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Dry Sliding Tribological Studies of ZA-27/Al_2O_3 Metal Matrix Nanocomposites by using Response Surface Methodology

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Keywords：ZA-27 alloy, Al_2O_3 nanoparticles, wear rate, RSM, SEM.

ABSTRACT

Alumina nanoparticles reinforced with ZA-27 matrix material are having considerable attention due to its improved wear resistance and high strength. ZA-27 alloy reinforced with various weight percentages of alumina nanoparticles for the fabrication of nanocomposites by using ultrasonic assisted stir casting process. Tribological behavior of ZA-27/Al_2O_3 nanocomposites was examined by using Pin on disc friction and wear testing machine. Response surface methodology (RSM) is used to evaluate the influencing parameters on nanocomposites according to the experimental plan by using design of experiments. The significant effect of various factors such as reinforcement content, sliding distance, applied load and sliding speed were investigated by using ANOVA. Tribological behavior such as dry sliding wear and friction coefficient of nanocomposites decreases with increase in filler content. The reinforcement content is most significant influencing factor for the tribological properties of ZA-27/Al_2O_3 nanocomposites. The interaction between the distance – speed and reinforcement content – speed also influences the wear rate of the nanocomposites. The mathematical equations were developed for wear rate and coefficient of friction of ZA-27/Al_2O_3 nanocomposites with the help of RSM. The microstructures of the wear surfaces were studied by using Scanning electron microscope (SEM).

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INTRODUCTION

In recent years' metal matrix composites (MMCs) have involved significant attention due to its high stiffness, higher specific strength and superior properties at higher temperatures over monolithic metals. MMCs are reflected as future industrial resources for several wear related applications because of its outstanding mechanical and tribological properties. Now a days MMCs are measured as favorable materials with their applications particularly in automotive industries, aerospace and aircraft (Miroslav Babic et al., 2011; K.H.W. Seah et al., 1996; Sirong Yu et al., 1996). The Zinc aluminium alloys are showing significant attention among the industrial applications due to the excellent fluidity, superior mechanical properties and good wear resistance. The low cost, high strength and low casting temperature of the ZA alloys are getting extensively approval in bearing applications which are capable of substituting the traditional aluminium and bronze bearing materials (Srimant Kumar Mishra et al., 2014; Gencaga Purcek et al., 2002; G. Ranganath et al., 2001). ZA-27 alloy is one which has shown good wear resistance and hardness extensively greater compare to regular cast aluminium alloys (S.C. Sharma et al., 1997). Alumina particles reinforced in ZA-27 matrix alloy have been observed that at low sliding speed, considerably base alloy is showing lower wear rate compare to composite. The wear rate of ZA-27 matrix alloy increases then composites at higher speeds (O.P. Modia., 2007). The influence of the process parameters like speed, load, distance and filler content on friction coefficient of silicon carbide (SiC) and graphite (Gr) particles at equal weight percentages reinforced with aluminium matrix were studied by using pin on disc machine according to the experimental plan. It was observed that the sliding speed and load are the influencing parameters whereas there is no effect of the friction coefficient of composites with sliding distance and filler content (S. Suresha et al 2012). Tribological behavior of the silicon having zinc-aluminium based alloy for journal bearings were fabricated by using permanent mould casting. The results show that the silicon modified zinc-aluminium (ZA-27) based alloy increases wear resistance properties compare to ZA-27 alloy (Hamdullah Cuvalc et a1, 2004; Marjorie et al., 1996)

Zircon particles reinforced with ZA-27 alloy at different weight percentages were fabricated by using liquid metallurgy method. The dry sliding wear behavior of composites was tested by using pin on disc machine. If the reinforcement content improves the wear rate of the composites decreases as compare to base alloy (Dinesh Kumar K et al., 2014; Miroslav Babic et al., 2010; S.C. Sharma., et al 1999). The Al6061 alloy reinforced with rock dust were prepared by using stir casting method, unlubricated sliding wear behavior of composites were tested by using of pin on disc testing machine. The tests were conducted with help of Taguchi's L27 orthogonal array and effect of control parameters on wear rate was carried out by using ANOVA. The result proves that filler content of rock dust in Al 6061 alloy will increase the wear resistance of the composites (K. Soorya Prakash et al., 2015). To minimize the number of experiments for unlubricated wear behavior of Al alloy reinforced with the ZrB_2 composites the central composite rotatable design was used. From the results it was observed that reinforcement of ZrB_2 particles in Al alloy enhance wear performance of composites (I. Dinaharan et al., 2012). Unlubricated sliding wear performance of graphite reinforced in Al alloy was conducted by using pin on disc. The experiments were carried out based on the experimental plan with the help of response surface methodology, the results reported that most influencing factor is sliding distance and the load has shown negligible effect on the wear (Pardeep Sharma et al., 2016). The wear resistance of the Al_2O_3 particles reinforced in Al alloy were studied by using pin on disc. The effect of alumina particles of the composites is shown superior wear resistance than base alloy (A. Pramanik, 2016).

The silica reinforced composites are fabricated by means of three various kinds of solid lubricants (MoS_2, h-BN & graphite) by power metallurgy. The friction and wear properties of these composites was investigated to find the influence of speed, load and solid lubricants by using design of experiments. The results reported that among the three composites, the most effective lubricant for improving dry sliding wear behavior of composites is MoS_2 lubricant for selected experimental domain. The solid lubricant is most substantial parameter affecting dry sliding wear behavior of composites among sliding speed, brake load and solid lubricant (T. Ram Prabhu, 2015; Bekir Sadk U et al., 2010). Stir casting technique is used to prepare mica and SiC particles reinforced in Al356 alloy to form hybrid composites. The wear and mechanical properties of hybrid composites were studied. The result shows that better mechanical properties are achieved with increase in SiC particles and the wear resistance improves with increase in mica particles of composites (T. Rajmohan et al., 2013). The current research article is focused on preparation of base alloy reinforced with different weight percentages which varied from 0.5, 1 and 1.5 wt % of Al_2O_3 nanoparticles to form nanocomposites by using ultrasonic assisted stir casting method. The unlubricated sliding wear behavior of nanocomposites were tested by using pin on disc testing apparatus according to the experimental plan using RSM. The influencing effects of various process parameters such as filler content, sliding distance, load and speed were analyzed by using analysis of variance (ANOVA). The mathematical model was developed for wear rate of the nanocomposites.

MATERIALS AND METHODS

Fabrication of nanocomposites

For the fabrication of the nanocomposites, the matrix material was used as ZA-27 alloy with chemical composition as per the ASTM B669-82 which is shown in the table 1. The alumina (Al_2O_3) nanoparticles of 50nm size were used as reinforcement material for preparation of nanocomposites.

Table 1. Chemical composition of the ZA-27 alloy

Material	Al	Cu	Mg	Zn
Weight percentage	25-28	1-2.5	0.01-0.02	Balance

ZA-27 alloy is placed in a graphite crucible and heated above its melting temperature of 800^0C in the electric resistance furnace. After melting the matrix alloy stirring is done by using a mechanical stirrer for 3 minutes for homogenization of the base alloy. The Al2O3 nano particles of various weight percentages (0.5, 1 & 1.5 wt %) are filled in the aluminium foils like pallets which are pre-heated upto 500^0C to avoid moisture and thermal stability of melt of the base alloy. While stirring is in progress add the pre-heated nano Al_2O_3 particles at different weight percentages (wt %) and stir it for 5 minutes. Once the ZA-27 alloy and Al_2O_3 nano particles are dispersed in the molten metal then stop the stirring process and continue the process with ultrasonification of the nanocomposites with the help of an ultrasonic probe about 3 minutes was done. After successful addition of Al_2O_3 nanoparticles in the base metal the composite melt was pour into a mild steel die in the form of cylindrical rods and wait for some time to solidify the melt. The specimens are removed from the die after solidification and standard specimens were prepared for the characterization and analysis of the composites. The experimental setup for preparing the nanocomposites and the cast specimen were shown in the figure 1 & 2.

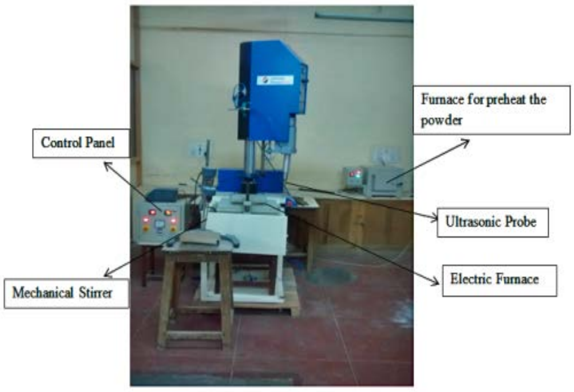

Fig .1. Experimental setup of Ultrasonic assisted stir casting machine

Fig.2. Cast Specimen of ZA-27 nanocomposite

Wear and Friction Characteristics

Wear and friction behavior of the nanocomposite specimens was tested with the help of Pin on disc friction and wear testing machine as per ASTM G99-95 standards. The tests were carried out at different loads and speeds were applied on nanocomposites which are pressed against the rotating hardened steel disc of EN32. To estimate average weight of nanocomposites materials before and after wear test were measured with help of electronic weighing machine. The average weight loss was calculated as a remainder between the specimen weight before and after dry sliding wear test and wear rate of nanocomposites were determined. The friction coefficient of nanocomposites was given by tribometer attached to the pin on disc machine. The reinforcement content, speed, distance and applied load were taken as input parameters to study the tribological characteristics of the nanocomposites.

Response surface methodology (RSM)

In traditional method it is very difficult to estimate interaction effects of the functional parameters. Response surface methodology is a statistical technique having several benefits compare to traditional methods. The experimental plan is used to conduct dry sliding wear behavior of the nanocomposites with help of design of experiment software (Design expert 9.0). The central composite face centered design is used to conduct the experiments to examine the wear rate of the composites. In present study the number of control factors is four and the levels are three, the number of experiments was conducted is 30 with actual values.

Table 2. Control factors and their levels with actual values

Factors	Levels		
	-1	**0**	**1**
(R) Reinforcement content (Wt %)	0.5	1	1.5
(S) Sliding speed (m/s)	1	2	3
(D) Sliding distance (m)	1000	2000	3000
(L) Applied load (N)	30	60	90

The control parameters which affect the tribological properties are filler content, distance, load and speed. Table 2, shows the control factors and their selected levels were taken for investigation of tribological behavior of nanocomposites. The mathematical model will be developed for wear rate and friction coefficient of the ZA-27/Al_2O_3 nanocomposite by using RSM.

RESULTS AND DISCUSSIONS

Wear and Friction Behavior

The wear and friction properties of nanocomposites were study by using central composite design (CCD) to study influencing control factors among reinforcement material, sliding distance, applied load and sliding speed. Table 3 shows the experimental design with actual values and responses of nanocomposites. The analysis of variance (ANOVA) of the model was carried out with help of design Expert software 9.0 to investigate the substantial parameters and interactions affecting the wear rate and friction coefficient. The ANOVA are used to study the control factors which are significantly affected by the wear rate and friction coefficient of the ZA-27 nanocomposites. The best combinations of the control parameters are predicted based on the ANOVA. Table 4 shows the result of the

ANOVA analysis for wear rate of ZA-27/Al_2O_3 nanocomposites.

Table 3. Experimental design with actual values and responses of nanocomposites

Expt No	Speed (m/s)	Dist. (m)	Load (N)	Filler (Wt %)	Wear Rate (mm^3/m)	COF
1	1	1000	90	0.5	3.171	0.45
2	1	1000	90	1.5	1.834	0.35
3	1	2000	60	1	2.49	0.48
4	2	2000	90	1	3.196	0.41
5	1	1000	30	0.5	2.814	0.58
6	3	2000	60	1	3.468	0.43
7	2	2000	60	1	2.272	0.48
8	3	1000	90	1.5	2.992	0.28
9	3	1000	30	1.5	2.446	0.38
10	3	3000	30	1.5	0.895	0.41
11	2	2000	60	1	2.62	0.49
12	1	3000	30	0.5	2.618	0.56
13	3	3000	90	1.5	1.354	0.31
14	2	3000	60	1	2.145	0.46
15	1	1000	30	1.5	1.441	0.41
16	2	2000	60	0.5	4.347	0.53
17	3	1000	90	0.5	7.75	0.41
18	1	3000	90	0.5	3.948	0.43
19	1	3000	30	1.5	1.397	0.42
20	3	3000	90	0.5	4.235	0.36
21	2	2000	60	1	2.403	0.47
22	2	2000	60	1.5	2.555	0.42
23	2	2000	60	1	2.99	0.49
24	2	2000	60	1	3.055	0.48
25	3	3000	30	0.5	4.158	0.54
26	3	1000	30	0.5	7.12	0.58
27	1	3000	90	1.5	1.689	0.41
28	2	2000	60	1	2.914	0.49
29	2	1000	60	1	2.87	0.46
30	2	2000	30	1	2.229	0.47

The reinforcement content is the most significant parameter which will affect the wear rate of nanocomposites is observed from the ANOVA table. The interaction affects such as speed-distance (SD) and speed-reinforcement (SR) will affect more compare the individual effect of distance and load. The R^2 and adjusted R^2 value are 93% and 90%. The percentages contribution of individual factors and their interactions for wear rate of nanocomposites were shown in column 7 from ANOVA table.

Table 4. Analysis of variance for wear rate of ZA-27 composites

Source	**Sum of Squares**	**DF**	**Mean Square**	**F-Value**	**P- Value Prob.> f**	**P (%) Cont.**
Model	59.47203	8	7.434004	34.94442	< 0.0001	93.5
S	9.412014	1	9.412014	44.2423	< 0.0001	14.7
D	5.554445	1	5.554445	26.10933	< 0.0001	8.7
L	1.417367	1	1.417367	6.662501	0.0174	2.3
R	30.83219	1	30.83219	144.9304	< 0.0001	48.3
SD	6.32271	1	6.32271	29.72065	< 0.0001	9.8
SR	5.506062	1	5.506062	25.8819	< 0.0001	8.7
DR	0.39627	1	0.39627	1.862716	0.1868	0.6
LR	0.030976	1	0.030976	0.145606	0.7066	0.5
Residual	4.467496	21	0.212738			6.8
Cor Total	63.93953	29				100

Table 5. Analysis of variance for coefficient of friction of the nanocomposites

Source	**Sum of Squares**	**DF**	**Mean Square**	**F-Value**	**P- Value Prob.> f**	**P (%) Cont.**
Model	0.147934	14	0.010567	53.7983	< 0.0001	98
S	0.00845	1	0.00845	43.02154	< 0.0001	6.6
D	1E-04	1	1E-04	0.509131	0.4865	0.07
L	0.049089	1	0.049089	249.9266	< 0.0001	34.8
R	0.06125	1	0.06125	311.8425	< 0.0001	43.8
SD	0.000225	1	0.000225	1.145544	0.3014	0.15
SL	0.003025	1	0.003025	15.4012	0.0014	2.55
SR	0.0004	1	0.0004	2.036522	0.174	0.27
DL	1E-04	1	1E-04	0.509131	0.4865	0.07
DR	0.004225	1	0.004225	21.51077	0.0003	2.85
LR	0.007225	1	0.007225	36.78469	< 0.0001	4.89
S^2	0.00053	1	0.00053	2.696788	0.1213	0.35
D^2	0.000224	1	0.000224	1.140469	0.3024	0.16
L^2	0.002224	1	0.002224	11.32308	0.0043	1.48
R^2	8.42E-05	1	8.42E-05	0.428843	0.5225	0.06
Residual	0.002946	15	0.000196			1.95
Cor Total	0.15088	29				100

Table 5. shows the ANOVA results of the friction performance of the ZA-27/Al_2O_3 nanocomposites. The filler content and load is the significant parameters which will affect the friction coefficient of composites are observed from ANOVA table. The interaction affects such as load-reinforcement (LR) will affect slightly on the friction coefficient of composites. The R^2 and adjusted R^2 value are 98% and 96%. The difference between the R^2 and R^2 (adj) values are minimum which improves the prediction capability of the model. The percentages contribution of individual factors and their interactions for the friction coefficient of the nanocomposites were shown in column 7 from ANOVA table.

Regression equation for wear rate and friction coefficient using RSM

RSM was used to generate mathematical model for wear rate and friction coefficient of nanocomposites. From the ANOVA the most influencing parameters and their combinations are involved and insignificant parameters and their combinations are excluded. The mathematical model was generated in terms of coded parameters for the wear rate and friction coefficient of nanocomposites after excluding insignificant parameters is given below.

Wear Rate = +2.98 + 0.72 * S - 0.56 * D + 0.28 * L - 1.31 * R - 0.63 * S * D - 0.59 * S * R + 0.16 * D* R - 0.044 * L * R. (1)

Friction coefficient = +0.48-0.022*S+0.000*D-0.052 * L-0.058 * R-3.750E-003 * S * D-0.014 * S * L-5.000E-003 * S * R+2.500E-003 * D * L+0.016 * D * R+0.021 * L * R-0.014 * S^2-9.298E-003 * D^2-0.029 * L^2+5.702E-003 * R^2 (2)

Effects of individual parameters on wear rate and friction coefficient

Effects of specific parameters on the wear rate of the nanocomposites are shown in the figure 3-6. The most influencing parameter on the wear rate of nanocomposites was filler content. The wear rate of nanocomposites decreases by improving in the distance as shown in fig 3.

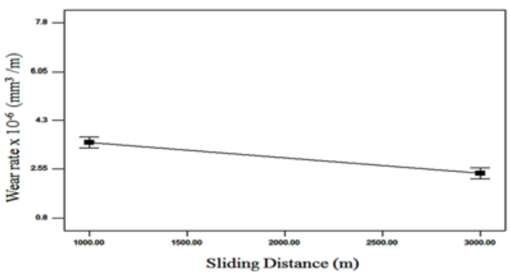

Fig.3. Effect of sliding distance on wear rate of the nanocomposites

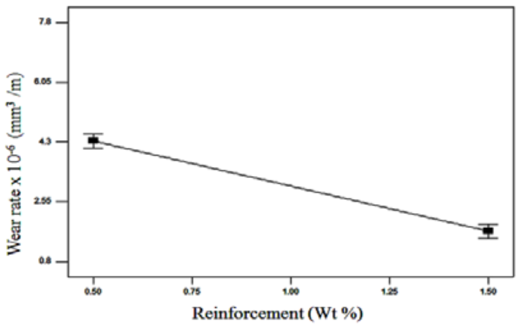

Fig.4. Effect of reinforcement on wear rate of the nanocomposites

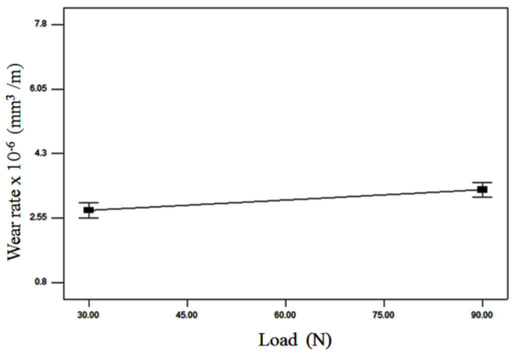

Fig.5. Effect of load on wear rate of the nanocomposites

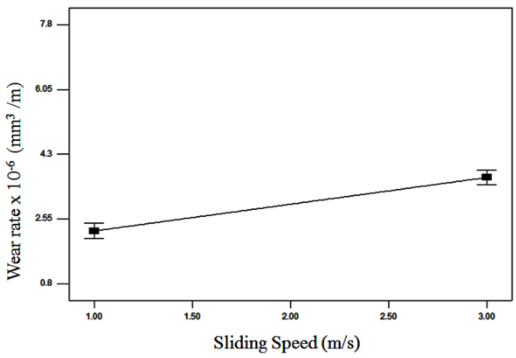

Fig.6. Effect of sliding speed on wear rate of the nanocomposites

This behavior is due to the surface temperature of the pin and disc increases which results in the softening of material and rubbing action is taking place between pin and disc which cause the less amount of material is removed from nanocomposites As the reinforcement content increases from 0.5 wt % to 1.5 wt % there is extreme reduction in the dry sliding wear of the nanocomposites, this is due to hard ceramic particles of Al_2O_3 are used to improve wear resistance of nanocomposites as shown in figure 4.The dry sliding wear behavior of nanocomposites increases as the increase in the speed and load as shown in figure 5 and 6.The related outcomes was obtained by the many other investigators that unlubricated sliding wear properties of nanocomposites increases with the increase in the sliding speed and applied load (Pardeep Sharma et al., 2015; O.Zgalat-Lozynsky et al., 2015; K. Niranjan et al., 2013; H. R. Ezatpour et al., 2013).

The main effects of the control factors on coefficient of friction of ZA-27/Al_2O_3 composites were shown in the figures 7-10. The friction coefficient of composites decreases as the reinforcement content increases as shown in figure 7.

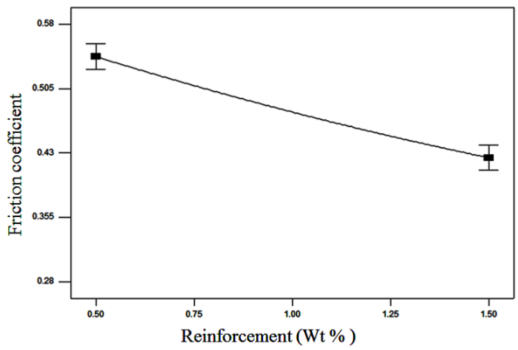

Fig.7. Effect of reinforcement on friction coefficient of the ZA-27/Al_2O_3 composites

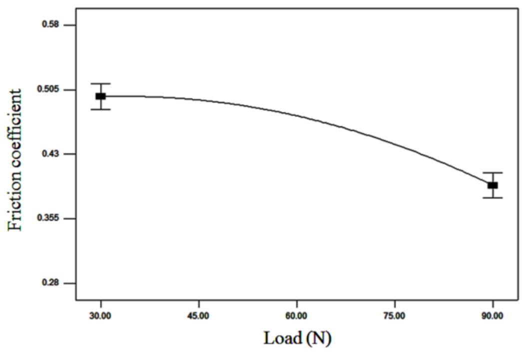

Fig.8. Effect of load on friction coefficient of the ZA-27/Al_2O_3 composites

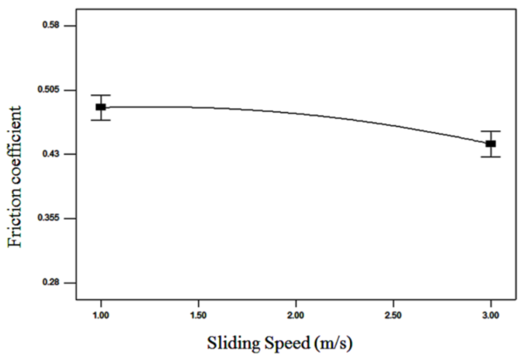

Fig.9. Effect of sliding speed on friction coefficient of the ZA-27/Al_2O_3 composites

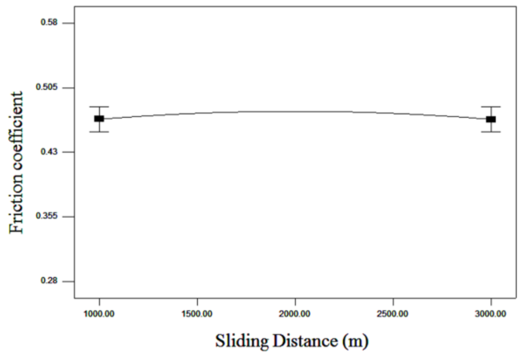

Fig.10. Effect of sliding distance on friction coefficient of the ZA-27/Al_2O_3 composites

The reduction of friction coefficient is due to percentage reinforcement may increases the seizure resistance of ZA-27/Al_2O_3 composites. The sliding of composites against the disc surface will release fine particles which are smeared on disc surface during testing because of this friction coefficient decreases as percentage reinforcement increases. The percentage reinforcement is the significant factor due to influencing friction behavior of composites. The other main factors which are influencing the coefficient of friction of composites are load and sliding speed. From the figure 8, it was observed that coefficient of friction the composites decreases as load increases. If load increases the friction behavior of the composites shows the linear trend up to certain limit then reduces because at higher loads the composites release fine particles on disc surface which improves removal resistance of composites. Coefficient of friction of composites is slightly influenced by sliding speed which is shown in figure 9. As sliding speed increases the coefficient of friction remains identical to certain limit this is due to at low speeds the contact between the disc surface and sliding pin is more, whereas at higher speeds the lesser amount of contact between disc surface and the sliding pin is taking place because of this coefficient of friction of the composites decreases.

Friction coefficient of ZA-27/Al2O3 composites is not effecting by the sliding distance. As the distance increases the value of the friction coefficient remains more or less unchanged as shown in figure 10. As distance increases a constant tribolayer occurs at the contact surfaces of the disc and the composite. In the present study, a constant tribolayer occurs for the sliding distance, as an outcome of which the coefficient of friction is not influenced by sliding distance. A similar result observed for the aluminium hybrid composites were coefficient of friction is not affecting by the sliding distance [9].

Interaction effect on the wear rate and friction coefficient of the nanocomposites

Figure 11 shows interaction influence of sliding distance and speed on wear rate of nanocomposites. The material is getting soften due to increasing the sliding distance, because of this the surface temperature of disc cause less removal of material from the nanocomposites. The dry sliding wear behavior deceases as sliding distance increases. As speed increases wear rate of nanocomposites increases because at higher speeds the surface are in contact with each other will remove more amount of the material.

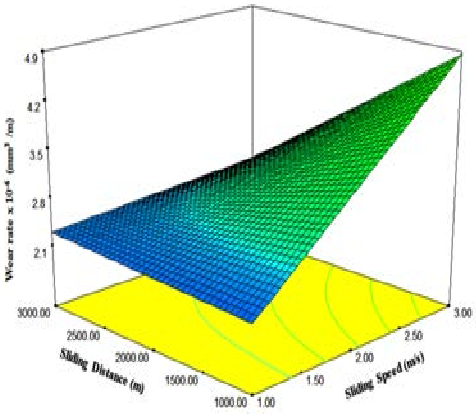

Fig.11. Interaction effect between sliding distance & sliding speed on the wear rate of the nanocomposites

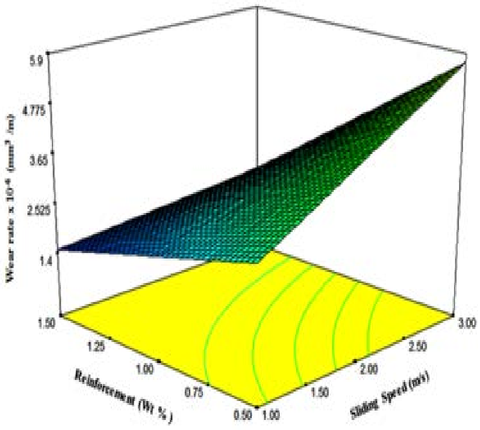

Fig.12. Interaction effect between reinforcement & sliding speed on the wear rate of the nanocomposites

Figure 12 shows the reduced wear rate because as reinforcement content increase in the nanocomposite will improve hardness which resulted into low volume of material removed. By increasing the both reinforcement percentage and speed will decrease dry sliding wear of nanocomposites.

The interaction effect on the coefficient of friction is effected by the filler content and load. Figure 13 shows the surface plot of interaction effect of percentage reinforcement and load on the coefficient of friction of the composites.

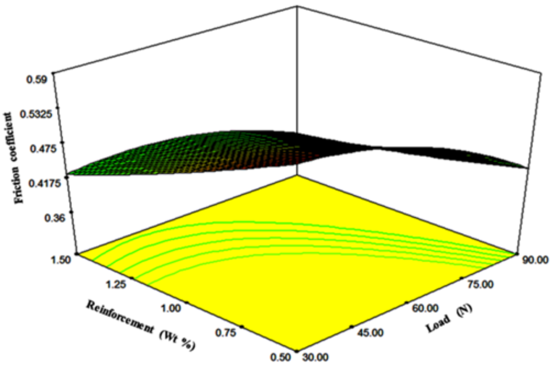

Fig.13. Interaction effect of filler content and load on friction coefficient of the composites

From surface plot it can be observed that as percentage reinforcement and load is increases friction coefficient of composites decreases. When percentage reinforcement increases the seizure resistance of ZA-27/Al_2O_3 composites improves due to this friction coefficient decreases. If load increases the friction behavior of composites shows linear trend upto certain limit then reduces because at higher loads composites release the fine particles on the disc surface which improves the removal resistance of composites. As percentage reinforcement and load increases the seizer resistance increases because of this the composites release the fine particles on the disc surface due to this the friction coefficient of the composites decreases.

Confirmations Experiments

The reliability of wear and friction model is determined by performing unlubricated sliding wear experiment was conducted on nanocomposites at altered values of process parameters like percentage filler, load, distance and speed. The regression equation was obtained from the independent variables should lie inside the ranges for conducting the confirmation experiments.

Table 6. Confirmation test parameters for wear rate

Expt No	S (m/s)	D (m)	L (N)	R (Wt %)	Experiment WR(x 10^{-6} mm^3	Predicted WR (x 10^{-6} $mm^{3)}$	Error %
1	2.59	2905	30	1.5	0.8845	0.8378	5.27

Table 7. Confirmation test parameters for COF

Expt No	S (m/s)	D (m)	L (N)	R (Wt %)	Expt COF	Predicted COF	Error %
1	3.00	1000	90	1.5	0.2895	0.2858	1.27

Microstructures of wear surfaces

The microstructures of the wear out surface of nanocomposites were shown in figures 14-16 by using SEM. From the SEM images it can be observed that dry sliding wear of nanocomposites is minor compare to ZA-27 matrix material.

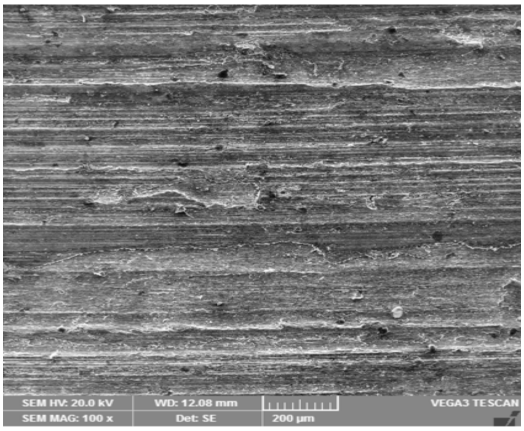

Fig.14.SEM image of ZA-27 alloy wear surface

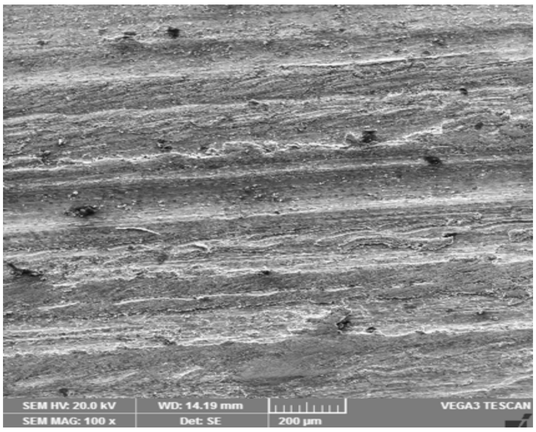

Fig.15.SEM image of ZA-27 + 1% Al_2O_3 wear surface of nanocomposites

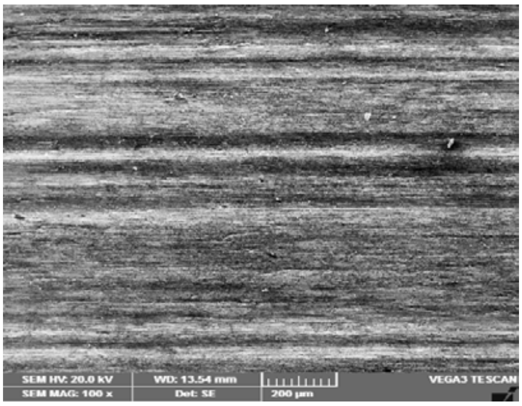

Fig.16.SEM image of ZA-27 + 1.5% Al_2O_3 wear surface of nanocomposites

From the SEM image of the ZA-27 alloy, it was observed that the deep and coarse grooves on wear surfaces due to action of wear-hardened deposits on disc track as shown in figure 14. At the edges of the grooves it was observed that there is a high plastic deformation, this is cause due to the frictional heat which softens the surface. In Figures 15 & 16, the wear surface of nanocomposites shows shallow grooves and fewer pits. The depth of grooves is reduced due to presence of Al_2O_3 nanoparticles improves the hardness of the nanocomposites. There is lesser plastic deformation is detected at edges of the grooves, along the path of sliding the ridges and grooves are parallel and aligned. It is obvious from worn surface that when content of Al_2O_3 nanoparticle increases, wear rate reduces.

CONCLUSIONS

The Al_2O_3 nanoparticles at various weight percentages of 0.5 to 1.5 wt % were reinforced with ZA-27 matrix material to form composites were successfully prepared with help of ultrasonic assisted stir casting process. Tribological behavior of ZA-27/ Al_2O_3 nanocomposites was conducted according to the experimental design and the mathematical model has been developed for the wear rate and coefficient of friction by using RSM approach. The wear rate of ZA-27/ Al_2O_3 nanocomposites were reduced when reinforcement content and sliding distance increases and the more amount of material were removed when the sliding speed and load increases. The friction coefficient of composites decreases as the percentage reinforcement and the load increases whereas the sliding distance increases the friction coefficient value remains more or less unchanged. From the ANOVA analysis it can be observed that most significant parameter for wear rate of nanocomposites was reinforcement content followed by the speed, distance and load has negligible influence.

From the ANOVA analysis it can be observed that significant factors for friction coefficient of ZA-27/ Al_2O_3 composites was percentage reinforcement followed by load, speed and distance will not affect coefficient of friction. The interaction effects of the distance – speed and reinforcement content- speed are showing influencing result on wear rate and reinforcement content – load are showing influencing result on friction coefficient of composites. The confirmation tests were conducted to evaluate the error among the predicted and experimental values of wear rate and friction coefficient of nanocomposites is 3.15 and 1.27%. The wear surface of the nanocomposites shows that when content of Al_2O_3 nanoparticle increases, wear rate and friction coefficient reduces.

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