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Fabrication and characterization and Wear analysis of Coated and Uncoated Nano Silica Reinforced ZA-27 MMC

Anuj Jain[1], Aayush Verma[2], Amandeep Singh[3], Arun Kumar[4], Dr. T.G.Mamatha[5]

[1,2,3,4]Students at JSS Academy of Technical Education, Mechanical Engineering, NOIDA
[5]Professor and Head of Dept. of Mechanical Engineering, JSS Academy of Technical Education , U.P,India.

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Abstract - *Tribological properties of materials are widely considered than that of the mechanical properties for their applications, In this regard MMCs are showing better physical, mechanical and tribological properties comparing to matrix materials.*

ZA-27 is an alloy with unparalleled bearing properties, the anti-friction properties of ZA-27 brings about a very fine running surface whereby pivots and shafts are protected. Energy loss due to friction is lowered for ZA-27 made bushings , hence this alloy is qualified for bushings applications for low speeds and high speeds with light and/or heavy loads. Despite being such applications, it is soft and has low temperature bearing capacity.

Reinforcing of nano particles in ZA-27 improves its mechanical properties. 2% , 4% , 6% by wt. nano particles are reinforced with matrix for both coated and uncoated reinforcement. Mechanical characterization as well as sliding wear resistance is tested. Addition of nano particles increases the micro hardness but slightly decrement in tensile strength , flextural strength and impact strength .It has been observed composite with coated nano has improved wear resistance. The hardness is maximum for 2% uncoated while minimum for 2% coated.

1. INTRODUCTION

ZA-27 is the lightest alloy and offers excellent bearing and wear resistance properties. It is also the high strength performer of the zinc alloys originally developed as a high strength gravity casting alloy and was suitable for thin wall die casting [1]. Its friction and wear characteristics can compare to the standard bearing material of industrial SAE660 lead-tin bronze [1]. Apart from its use as thin wall castings and in components such as electrical, automotive, industrial and farm equipment, it is increasingly popular in the markets for bearings, wear resisting parts, valves, pulleys and sheaves [13]. Because of good tribo-mechanical properties, low weight, excellent foundry castability , good machining properties, high as-cast strength and hardness, corrosion resistance, low initial coat and equivalent or even superior bearing and wear properties, the ZA alloys (mostlyZA-12 and ZA-27) are capable of replacing aluminum cast alloys and bearing bronzes [3]. An important aspect that makes these alloys attractive is the reductions in cost from 25 to 50% and 40 to 75%, compared with aluminum and brass alloys respectively [9]. However, major limitations of the alloy system are its inferior elevated temperature mechanical and wear properties, dimensional instability at temperature above 1000 C [14,15]. Several researchers reported on the mechanical and tribological behavior of ZA27 metal matrix composites reinforced with particulates or short fibers fillers. Sharma et al. [4], in 1996, reported on the effect of short glass fibers on mechanical properties of ZA-27 alloy composites. Again in 1998, they studied the aging characteristics of the same composites [5]. In 2001, Sharma [6] studied the elastic properties of ZA-27 alloy composites reinforced with short glass fibers using destructive test. He also made some prediction of analytical value using shear-lag model, Nielsen-Chen model, and computational model. Different reports on the wear behavior of ZA-27 metal matrix composites reinforced with different particulate filler like SiC [7], alumina [8], garnet [9], Mn [13], silicon [15], zircon [2] and graphite [9] etc. Seah et al. [10] in 1996, investigated the mechanical properties of cast ZA-27/graphite particulate composites. Again in 1997, they compared the mechanical properties of as cast and heat-treated ZA-27/graphite particulate composites [12]. Patnaik et al. [11] studied solid particle erosion of ZA-27 alloy matrix composites reinforced with titania particles.

However, the use of other nano sized refractory materials such as silica for reinforcing MMCs has received limited attention from researchers in materials engineering fields. In the light of this, the present research is aimed at developing and characterizing ZA-27 alloy matrix nano composites reinforced with zinc oxide nano particles. The use of coated and uncoated silica nano particles in this research is expected to bring about significant improvement in strength, wear. ZA-27 was embedded with 2,4,6 by wt% of coated and uncoated silica nano particles. All obtained results for the nano composites were compared to the results obtained for base ZA-27 alloy. Also, influence of volume fraction on mechanical properties of nano composites was investigated.

2 Materials and methods

2.1 Material

T he ZA-27 alloy with chemical compositions as per ASTM B66982 presented in was selected as the matrix and silica Table 1 nano particles were used as reinforcement

Elements	Al	Cu	Mg	Zn
Compositions	25-28	1.0-2.5	0.01-0.02	Balanced

Table 1: Elemental Composition of ZA-27 Alloy.

Nano particles used were silica coated with hexamethyldisilazane and uncoated nano silica.

2.2 Composite fabrication

In this process, melting of the matrix alloy ZA-27 is carried out separately about 650^{0}C, above its melting temperature . After melting, the required quantity of filler particulates (0, 2, 4 and 6 wt%), preheated to around 400^{0}C, (to remove moisture contents and improve wettability with the ZA-27 alloy as reported by Shivakumar et at[16]) are added to the molten metal and stirred continuously by using a mechanical stirrer . The stirrer is rotated at a speed of 450 rpm for 2-3 min in order to get uniform mixing of filler particulate in the matrix material. During stirring, to enhance the wettability, small quantities of magnesium are added to the melt. The molten metal is then poured into permanent mould of cast iron of size 100×90×10mm3 (i.e. length × width × thickness) for casting and the temperature is then lowered gradually . After solidification, the castings are taken from the mold and are cut to the required shape and sizes for different test

2.3 Micro-hardness measurement

Micro-hardness measurement is done using a Micro-Hardness Tester . A diamond shaped indendator as right angled pyramid with a square base and with an angle of 136^0 between the opposite faces, is striked into the material with a load F. The two diagonals X1and X2 of the indentation left on the surface of the material after removal of the load are measured and their arithmetic mean L is calculated. Vickers hardness number is calculated using the following equation

$$H.V=0.1889\ F/L^2$$

And L=(X1+X2)/2

Where F is the applied load (N), L is the diagonal of square impression (mm), X1 is the horizontal length (mm) and X2 is the vertical length (mm).

2.4 Tensile, flexural and impact strength measurement

The tensile test is performed on flat specimen.Generally dog bone type specimen are used in tensile test and the straight side type with end tabs. During the test a uni-axial load is applied through both the ends of the specimen. The ASTM standard test method for tensile properties of metal matrix composites has the designation D3552/D3552M. The length of the test section should be 76 mm. The tensile test is performed in the universal testing machine (UTM) and results are analyzed to calculate the tensile strength of composite samples

The short beam shear (SBS) test is performed on the specimen at room temperature to calculate the value of flexural strength. The test is conducted as per ASTM standard (D5379/D5379M) using the same UTM. The flexural strength (F.S.) of any composite specimen is evaluated using the following equation.

$$F.S=3PL/2bt^2$$

Where,

L is the span length of the sample. P is the load applied; b and t are the width and thickness of the specimen respectively.

The impact testing machine (ASTM D-256) tested the impact strength of the V-notched specimens by impacting it with a pendulum hammer. By measuring the spent energy and relating it to the cross section of the specimen, the impact strength is calculated.

2.5 Pin-on disc test

Pin-on-disc machine was used to evaluate the sliding wear resistance of MMC specimen.The pin was held against the counter face of a rotating disc with wear track diameter 100 mm. The pin was held against the disc and a dead weight load is applied. The wear test for all specimens was conducted under the normal loads of 10N, 20N, 30N, 40N and a sliding velocity of 1 , 1.5, 2, 2.5 m/s. Wear tests were carried out for different sliding distances of 10, 15, 20, 25cm under similar conditions as discussed above. The length of specimen was 30mm and diameter was12 mm. The surfaces of the pin samples were slides using emery paper (80 grit size) prior to test in order to ensure better contact of fresh and flat surface with the steel disc. The crossectional surface and wear track both were cleaned with acetone and weighed (up to an accuracy of 0.0001 gm using microbalance) before and after each test. The specific wear rate (mm^3/N-m) can be expressed on volume loss basis as:

$$\mathbf{W_S= \Delta m / (\rho * t * V_S * F)}$$

Where Δm is change in mass in the test interval (gm), ρ is the density of the composite specimen (gm/mm^3), t is time duration for test (s), V_S is sliding velocity (m/s) and F_S is load applied(N).

The specific wear rate is calculated as the volume loss of specimen per unit sliding distance per unit applied normal load.

3 Results and discussions

3.1 Mechanical characterisation

The results of mechanical properties of the composites are presented in : The hardness and Ultimate tensile Figs. 1-4 Fig. 1 Among all the composites under this investigation, the maximum hardness value is observed for ZA-27 filled with 2 wt.% of uncoated SiO_2 .The test results show that with the presence of nano particles, micro-hardness of the ZA-27 metal matrix composites improved from 126.1 Hv to 140.1 Hv for uncoated nano filler and to 139.4 Hv for 4% coated nano filled ZA-27 metal matrix composites. This implies an increment of 11.10% and 11.55% in hardness for uncoated and coated nano reinforced ZA-27 MMCs respectively.

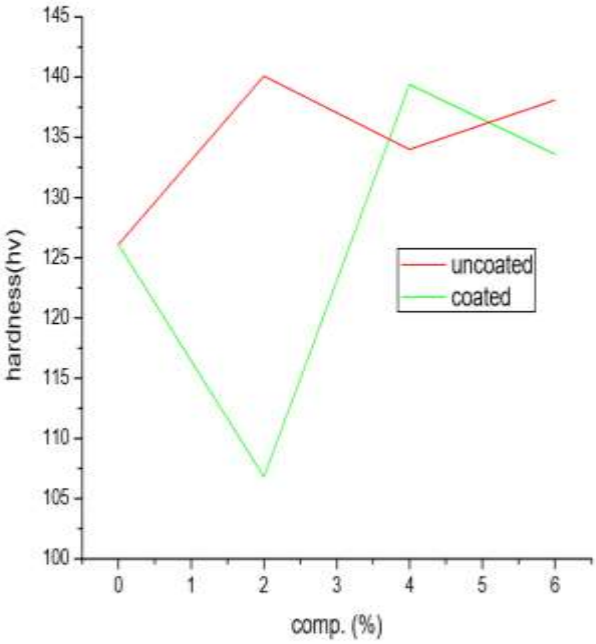

Fig1 Variation of hardness with different composition.

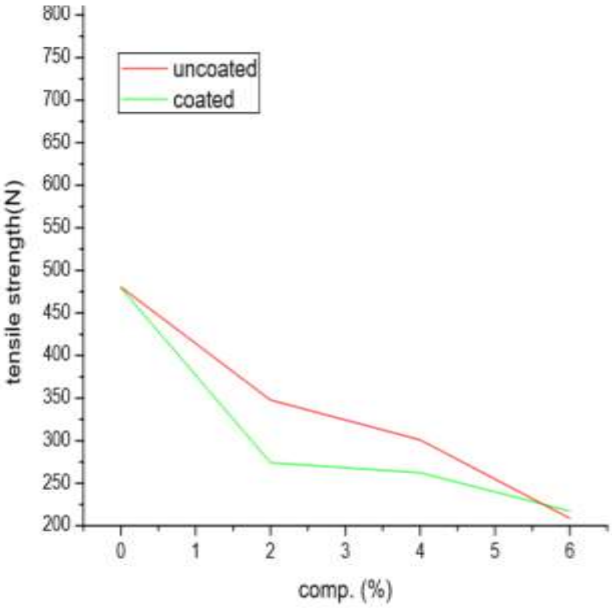

Fig2 Variation of tensile strength with different composition.

Fig. 2 shows the tensile strength of the composite decreases with increase in reinforced content. The unfilled ZA-27 metal matrix composite has a strength of 479.60MPa in tension and this value decreases to 217.29MPa with addition of 6 wt% of coated nano particles. In the case of uncoated nano particles, this is found to be from 207.90MPa.

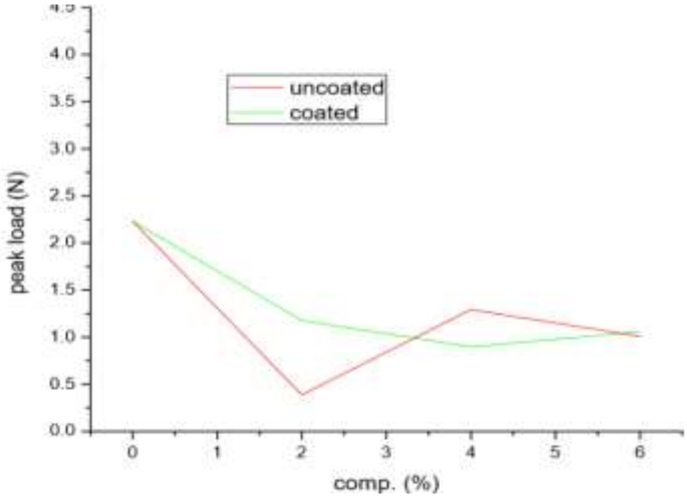

Fig3 Variation of bendind strength with different composition

Fig 3 Decrement in flexural strength is recorded for all the composite samples with the incorporation of nano particles irrespective of the type of reinforcement.Fig 4 shows the impact energies of the composites decreases gradually with filler content increasing from to 2% to 6%.

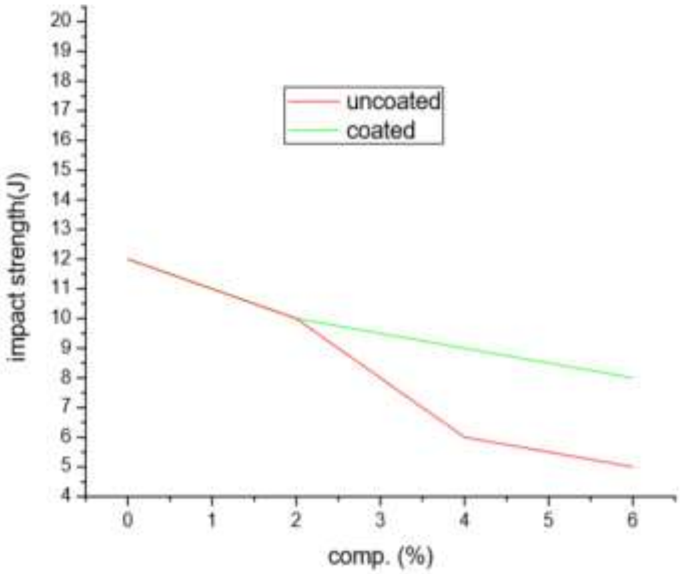

Fig4 Variation of impact strength with different composition

3.2 Sliding Wear Test Results and Taguchi Analysis

This one-factor-at-a-time approach will provide the most favorable level for each factor but not the optimum combination of all the interacting factors involved. Thus, experimentation in this scenario can be considered as an iterative process. The impact of five parameters

- Composition
- Speed

- Load
- Temperature
- Sliding distance

on the erosion wear rate of nano reinforced ZA-27 metal matrix composites is therefore studied in this work using Taguchi's L16 orthogonal array design.

The control factors and the parameter settings for wear test are given in **Table 2.**

Parameters	Range:1	Range:2	Range:3	Range:4	Units
Composition	0	2	4	6	%
Speed	191	286	382	478	rpm
Load	10	20	30	40	N
Temperature	40	44	48	52	Celcius
Sliding distance	10	15	20	25	cm

Table 3 Taguchi orthogonal array design (L16) for pin on disc test

Test Run	Composition	Speed	Load	Temperature	Sliding distance
1	0	191	10	40	10
2	0	286	20	44	15
3	0	382	30	48	20
4	0	478	40	52	25
5	2	191	20	48	25
6	2	286	10	52	20
7	2	382	40	40	15
8	2	478	30	44	10
9	4	191	30	52	15
10	4	286	40	48	10
11	4	382	10	44	25
12	4	478	20	40	20
13	6	191	40	44	20
14	6	286	30	40	25
15	6	382	20	52	10
16	6	478	10	48	15

The sliding wear rates of nano reinforced ZA-27 metal matrix composites under various test conditions are given in Table 4 and 5

The difference between the weights of the composite before and after the sliding wear test is the wear loss or the mass loss of the specimen due to wear. Samples are run for each combination of the test parameters employed and the results are reported. The experimental observations are then transformed into signal-to-noise (S/N) ratios. In the graph 5 and 6 represents S/N ratio of the sliding wear rate for coated and uncoated nano particles.

There are several S/N ratios available depending on the type of characteristics.

The S/N ratio for minimum wear rate for smaller-is-better characteristic can be calculated as logarithmic transformation of the loss function as shown below:

$$S/N = -10\log(1/n\sum y^2)$$

where, n the number of observations and

y the observed data.

The analysis is made with popular software used for design of experiment applications known as MINITAB 18.

Figure 5, 6 shows graphically the effect of the five control factors on the wear rate.

COATED			
Test no.	sp wear rate (10^-8) (mm3/N-m)	SNR	MEAN (10^-8)
1	6.944	143.168	6.944
2	12.731	137.903	12.731
3	8.680	141.230	8.680
4	5.555	145.106	5.555
5	36.458	128.764	36.458
6	53.241	125.475	53.241
7	15.191	136.368	15.191
8	15.277	136.319	15.277
9	50.925	125.861	50.925
10	28.935	130.772	28.935
11	43.402	127.250	43.402
12	21.523	133.342	21.523
13	30.382	130.348	30.382
14	24.691	132.149	24.691
15	35.590	128.973	35.590
16	36.111	128.847	36.111

Table4 Sliding wear test results with COATED nano particles.

UNCOATED			
Test no.	sp wear rate (10^-8) (mm3/N-m)	SNR	MEAN (10^-8)
1	6.944	143.168	6.944
2	12.731	137.903	12.731
3	8.680	141.230	8.680
4	6.944	143.168	6.944
5	10.416	139.646	10.416
6	9.259	140.669	9.259
7	8.680	141.230	8.680
8	9.259	140.669	9.259
9	6.944	143.168	6.944
10	1.157	158.733	1.157
11	17.361	135.209	17.361
12	6.944	143.168	6.944
13	1.736	155.209	1.736
14	7.716	142.252	7.716
15	16.493	135.654	16.493
16	23.611	132.538	23.611

Table5 Sliding wear test results with UNCOATED nano particles.

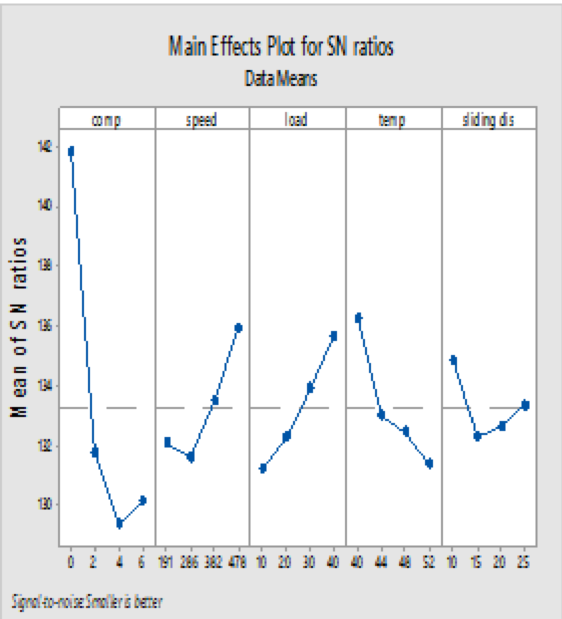

Fig5 Effect of control factors on wear rate (**coated**).

From the above graph , it is concluded that with increase in nano percentage , the wear rate decreases. As wear rate is inversely proportional to wear resistance, so wear resistance increases with increase in nano content.

MEAN = 6.944*10^-8 ; S/N RATIO= 143.168

From the fig6, we can conclude that with increase in nano percentage in MMC , the wear resistance of ZA-27 is not improving .

MEAN =6.944*10^-8 ; S/N RATIO=143.168

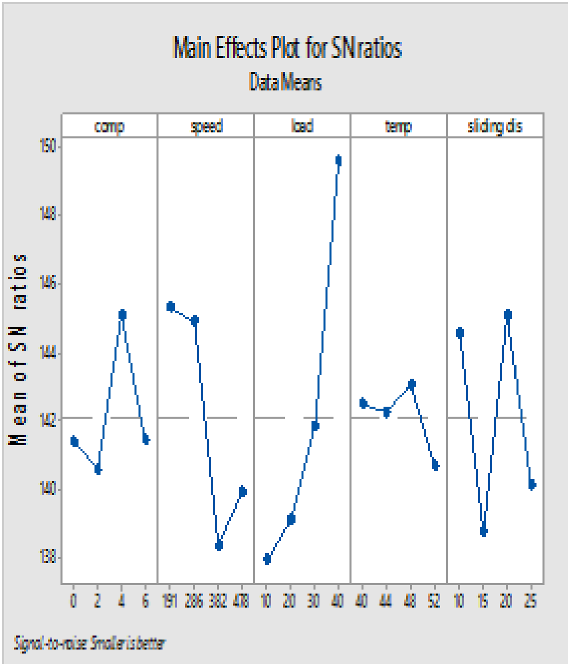

Fig6 Effect of control factors on wear rate (**Uncoated**).

4 Conclusions

- This analytical and experimental investigation on nano particle reinforced ZA-27 MMCs has led to the following specific conclusions:
- Successful fabrication of ZA-27 metal matrix composites with reinforcement of nano silica is possible using stir casting method.
- These composites possess improved micro hardness . However, they exhibit slightly inferior tensile ,flexural strengths and impact strength than those of the pure ZA-27 alloy.
- Sliding wear characteristics of these composites can also be successfully analyzed using Taguchi experimental design scheme. Taguchi method provides a simple, systematic and efficient methodology for the optimization of the control factors. Significant factors affecting the wear rate of composites are identified through successful

implementation of signal-to-noise response approach.

- Although the composites do not show any promising behaviour in mechanical properties but the composite has shown improvement in wear resistance in case of coated nano silica

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