	5.08	45.88
21	41	100	11	5.15	45.76
22	41	150	1	4.29	47.35
23	41	150	6	4.83	46.32
24	41	150	11	5.08	45.88
25	41	200	1	3.86	48.27
26	41	200	6	4.38	47.17
27	41	200	11	5.25	45.60

Figure 6a shows the influence of the applied load on the abrasive wear behaviour of composite and found out that the wear rate of the composite is quite sensitive to the applied load. The applied load is responsible for the amount of abrasion that takes place on the composite surface. At low load conditions of 29 N, the penetration of abrasive sand particles to the composite surface is less due to minimum contact which actually made a free rolling effect between rubber wheel and composite surface. Due to this effect, mild abrasion on the composite surface takes place. As the load increases to 34 N, the contact between abrasives with rubber wheel and composite surface increases which results in higher penetration of abrasive particles to the composite surface. This produces ploughing action (Fig. 7) which results in more removal of the material. When the load turned to 41 N, defragmentation of abrasive particles occurs at the entrance zone between the rubber wheel and composite surface. As a result of crushing, the abrasive particles get converted into smaller sizes and these reduced particles have higher surface area to volume ratio which results in more material removal. The reduced size of sand particles is also embedded over rubber wheel due to buildup of temperature at the interface which causes repetitive abrading action on the composite surface that results in severe delamination [24].

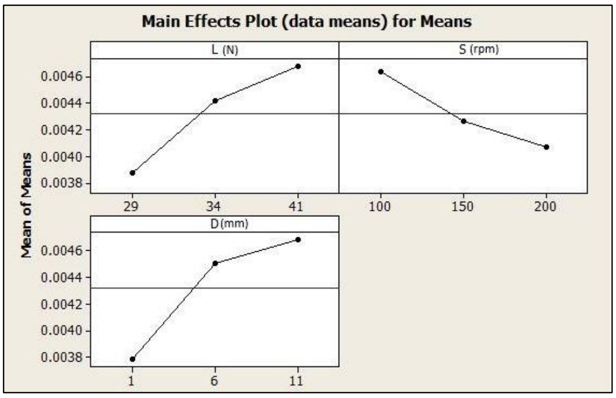


Fig. 6. Wear rate main effects plot (a) load, (b) speed, and (c) distance.

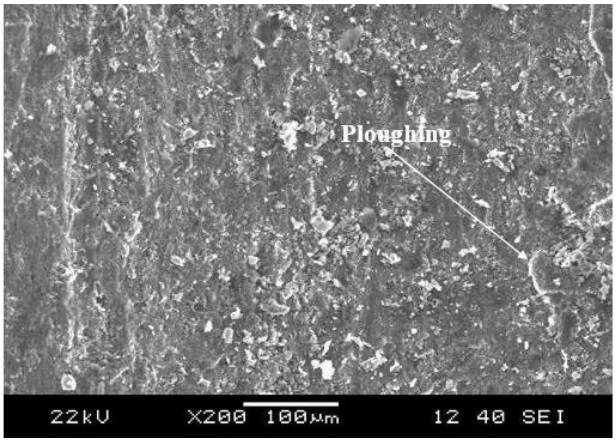


Fig. 7. Worn surface of composite (L=34 N, S=150 rpm and D= 6 mm).

From Fig. 6b, it is evident that the abrasive wear rate of the composite decreases with increase in rotational speed of the rubber wheel. At rotational speed of 100 rpm, the contact time between specimen surface and rubber wheel with sharper abrasive particles are higher. Due to this, the packing density of the abrasive particles in the contact zone is high and results in more amount of material removal on the composite surface. The wear rate of the composite was found to be decreasing as the speed increases from 100 rpm to 150 rpm due to lesser contact time between specimen and abrasives so that embedding of the sand particles to specimen surface also decreases. Also, some abrasive particles slides at the sides of the rubber wheel as it contacts with composite specimen and thereby reduces wear rate. With further increase in rotational speed of the rotating wheel from 150 to 200 rpm, the wear rate of the composite further decreases due to reduction of eroding action of the sand abrasive particles to specimen surface [25].

From Fig. 6c, it is inferred that the wear rate of the composite increases as a function of the radial distance. At radial distance of 1 mm, minimum wear rate of the composite was observed due to the presence of more volume fraction of reinforcement particles, thus most of the contact is possibly made between reinforcement particles and abrasives and very little amount of contact occurs in the matrix of composite with abrasives. The higher concentration of reinforcement particles at the outer region of the composite is due to the centrifugal force produced during the process which tends to move the high dense particles towards the outer region and the coating of Ni over SiC also enhances wettability. From the radial distance of 1 to 6 mm, wear rate of the composite is increased due to the presence of lesser volume fraction of reinforcement particles and hence the contact made between the matrix and abrasives. This increase lead to raise more material removal on the composite and a similar trend is observed for the radial distance of 6 to 11 mm.

5.3 Signal-to-Noise Ratio and Analysis of Variance analysis

S/N ratio analyses are used to describe the most influencing parameter on the wear rate. For this analysis, the quality characteristic of "smaller-the-better'' is chosen and it gives better result with minimum deviation. The delta value which is shown in Table 4 is used to explicit the difference between maximum and minimum value of mean S/N ratio. The ranking is given to the parameters based on delta value. This analysis is carried out using commercial Minitab software. The S/N ratio is calculated using the following equation (2),

$$\text{S/N ratio} = -10*\text{Log}\,(\text{sum}\,(y^2)/n) \qquad (2)$$

where, y-Response of the abrasive wear, n-No. of observations.

Based on the S/N ratio analysis (Table 4), it is observed that the radial distance had major impact on thewear rate followed by the applied load and rotational speed.

Table 4. S/N ratio Response table.

Level	L (N)	S (rpm)	D (mm)
1	48.29	46.84	48.74
2	47.27	47.66	46.88
3	46.64	47.69	46.57
Delta	1.65	0.85	2.17
Rank	2	3	1

The S/N ratio plot (Fig. 8) gives the optimum value of parameters which is used for improving the abrasive wear behavior of the composite. The optimum conditions are the applied load (L = 29 N), rotationalspeed (S=200 rpm) and radial distance (D=1 mm).

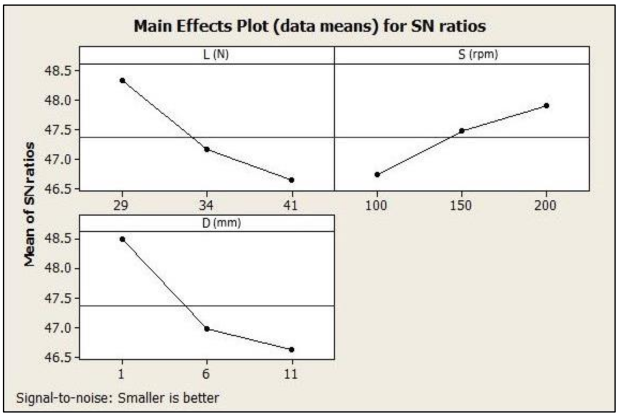


Fig. 8. S/N ratio main effects plot.

Analysis of Variance (ANOVA) is used to find out the highest influence of design parameters on thewear rate. The ANOVA is conducted with the help of a general linear model. The combinations of both, qualitative and quantitative variables are analyzed using a general linear model. The ANOVA is performed for aconfidence interval of 95 % and significance level of 5 %. P values which are likely way to describe the most influencing parameters on thewear rateare shown in Table 5 and the parameters having P value less than 0.05, indicates themost statistically significant parameters on thewear rate. From their percentage contribution of each parameter, it is inferred that radial distance (40.59 %) is most influential parameter on thewear rate followed by theappliedload (29.7 %) and rotational speed (14.85 %). As can be seen in Table 5, interaction between the process parameters have less significant effect on thewear rate.

Table 5. Analysis of Variance.

Source	DF	Seq SS	Adj SS	Adj MS	F	P value	P (%)
L (N)	2	3E-06	3E-06	2E-06	44.31	0.000	29.70
S (rpm)	2	2E-06	2E-06	8E-07	59.58	0.001	14.85
D (mm)	2	4E-06	4E-06	2E-06	22.21	0.000	40.59
L (N)*D (mm)	4	5E-07	5E-07	1E-07	3.31	0.070	4.95
L (N)*S (rpm)	4	2E-07	2E-07	1E-07	1.79	0.224	1.90
D (mm)*S (rpm)	4	5E-07	5E-07	1E-07	3.59	0.058	4.90
Error	8	3E-07	3E-07	0.0			2.90
Total	26	1E-05					

Note: DF-Degree of Freedom, Seqss-Sequential Sum of Square, Adjss-Adjacent Sum of Square, Adj MS-Adjacent Mean Square, F-Fisher Test, P-Probability, P (%)-Percentage Contribution.

5.4 Linear regression analysis

The correlations between factors such as applied load, rotational speed and radial distance are obtained by linear regression equation derived using Minitab software.

The regression equation is as follows:

$$W\ (mm^3/Nm) = 4.27E\text{-}3 + 15E\text{-}5\ L - 1.6E\text{-}5\ S + 9E\text{-}6\ D + 0E\text{-}7\ L*S + 2E\text{-}6\ L*D + 0E\text{-}7\ S*D \quad (3)$$

The sign of this equation (3) explains about the wear behavior of the composite. The positive sign denotes increase in wear rate of the composite while negative sign denotes decrease in wear rate of the composite. Based on the regression equation (Eq. 3) it is inferred that the wear rate of the composite increases with applied load and radial distance but decreases with rotational speed.

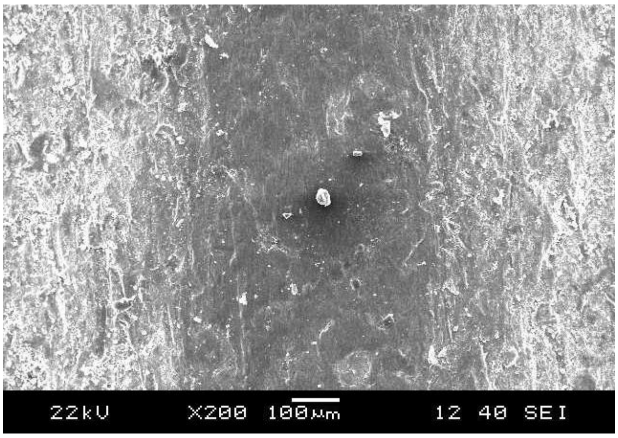
Table 6. Optimised parameters and validation.

S. No	L (N)	S (rpm)	D (mm)	Experimental wear rate (mm^3/Nm)	Regression wear rate (mm^3/Nm)	Error %
1	31	125	3	0.00291	0.00295	1.3
2	37	165	7	0.00304	0.00277	8.8
3	40	185	10	0.00302	0.00280	7.2

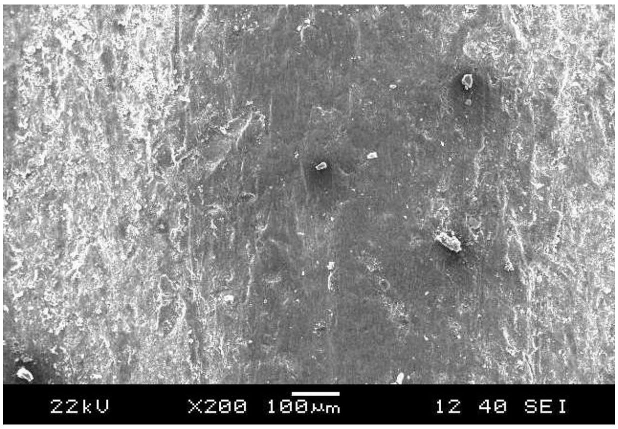
The confirmation experiment is performed with the parameters other than the selected parameters as shown in Table 6 and the error percentage is found to be less than 10 %. Hence needless to say that the developed model has higher efficiency to predict wear rate of the composite.

5.5 Scanning electron microscopy analysis

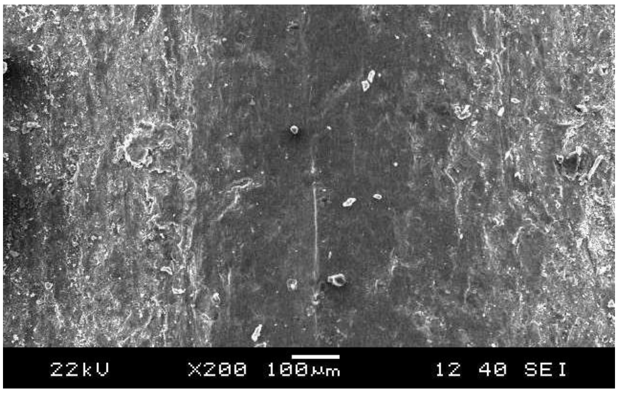
The SEM analysis is conducted on the functionally graded composite in order to observe the dominant wear mechanism during abrasive wear experiments. The effect of radial distance of functionally graded composite is considered for worn surface analysis since this is the most influential parameter on the wear rate. The SEM analyses (Figs. 9a-9c) are carried out at different radial distances (1, 6 and 11 mm) with constant rotational speed (100 rpm) and at constant load (29 N). At a radial distance of 1 mm (Fig. 9a), minimum wear rate on the composite surface is observed. This is due to the presence of more volume fraction of reinforcement particles which prevents the matrix to contact with abrasives. From Fig. 9b (6 mm radial distance), significant amount of grooves are observed on the worn surface due to increase in contact between abrasives and matrix. As the radial distance turned to 11 mm (Fig. 9c), severe scratches on the worn surface are observed due to the presence of less volume fraction of reinforcement particles, so the abrasives slide over soft aluminium matrix and removed more material from surface.



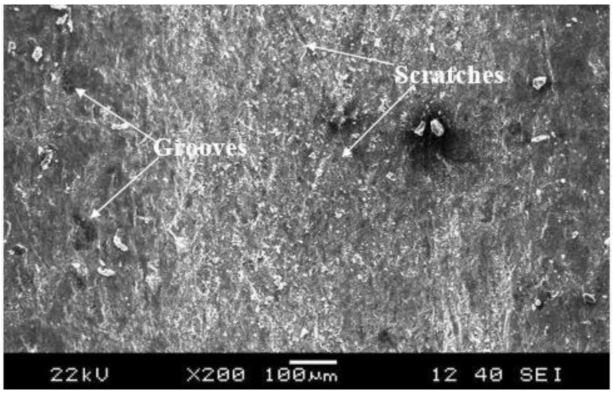
a)



b)



c)



d)

Fig. 9. SEM analysis of worn specimen surface at different conditions: a) D=1 mm, L=29 N, S=100 rpm; b) D=6 mm, L=29 N, S=100 rpm; c) D=11 mm, L=29 N, S= 100 rpm and d) D=11 mm, L=41 N, S=100 rpm.

Figure 9d shows the worn out surface of the composite which is tested under high load of 41 N. Comparison is made between Figs. 9c and 9d to determine the effect of applied load on the wear rate at constant rotational speed (100 rpm) and at constant radial distance (11 mm). More grooves and scratches are observed in the Fig. 9d, which indicates that, the wear rate of the composite increases with increase of applied load for the same radial distance and rotational speed.

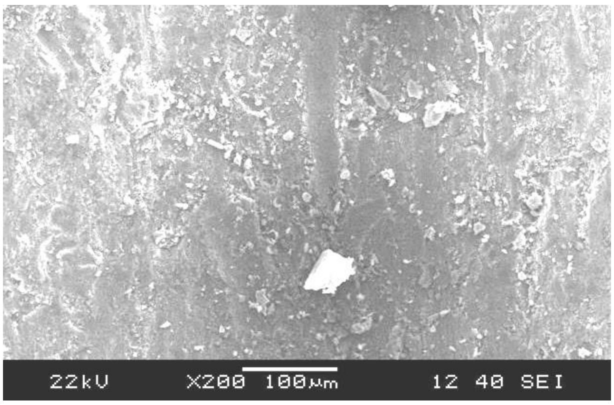


Fig. 10. Worn surface at optimum condition of the composite.

The worn composite surface at optimum condition (L=29 N, S=200 rpm and D=1mm) is shown in Fig. 10 and can be observed that the specimen presents minimum grooves and shallow scratches which concludes lesser wear rate due to higher concentration of reinforcement particles.

6. CONCLUSIONS

Functionally graded Al LM21 composite reinforced with Ni coated SiC is successfully fabricated by centrifugal casting technique. This composite exhibits higher wear resistance due to the formation of good bonding between aluminium matrix and Ni coated reinforcement particles. The experimental results show that the wear rate increases with respect to applied load and radial distance, whereas it decreases with rotational speed. S/N ratio analysis is used to find out the dominant parameters on the wear rate and it also gives optimum condition of process parameters such as applied load of 29 N, rotational speed of 200 rpm and radial distance of 1 mm in order to achieve minimum wear rate. From the percentage contribution of ANOVA, it is confirmed that the radial distance is a dominant factor followed by the applied load and rotational speed on wear rate of the composite. The regression equation implies that the wear rate of the composite is directly proportional to the radial distance and load but inversely proportional to the rotational speed. SEM analysis shows, delamination, deep grooves and severe scratches are dominating mechanisms on wear rate of the composite. The wear resistance of composite is maximum at particle rich region and minimum at particle less region. Thus, the fabricated functionally graded composite can be used in automotive applications such as cylinder blocks, cylinder liners, pistons and connecting rods, where abrasive wear resistance becomes of major consideration.

REFERENCES

[1] D.B. Miracle, *Metal matrix composites – From science to technological significance*, Composites Science and Technology, vol. 65, iss. 15, pp. 2526-2540, 2005, doi: 10.1016/j.compscitech.2005.05.027

[2] N. Radhika, R. Raghu, *Evaluation of dry sliding wear characteristics of LM 13 Al/B_4C composites*, Tribology in Industry, vol. 37, no. 1, pp. 20-28, 2015.

[3] J.R. Gomes, A.S. Miranda, L.A. Rocha, R.F. Silva, *Effect of functionally graded properties on the tribologicalbehaviour of aluminium-matrix composites*, Key Engineering Materials, vol. 230-232, pp. 271-274, 2002.

[4] P. Shanmugavel, G.B. Bhaskar, M. Chandrasekaran, P.S. Mani, S.P. Srinivasan, *An overview of fracture analysis in functionally graded materials*, European Journal of Scientific Research, vol. 68, no.3, pp. 412-439, 2012.

[5] Y. Watanabe, Y. Fukui, *Fabrication of functionally-graded aluminum materials by the centrifugal method*, Aluminum Transaction, vol. 2, no. 2, pp. 195-208, 2000.

[6] N. Radhika, R. Raghu, *Synthesis of functionally graded Al LM25/zirconia composite and its sliding wear characterization using response surface methodology*, Iranian Journal of Materials Science & Engineering, vol. 13, no. 4, pp. 41-52, 2016.

[7] J. Zhang, Y.Q. Wang, B.L. Zhou, Q.W. Xing, *Functionally Graded Al/Mg_2si In-Situ Composites, Prepared by Centrifugal Casting*, Journal of Materials Science, vol. 17, iss. 19, pp. 1677-1679, 1998, doi: 10.1023/a:1006635221379

[8] S. Omer, *Production of functionally graded AlB_2/Al-4% Mg composite by centrifugal casting*, Periodical of Engineering and Natural Sciences, vol. 1, no. 2, pp. 1-7, 2013.

[9] Q. Cong, F.M. Xu, J.Y. Li, Y. Tan, X.L. Shi, S.A. Shi, W. Dong, *Fabrication and properties of Al/Al-Cu functionally graded material,* Materials Science Forum, vol. 675, pp. 575-578, 2011, doi: 10.4028/www.scientific.net/MSF.675-677.575

[10] K.S. Al-Rubaie, H.N. Yoshimura, J.D.B. De Mello, *Two-body abrasive wear of Al–SiCcomposites*, Wear, vol. 233–235, pp. 444–454, 1999, doi: 10.1016/S0043-1648(99)00185-4

[11] M.O. Shabani, A. Mazahery, *Development of an extrusion process to ameliorate the tribological properties of heat treated Al Mg Si (Cu) system alloys matrix composites in consolidated state*, Tribology in Industry, vol. 34, no. 3 pp. 166-173, 2012.

[12] A. Canakci, F. Arslan, *Abrasive wear behaviour of B_4C particle reinforced Al2024 MMCs*, The International Journal of Advanced Manufacturing Technology, vol. 63, iss. 5-8, pp. 785–795, 2012, doi: 10.1007/s00170-012-3931-8

[13] S. EzhilVannan, S. Paul Vizhian, *Development and characterization of copper-coated basalt fiber reinforced aluminium alloy composites*, International Journal of Engineering Research and Technology, vol. 2, iss. 8, pp. 2278, 2013.

[14] C.S. Ramesh , R. Keshavamurthy, S. Pramod, P.G. Koppad, *Abrasive wear behavior of Ni–P coated Si_3N_4 reinforced Al6061 composites*, Journal of Materials Processing Technology, vol. 211, iss. 8, pp. 1423–1431, 2011, doi: 10.1016/j.jmatprotec.2011.03.015

[15] F. Ficici, S. Koksal, R. Kayikci, O. Savas, *Investigation of unlubricated sliding wear behaviours of in-situ AlB_2/Al metalmatrix composite*, Advanced Composites Letters, vol. 20, no. 4, pp. 109-116, 2011.

[16] M. Singh, D.P. Mondal, O.P. Modi, A.K. Jha, *Two-body abrasive wear behaviour of aluminium alloy–sillimanite particle reinforced composite*, Wear, vol. 253, iss. 3, pp. 357-368, 2002, doi: 10.1016/S0043-1648(02)00153-9

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

[18] L.V. Priyanka Muddamsetty, N. Radhika, *Effect of heat treatment on the wear behaviour of functionally graded LM13/B_4C composite*, Tribology in Industry, vol. 38, no. 1, pp. 108-114, 2016.

[19] S. Singh, M. Garg, N.K. Batra, *Analysis of dry sliding behavior of Al_2O_3/B_4C/Graphite aluminum alloy metal matrix hybrid composite using taguchi methodology*, Tribology Transactions, vol. 58, iss. 4, pp. 758-765, 2015, doi: 10.1080/10402004.2015.1015757

[20] Phool Kumar, A.M. Azadand Vinod Kumar, *Frictional and wear characteristics of stir-cast hybrid composite aluminium Al6061reinforced with SiC particulates*, International Journal of Engineering Research and Technology, vol. 2, iss. 9, pp. 7-14, 2013.

[21] A.P. Harsha, U.S. Tewari, B. Venkatraman, *Three-body abrasive wear behaviour of polyaryletherketone composites*, Wear, vol. 254, iss. 7-8, pp. 680-692, 2003, doi: 10.1016/S0043-1648(03)00142-X

[22] M.R. Rahimipour, A.A. Tofigh, M.O. Shabani, P. Davami, *The enhancement of wear properties of compo-cast A356 Composites Reinforced with Al_2O_3 nano particulates*, Tribology in Industry, vol. 36, no. 2, pp. 220-227, 2014.

[23] A.A. Tofigh, M.O. Shabani, *Efficient optimum solution for high strength Al alloys matrix composites*, Ceramics International, vol. 39, iss. 7, pp. 7483-7490, 2013, doi: 10.1016/j.ceramint.2013.02.097

[24] A. Mazahery, M.O. Shabani, *The accuracy of various training algorithms in tribological behavior modeling of A356-B_4C composites*, Russian Metallurgy, vol. 2011, iss. 7, pp. 699-707, 2011, doi: 10.1134/S0036029511070196

[25] A.N.J. Stevenson, I.M. Hutchings, *Development of the dry sand/rubber wheel abrasion test*, Wear, vol. 195, iss. 1-2, pp. 232-240, 1996, doi: 10.1016/0043-1648(96)06965-7