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Dry sliding wear characterization of squeeze cast LM13/FeCu composite using response surface methodology

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Abstract: Dry sliding wear is one of the predominant factors to be considered while selecting material for automotive and aerospace applications. Researchers have been exploring novel aluminium matrix composites (AMC), which offer minimum wear rate for various tribological applications. In this present work, an attempt has been made to reinforce LM13 aluminium alloy with copper coated steel fibers (10wt.%) using squeeze casting process and to perform dry sliding wear test using pin-on-disc tribometer. Microstructure of cast samples was examined using image analysis system to investigate the dispersion of reinforcement in matrix. Dry sliding wear test was performed by considering factors such as load (10–50 N), sliding velocity (1–5 $m \cdot s^{-1}$) and sliding distance (500–2,500 m). Wear test was performed according to the experimental design at room temperature. Three factors and five levels central composite design were used to design the experiments using response surface methodology. Based on the results of the experiments, a regression model was developed to predict the wear rate of composites and checked for its adequacy using significance tests, analyses of variance and confirmation tests. Worn surface of samples was investigated using field emission scanning electron microscope and reported with its mechanisms. Microstructure of cast samples revealed uniform dispersion of reinforcement throughout the matrix. Response surface plots revealed that wear rate of composites increases with increasing load up to 50 N with the velocity 1–5 $m \cdot s^{-1}$ and a sliding distance up to 2,500 m. However wear rate decreasesd with increasing velocity at lower loads (up to 20 N) and increased after reaching transition velocity of 2 $m \cdot s^{-1}$. Dry sliding wear process parameters were optimised for obtaining minimum wear rate and they were found to be a load of 18.46 N, velocity of 4.11 $m \cdot s^{-1}$, sliding distance of 923 m. Worn surface of samples revealed a mild wear at lower loads (up to 30 N), and severe wear was observed at high loads (40–50 N) due to higher level of deformation on the surface.

Key words: aluminium alloy; casting; response surface methodology; microstructure; wear

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Aluminium alloys have been used in automotive, space and aeronautical industries because of its light weight, high specific strength and stability at high temperatures[1,2]. However, these alloys exhibit poor tribological properties. Previous studies showed that wear resistance of aluminium alloys can be improved by reinforcing with hard particles such as SiC, Al_2O_3, B_4C, TiB_2, AlN, ZrB_2, rock dust and Fe[3–10].

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Aluminium matrix composites have been prepared by powder metallurgy, diffusion bonding, spray co-deposition, in-situ solidification and casting methods. Among all manufacturing processes, casting route has been widely accepted as a simple, viable and most economical method to produce composites[11]. Squeeze casting is the combination of gravity die casting and closed die forging, which produces near net shaped components with minimal post processing operations, minimum porosity, excellent surface finish, low operating cost, zero defects and have superior mechanical and tribological properties over the conventional castings due to fast heat transfer rate. In this process, a premeasured quantity of molten metal is poured into the preheated die and pressure is applied until the solidification process is completed [12–14].

Suresh et al. [15] investigated the mechanical and wear properties of Al-Si-Mg/beryl composites fabricated by squeeze casting and gravity casting process. It was found that squeeze cast composites could offer better tensile strength and hardness than gravity casting process, and addition of beryl particles in matrix increased the wear rate as compared to gravity cast composite.

Senthil and Amirthagadeswaran [16] studied the influence of squeeze casting process parameters on tensile strength and hardness of AC2A aluminium alloy. L27 orthogonal array was used to design the experiments. The results showed that squeeze pressure, die preheating temperature and compression holding time were significant process parameters. Squeeze pressure was the predominant contributing factor for the improvement of mechanical properties of castings.

Many researchers have attempted the reinforcement of steel wires/preform in aluminium alloys by various manufacturing processes. Bhagat [17] experimented the reinforcement of stainless steel wires in aluminium alloy using squeeze casting process, and found that tensile strength and hardness of composites increase with increasing fiber volume fraction. Several iron-aluminide intermetallic compounds such as Fe_3Al, FeAl, Fe_2Al_5, $FeAl_2$, $FeAl_3$ and Fe_2Al_7 were observed at fiber/matrix interface. Weak interface bonding between fiber and matrix caused fiber pull-out while the composite was subjected to tension.

Mandal et al. [7] investigated the wear behaviour of copper and nickel coated steel fibers reinforced in aluminium by stir casting process. It was observed that addition of steel fibers reduced the wear rate considerably at all applied loads. Copper coating on steel fibers improved the wettablity and high stirring speed during the processing resulted in uniform dispersion of reinforcement in matrix. Coating on fibers eliminated the formation of iron-aluminide intermetallic compounds and copper coated steel fibers reinforced composites offered better wear resistance than uncoated and nickel coated reinforced composites. However from the literatures, it is found that scanty research works have been carried out on the wear behaviour of copper coated steel fibers/aluminium alloy composites. In this present work, LM13 aluminium alloy was selected as matrix because of its wide range of applications like pistons in automotive industries. Copper coated steel fibers were selected as reinforcement. Three factors (load, velocity and sliding distance), five levels central composite design were selected to design the experiments using response surface methodology (RSM). A regression model has been developed to predict the wear rate of composites within the levels and checked its adequacy using significance tests, analyses of variance and confirmation tests. The main aim of this research work is to develop a regression equation to predict the wear rate of LM13/FeCu composites and analyse the influence of load (L), velocity (V) and sliding distance (D) on wear rate.

1 Materials and experimental methods

1.1 Selection of materials and composite fabrication

Commercially available steel fibers of 133 µm diameter with chemical composition as listed in Table 1, were copper coated using electroless plating technique and deoxidized in hydrogen atmosphere for 2 h at a temperature of 800 ºC [3]. Copper coated steel fibers were chopped into minimum length (500 – 1,500 µm) and the coating thickness was measured as 27 µm. LM13 aluminium alloy was selected as matrix because of its tribological applications in automotive pistons. Density of copper coated steel fiber (3.01 $g\cdot cm^{-3}$) and aluminium alloy (2.69 $g\cdot cm^{-3}$) were measured using Archimedes (water displacement) principle [18]. Bottom pouring type of squeeze casting machine with a maximum capacity of 40 tonnes as shown in Fig.1 was used to prepare composites. Die and punch were made up of H11 die steel and EN8 alloy steel, respectively. 1.2 kg of LM13 aluminium alloy with chemical composition as listed in Table 2 was melted, degassed using hexachloroethane tablets and the temperature was raised to 750 ºC. 10wt. % of copper coated steel fibers were preheated to 200 ºC using muffle furnace and added to the melt in a continuous stream while stirring was continued. The melt was stirred using stainless steel stirrer at a constant speed of 750 rpm to form vortex. Die was preheated to a temperature of 225 ºC using ceramic electric heater and the composite melt was poured using bottom pouring arrangement. Subsequently a squeeze pressure of 125 MPa was applied on the melt until the solidification was complete. Cylindrical castings of 50 mm diameter with 130 mm height were prepared using this process.

Table 1: Chemical composition of steel fiber (wt.%)

C	Si	Mn	Ni	Cr	S	Fe
0.10	0.36	18.29	0.33	3.20	0.003	Bal.

Table 2: Chemical composition of LM13 aluminium alloy (wt.%)

Si	Fe	Cu	Mn	Mg	Ni	Pb	Ti	Al
10.8	0.51	1.3	0.12	0.86	0.72	0.01	0.05	Bal

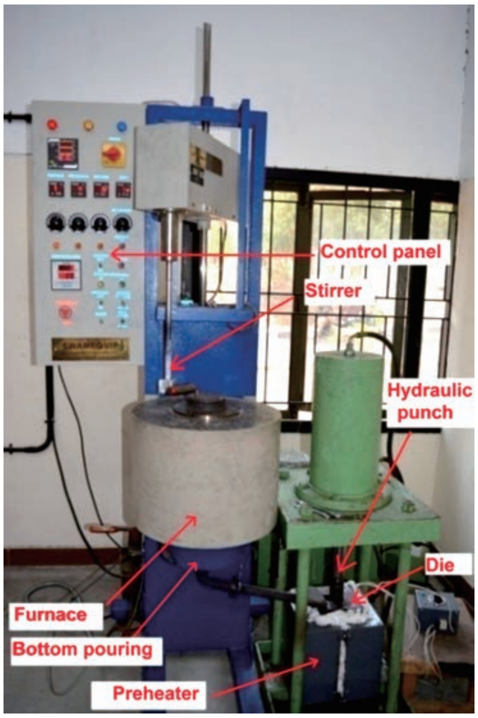


Fig. 1: Squeeze casting setup

1.2 Microstructure and hardness examination

The microstructure observation was performed for cast samples to study the dispersion of reinforcement in matrix. Linisher polisher (Model VLWS97307, U.P. National Manufacturers Ltd., India) was used to polish the samples at the earlier stages, followed by different grades of emery sheets to obtain good surface finish. Subsequently, disc polisher (Model 7800, B.S. Pyromatic India Ltd., India) was used to obtain the scratch free surface. Keller reagent was used to etch the specimen and the samples were examined using image analysis system. Samples of 20 × 20 × 10 mm^3 were prepared to investigate the hardness of composites. Hardness was measured using a semi automatic micro hardness tester (Model MVK-H11, Mitutoyo make, Japan) by applying a load of 0.02 kg for a dwell time of 15 s. Hardness test was repeated for six times and the average value of hardness was presented.

Chemical analysis of sample was performed using scanning electron microscope (Model S-3000H, Hitachi High-Technologies Corporation) with energy dispersive X- ray spectroscopy (EDS).

1.3 Design of experiments using response surface methodology

Three parameters viz., load (10–50 N), velocity (1–5 $m \cdot s^{-1}$) and sliding distance (500–2,500 m) were considered. Design expert version 10 was used to design the experiments. Central composite design was selected and it generated 20 experimental runs for three factors and five levels. Dry sliding wear test process parameters and their levels are shown in Table 3. The objective function of optimisation is to minimise the wear rate of composites. Wear rate was calculated using cumulative volume loss and sliding distance. Also a second order polynomial regression equation as shown in Eq. (1) was developed to predict the response by correlating the input parameters:

$$w = b_0+\sum b_1 x_i+\sum b_2 x_i^2+\sum b_3 x_i x_j \qquad (1)$$

where, w is wear rate (response), b_0, b_1, b_2 and b_3 are coefficients. The second term (x_i) denotes linear effect; third term (x_i^2) represents second order effect and fourth term ($x_i x_j$) represents interaction effect.

Table 3: Experimental process parameters and their levels

Parameters	Levels				
Load (N)	10	18	30	42	50
Velocity ($m \cdot s^{-1}$)	1	1.8	3	4.2	5
Sliding distance (m)	500	905	1500	2095	2500

1.4 Dry sliding wear testing

Samples of 10 mm diameter with 40 mm height were prepared as per ASTM G99 standard [4] to test the wear rate of composites. Dry sliding wear test was performed as per experimental design using pin-on-disc wear testing apparatus (Model TR-20LE-M108 and Ducom make, India) at room temperature. Pin-on-disc apparatus consists of a hardened steel disc with hardness of 64 HRc and the samples were rotated against the disc, producing sliding wear. Load was applied through a lever arrangement which makes the contact between the specimen and the disc.

Initially the samples were cleaned with acetone and the disc was polished using emery sheet to obtain a clean surface. Based on the experimental design, samples were tested and the weight of the pin was measured using electronic weighing balance with an accuracy of 0.001 mg. Wear rate was calculated using the following formula:

$$w = m/\rho D \qquad (2)$$

where, w is wear rate of specimen ($mm^3 \cdot m^{-1}$), m is mass loss (g). ρ is density ($g \cdot mm^{-3}$) and D is sliding distance (m).

Mass loss was calculated by measuring the weight of the pin before and after wear test. Density of pin was calculated using Archimedes principle and wear rate was calculated based on the mass loss, density and sliding distance for each experiment.

According to Archards law [4], wear rate is given as follows:

$$w = bLD \quad (3)$$

where, w is wear rate of specimen ($mm^3 \cdot m^{-1}$), b is wear coefficient, L is load applied in normal direction (N), and D is sliding distance (m).

Worn surfaces of samples were examined and characterized using field emission scanning electron microscope (FESEM).

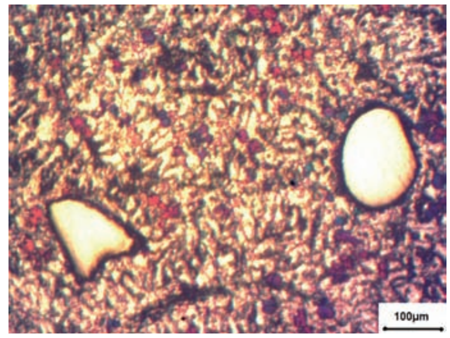


Fig. 2: Optical microstructure of LM13/FeCu composite

2 Results and discussion

2.1 Microstructure

Figure 2 shows the microstructure of FeCu/LM13 composite examined using image analyser. It can be seen that copper coated steel fibers are uniformly dispersed in matrix. During the composite preparation, composite melt stirred at a high speed of 750 rpm produced vortex, and the fibers were uniformly distributed throughout the matrix. Better interface bonding between steel fibers and aluminium alloy was observed due to the presence of copper coating on fibers. A constant pressure was applied during the solidification which minimized the porosity resulting in fine grain structure. Radhika, et al [8] also reported a similar result of uniform dispersion which were achieved using a high stirring speed in the stirring casting process.

Micrograph of FeCu/LM13 composite as shown in Fig. 3 reveals the reinforcement of copper coated steel fibers in LM13 aluminium alloy with various elements distribution in matrix and reinforcement. Figure 4 shows EDS spectrum of FeCu/LM13 composite which reveals the presence of major constitutions in matrix such as Al and Si and reinforcement (Fe). Also intermetallic compound (Fe,Cu) is observed at the interface of aluminium and steel fibers. This may be attributed to the effect of copper coating on reinforcement which prevents the formation of Fe/Al compounds at the interface of matrix and reinforcement.

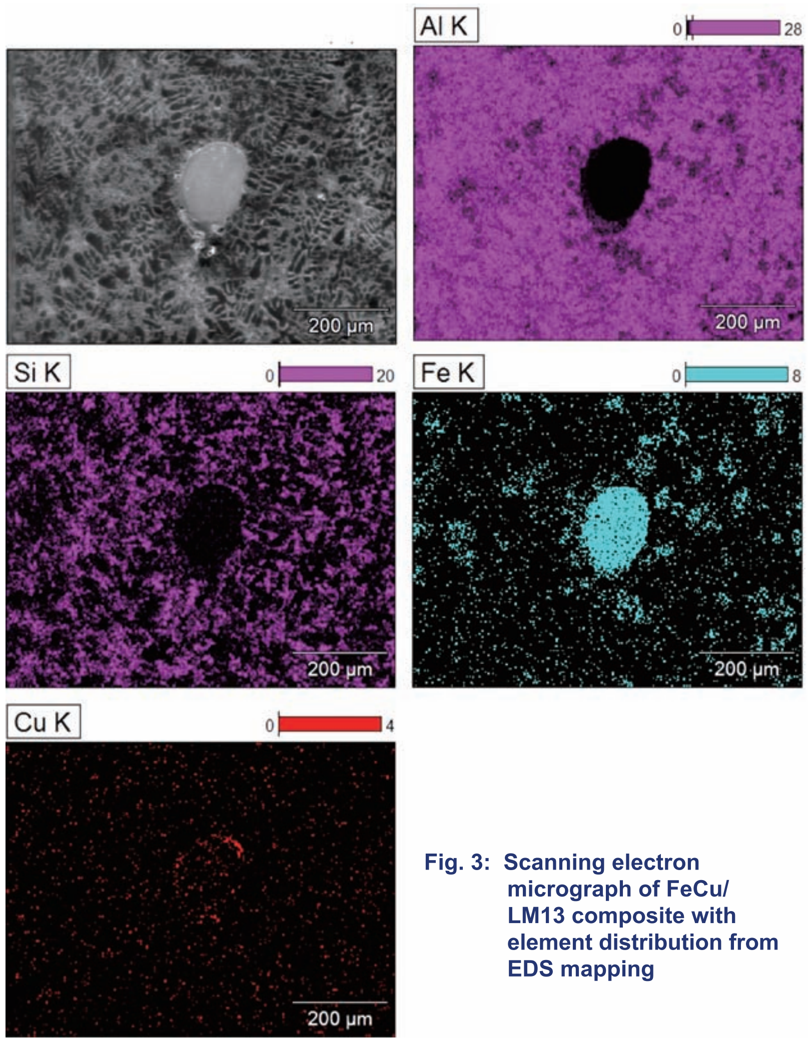


Fig. 3: Scanning electron micrograph of FeCu/LM13 composite with element distribution from EDS mapping

2.2 Characterization of dry sliding wear

Design of experiments developed using RSM for three parameters (load, velocity and sliding distance) and five levels are shown in Table 4. Six trials were performed for each experiment and average wear rate of composite was presented. During the wear test, it was observed that weight loss of pin decreased due to the reinforcement of copper coated steel fibers in LM13 aluminium alloy.

R^2 and adjusted R^2 values are found as 98.75

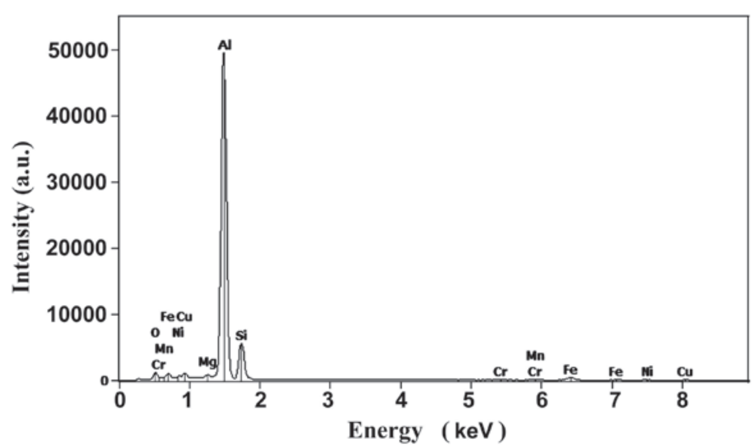


Fig. 4: Spectrum of FeCu/LM13 composite EDS

Table 4: Experimental design matrix and results of wear rate

Test run	Load (N)	Velocity ($m \cdot s^{-1}$)	Sliding distance (m)	Wear rate ($mm^3 \cdot m^{-1}$)
1	30	3	500	0.00282
2	10	3	1,500	0.00238
3	42	4.2	2,095	0.00354
4	18	4.2	905	0.00234
5	42	4.2	905	0.00328
6	30	1	1,500	0.00275
7	30	5	1,500	0.00298
8	30	3	1,500	0.00287
9	30	3	1,500	0.00285
10	30	3	1,500	0.00285
11	18	1.8	905	0.00274
12	50	3	1,500	0.00340
13	30	3	1,500	0.00292
14	18	1.8	2,095	0.00274
15	42	1.8	2,095	0.00294
16	42	1.8	905	0.00284
17	30	3	1,500	0.00292
18	18	4.2	2,095	0.00259
19	30	3	1,500	0.00280
20	30	3	2,500	0.00297

and 97.63%, respectively. These values are very closer to each other and the parameters were tested for the significance at 95% confidence level. Significant parameters are considered in regression model and insignificant parameters are removed without affecting the accuracy. The results showed that load, velocity, sliding distance, interaction of load and velocity, interaction of velocity and sliding distance have more significant effects on wear rate. In addition, the interaction of load and sliding distance, second order terms of load, velocity and sliding distance have the p value greater than 0.10, which are not significant. A regression equation is obtained for predicting the wear rate and is given as:

$$w = b_0 + b_1L + b_2V + b_3D + b_4LV + b_5VD \quad (4)$$

where, w is wear rate of specimen ($mm^3 \cdot m^{-1}$), b_0, b_1, b_2, b_3, b_4 and b_5 are regression coefficients, L is load applied in normal direction (N), V is sliding velocity ($m \cdot s^{-1}$) and D is sliding distance (m). The coefficients of regression equation are listed in Table 5.

This developed model can predict the wear rate of composites with respect to input parameters, viz., load, velocity and sliding distance. To check the accuracy of the regression model, confirmation tests were performed and new sets of input parameters were selected which differed from the earlier experimental design developed using central composite design. Wear rate was calculated for the new sets of dry sliding wear parameters which were compared with predicted wear rate

Table 5: Coefficients of regression equation for wear rate of FeCu/LM13 composites

	Regression coefficients					
	b0	b1	b2	b3	b4	b5
Value	0.00362	0.000017	0.00054	0.00000025	0.000014	0.00000012

Table 6: Comparison of wear rate using regression analysis and experimental results

Test run	Load (N)	Velocity ($m \cdot s^{-1}$)	Sliding distance (m)	Actual wear rate ($mm^3 \cdot m^{-1}$)	Predicted wear rate ($mm^3 \cdot m^{-1}$)	Error (%)
1	5	1.5	800	0.00287	0.002779	3.27
2	15	3.5	1,600	0.00243	0.002487	-2.29
3	25	4.5	2,400	0.00321	0.003041	5.56

and the results are shown in Table 6. The percentage of error was calculated using experimental and predicted wear rates and the error percentage was within ± 6, which confirms that the developed model can predict the wear rate with greater accuracy. Several researchers used central composite design and developed the regression model to predict the response[20–23]. The relationship between predicted and actual wear rates is shown in Fig. 5. It can be seen that there is a good agreement between predicted and actual wear rates, and the values are scattered on both sides and the slope is close to unity.

Analysis of variance (ANOVA) for wear rate is shown in Table 7. The significance of each term in regression model is checked at 95% confidence level and 5% significance level. The load, velocity, sliding distance, interaction of load and velocity, interaction of velocity and sliding distance have significance in wear rate (p value < 0.05). Also the lack of fit has F value of 0.82, which is lesser than the standard F value of 5.05 (95% confidence level), hence the developed model is adequate with greater accuracy and it can be used to predict the wear rate within these input parameters and their levels.

Figures 6 – 8 show the response surface plot of actual wear rate for all pairs of process parameters. Figure 6 shows the interaction of load and velocity with respect to wear rate. It can be seen that wear rate of composites increases with increasing load at all levels of velocity and sliding distances (Figs. 6 and 7). During the wear test, the load was applied using lever attachment, which made the composite pin closer contact to the rotating steel disc. As load increases from 10 to 50 N,

Table 7: Analysis of variance for wear rate

Source	Sum of Squares	Degree of freedom	Mean square	F value	p - value
Model	0.000001567	9	0.0000001741	87.86	< 0.0001*
Load (N)	0.000001083	1	0.000001083	546.57	< 0.0001*
Velocity (m·s^{-1})	0.000000060	1	0.00000006045	30.50	0.0003*
Sliding distance (m)	0.000000026	1	0.00000002603	13.14	0.0047*
Load (N) x Velocity (m·s^{-1})	0.000000338	1	0.0000003383	170.73	< 0.0001*
Load (N) x sliding distance (m)	0.000000003	1	0.0000000027	1.40	0.2640
Velocity (m·s^{-1}) x sliding distance (m)	0.000000055	1	0.00000005538	27.94	0.0004*
Load (N) x load (N)	0.0000000001	1	0.00000000015	0.078	0.7863
Velocity (m·s^{-1}) x velocity (m·s^{-1})	0.0000000003	1	0.00000000032	0.16	0.6955
Sliding distance (m) x sliding distance (m)	0.0000000004	1	0.00000000042	0.22	0.6516
Residual	0.0000000198	10	0.00000000198		
Lack of fit	0.0000000089	5	0.00000000178	0.82	0.5859
Pure error	0.0000000109	5	0.00000000218		
Total	0.00000158	19			

R^2 : 0.9875, adjusted R^2: 0.9763; *significant at $p < 0.05$

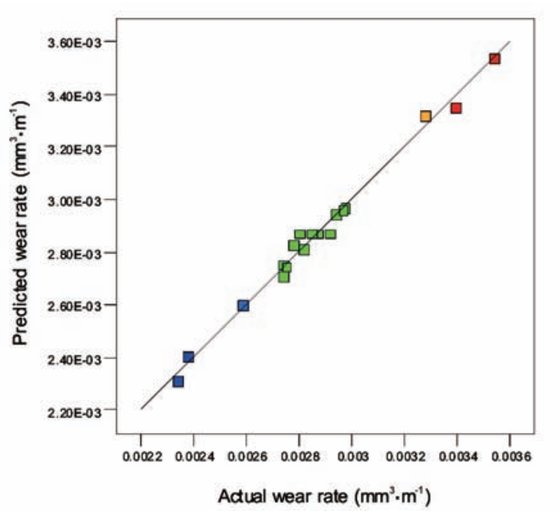


Fig. 5: Scatter diagram for wear rate of FeCu/LM13 composite

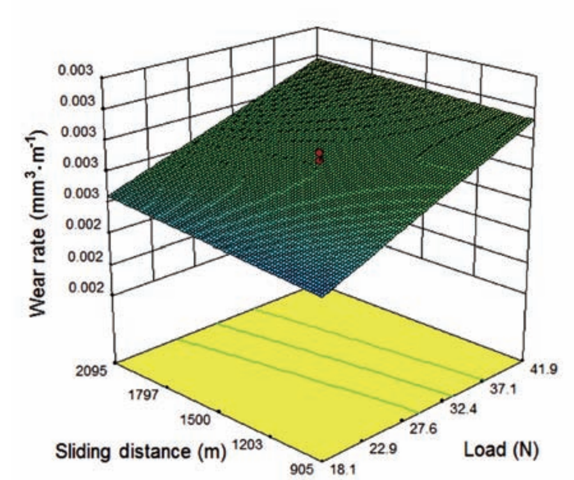


Fig. 7: Response surface plot of wear rate as a function of load and sliding distance for a constant velocity of 3 m·s^{-1}

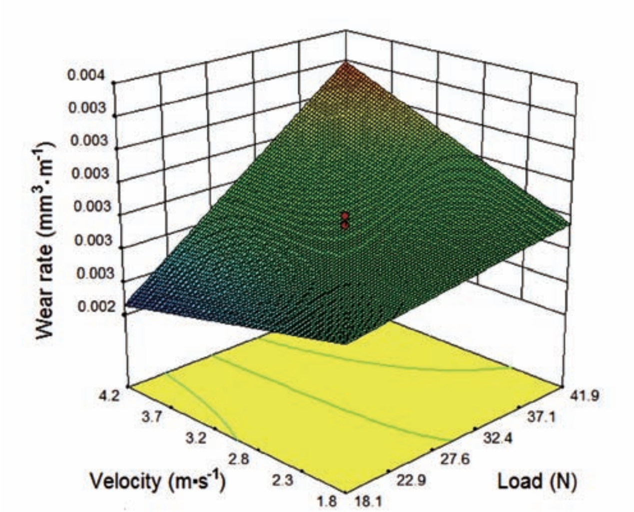


Fig. 6: Response surface plot of wear rate as a function of load and velocity for a constant sliding distance of 1,500 m

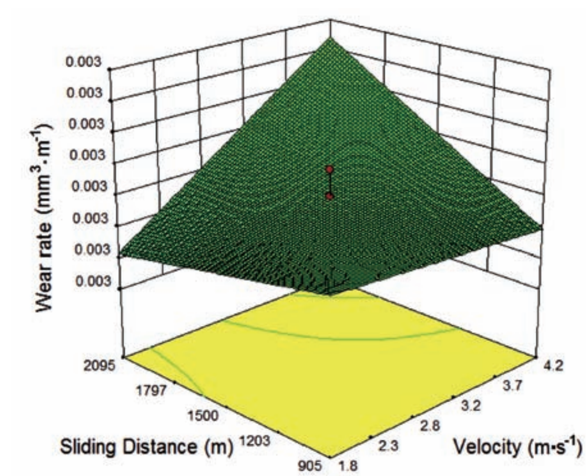


Fig. 8: Response surface plot of wear rate as a function of velocity and sliding distance for a constant load of 30 N

the contact between the pin and disc reduces which in turn increases the temperature at the interface resulting in increased wear rate. The same wear behaviour has been obtained in other studies by our research team [4,24]. The increase in sliding velocity (1.8–4.2 m·s^{-1}) decreases the wear rate of composites at lower loads. Wear rate of composite is found minimum at the earlier stage and reaches the maximum value while increasing load and sliding velocity. At lower velocity, the contact time between pin with disc is more, which increases the amount of material loss resulting in high wear rate. As sliding velocity increases, the temperature at the interface increases which forms a mechanically mixed layer (MML) over the surface of pin. This oxide layer prevents the specimen from adhesive wear, which reduces the wear rate of composite at minimum load. As load increases from 10 to 50 N, the oxide layer breaks down that causes high wear rate at 50 N and velocity of 5 m·s^{-1}. Similar wear mechanism has been observed in other studies [9,25] which reported that wear rate of materials increases with increment in sliding velocity.

The interaction of load and sliding distance with wear rate is depicted in Fig. 7. The wear rate increases with increasing sliding distance at all levels of loads. Figure 8 shows the relationship between velocity and sliding distance with respect to wear rate. It is observed that wear rate increases with increasing velocity and sliding distance. At earlier stage, wear rate of composites decreases slightly with increasing sliding distance. This is due to presence of copper coated steel fibers that protrude at the surface, which establishes contact with the counterface. As sliding distance and velocity increases, the hard asperities at the surface smoothes after run for a certain sliding distance. A few researchers [3,10] also reported the same mechanism that uniform contact between pin surface and disc resulting minimum wear rate of specimen.

2.3 Optimisation of dry sliding parameters

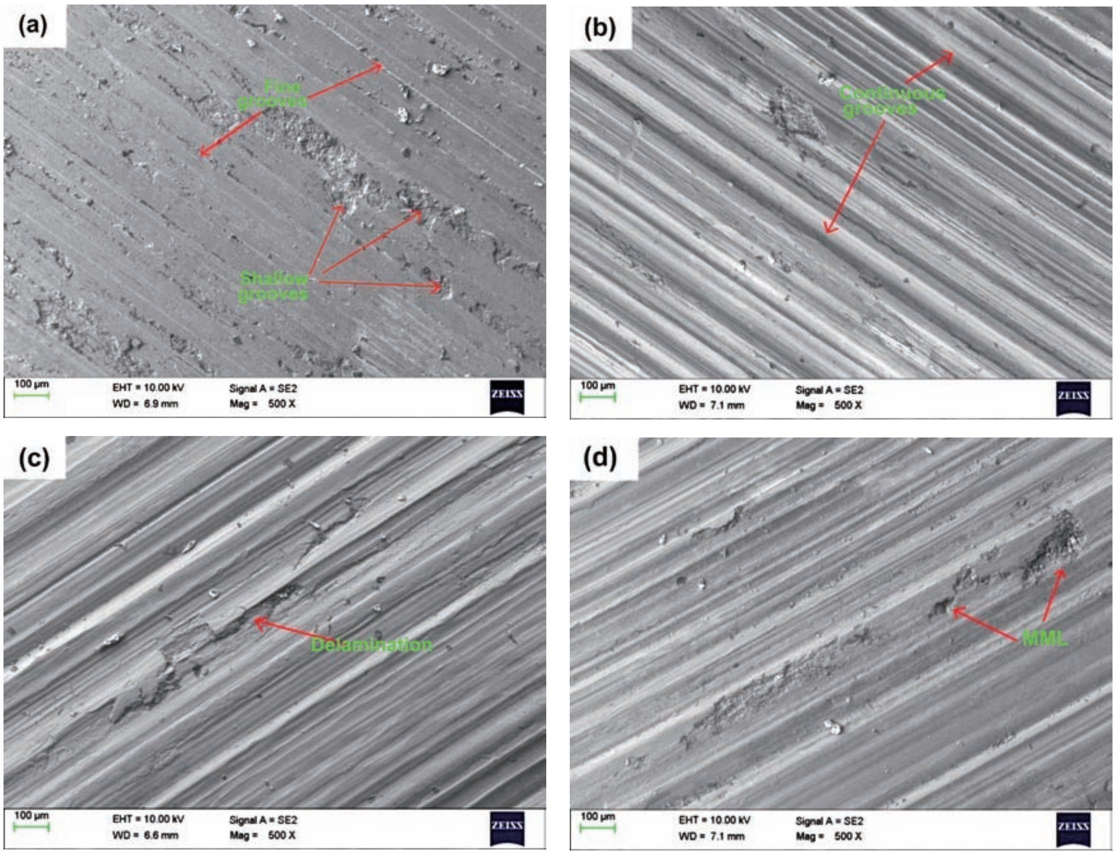
Dry sliding parameters viz., load (10–50 N), velocity (1–5 m·s^{-1}) and sliding distance (500–2,500 m) were considered in this present work and experiments were carried out according to the experimental design using response surface methodology. Wear rate of samples were measured and response surface were plotted which reveals the interaction of load, velocity and sliding distance with wear rate. The main objective of optimisation process was to obtain minimum wear rate for FeCu/LM13 composites. During the experimental work, a minimum wear rate of 0.00234 mm^3·m^{-1} (Table 4) was achieved. Hence the target wear rate of 0.00233 mm^3·m^{-1} was used as input for optimisation process, which is less than the minimum experimental wear rate (0.00234 mm^3·m^{-1}). A load of 18.46 N, velocity of 4.11 m·s^{-1} and a sliding distance of 923 m were obtained as the optimum dry sliding parameters for the wear rate of 0.00233 mm^3·m^{-1} .

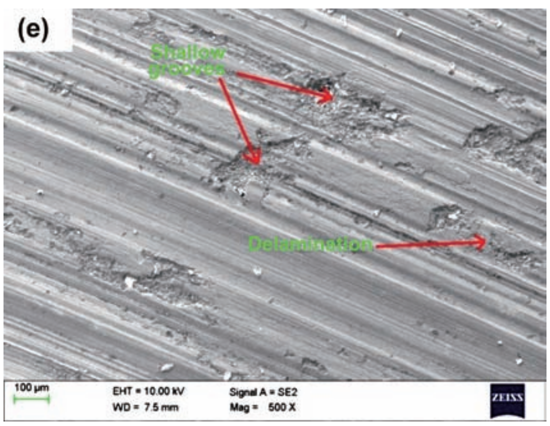
2.4. Worn surface analysis

Figure 9 shows the worn surface of LM13 – 10wt% copper coated steel fibers reinforced composites tested at dry sliding condition. Worn surface of composites is shown in Fig. 9(a-c). It can be seen from Fig. 9(a) that there are shallow grooves at some regions in addition to fine grooves at lower load (10 N). The wear rate is lower at lower load, since the reinforcement particles act as load bearing elements which avoid the contact between pin and disc. These elements would bear the load and prevent the transfer of load to the LM13 aluminium alloy, resulting in minimum wear rate. Figure 9(b) shows that the worn surface of composite tested at 30 N have continuous grooves parallel to the sliding direction. While increasing load from 10 to 30 N, the contact between pin and disc reduces which results in more amount of material removal from the pin. This removed material slide along the surface of specimen while friction counterface rotates continuously, resulting in continuous grooves on the surface of pin. The worn surface of composite tested at 50 N as shown in Fig. 9(c), reveals local delamination on the surface in addition to continuous grooves. This is due to the generation of high temperature at the interface. As load increases from 30 to 50 N, more amount of heat is generated due to friction which results in deformation of material and in removal of more materials. Wear mechanism changes from mild adhesion wear to severe delamination when load increases from 10 to 50 N. These results are verified with wear trends as observed from the surface plots (Figs. 6 and 7) that wear rate increased linearly with increasing load from 10 to 50 N. The same phenomenon has been observed in a previous study [10].

In general, wear rate of composites increases with increasing load, but the severity of wear is delayed at all loading conditions. This is due to the surface hardness of composites, as the composite has the surface hardness of 251 VHN which resists the amount of deformation at all loading conditions. Hardness of composites increases by reinforcing hard copper coated steel fibers in LM13 aluminium alloy, which reduces the wear rate at all loads. The lower wear rate can also relate to the materials and process parameters. LM13 aluminium alloy has high silicon content of 10.9%, which imparts higher hardness and results in wear resistance to matrix. Also the preheating of reinforcement, stirring at high speed, bottom pouring of composite, and application of squeeze pressure result in uniform dispersion of steel fibers in LM13 aluminium alloy and minimize the porosity in composites. Further, magnesium and silicon content in aluminium alloy promote the wettablity, and copper coating on reinforcement offers better interface bonding between reinforcement and matrix. This good interface bonding and uniform dispersion of reinforcement in matrix result in lower wear rate at all testing conditions.

Figures 9(d) and (e) show the transition of wear mechanism of composite from the sliding velocity of 1 to 3 m·s^{-1}. The worn surface depicted in Fig. 9(d) (V = 1 m·s^{-1}) reveals less amount of material removal than that shown in Fig. 9(e) (V = 3 m·s^{-1}). Increase in sliding velocity causes more frictional heat in the contact area [26]. At lower velocity, low frictional heat is developed in the contact area, low amount of material removal results in minimum wear rate and mild damage on the surface. Figure 9(e) shows that the worn surface of composite tested at





(a) L = 10 N, V = 3 m·s^{-1}, D = 1,500 m
(b) L = 30 N, V = 3 m·s^{-1}, D = 1,500 m
(c) L = 50 N, V = 3 m·s^{-1}, D = 1,500 m
(d) L = 30 N, V = 1 m·s^{-1}, D = 1,500 m
(e) L = 30 N, V = 3 m·s^{-1}, D = 500 m

(L – Load, V – Velocity and D – Sliding distance)

Fig. 9: Worn surfaces of FeCu/LM13 composite tested at various conditions

a velocity of 3 m·s^{-1} have shallow grooves and delamination on the surface. It may be attributed to the high frictional heat developed in the contact area due to high velocity. The results are verified with wear trends as observed from the response surface plots (Fig. 8) that wear rate of composites increases with an increase in the sliding velocity. The same mechanism was observed in previous studies [10,27] that increase in velocity cause severe damage on the surface of pin.

Figure 10 shows the worn surface of composite tested at optimum conditions [L = 18.46 N, V= 4.11 m·s^{-1}, D = 923 m]. The accuracy of developed regression model is checked by investigating the worn surface tested at optimum process parameters. Fine scratches are observed at some regions on the surface resulting in minimum wear rate. This ensures the accuracy of developed regression model which predicts the wear rate within the ranges of load, velocity and sliding distance.

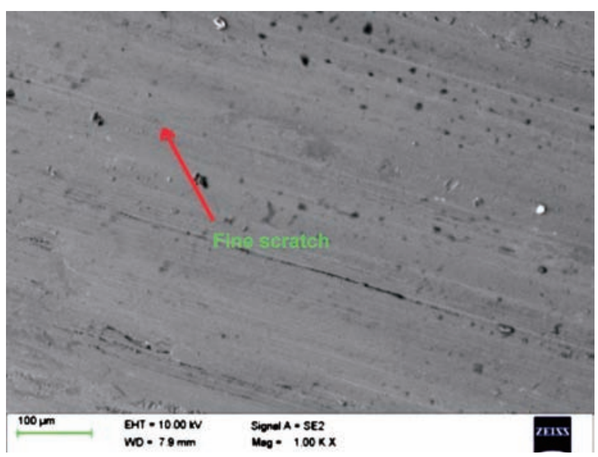


Fig. 10: Worn surface of FeCu/LM13 composite tested at optimum conditions: L = 18.46 N, V = 4.11 m·s^{-1}, D = 923 m (L – Load, V – Velocity and D – Sliding distance)

3 Conclusions

(1) A regression model is developed to predict the wear rate of composite and the error percentage is within ± 6.

(2) Response surface plots reveal that wear rate of composites increases with increasing load up to 50 N with the velocity 1–5 $m \cdot s^{-1}$ and a sliding distance up to 2,500 m. However wear rate decreases with increasing velocity at lower loads (up to 20 N) and increases after reaching transition velocity of 2 $m \cdot s^{-1}$.

(3) 18.46 N load, 4.11 $m \cdot s^{-1}$velocity and 923 m sliding distance are obtained as the optimum dry sliding parameters for obtaining minimum wear rate of 0.00233 $mm^3 \cdot m^{-1}$.

(4) Worn surface of composite shows shallow grooves at lower loads (upto 30 N) and severe wear at higher loads (40–50 N) resulting in delamination and the highest wear rate being 0.00354 $mm^3 \cdot m^{-1}$.

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