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Analysis of Wear and Strength Behaviour of SiO_2 Nanoparticles Mixed in Epoxy Powder Coating on Mild Steel Material

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Abstract: Coating plays an important role in protecting the base metal from environmental and mechanical damages. Abrasive wear resistance is an important property of the coating. The objective of this paper is to study the wear resistance and scratch hardness of epoxy resin powder coating. Adding SiO2 nanoparticles changes the strength of the coating. Optimum percentage of SiO2 nanoparticles has to be decided to obtain the minimum wear rate. Three different powder were manufactured having 0, 5 and 10 % wt SiO_2 nanoparticles in epoxy powder. This powder was deposited on mild steel using electrostatic spray gun. The wear resistance of the coating was evaluated on linear reciprocating wear machine, and the overall weight loss can determine the wear rate. Scratch testing machine was used to determine the scratching hardness of the coatings. With the help of Analysis of variance [ANOVA] the percentage contribution of each parameter were identified also it has been found that the minimum wear rate obtained for 5 % wt SiO_2 nanoparticle with improved scratch hardness of 94.024 GPa.
Keywords: Epoxy coating, nanoparticles, Wear, Taguchi, ANOVA

I. INTRODUCTION

Epoxy resin are well known for their adhesive properties. They are mostly used as composite with addition of nanoparticles for improving their properties [1]. In recent years these resins are also used in powder coating as they are easily available and processing can be done without much efforts. The curing required for the deposited layer is also simple and give a surface with good heat and chemical resistance [2]. These can also be used in industrial application due to their good properties. It doesn't required a solvent that as liquid coating so they are environment friendly [3]. So these coatings are widely used in automobile industries, domestic appliances, Refrigerator racks and liners among other application [4].

In organic powder coatings, epoxy powder coating has a better mechanical properties. But it sometimes shows lower resistance to development and spreading of crack. It is also susceptible to get damaged by abrasive wearing and also there is process introduced localized defects in coating which affects the mechanical strength [5].

To increase the wear and abrasion resistance of the epoxy powder coating nanoparticles can be used it will help to improve the mechanical properties of coating [6]. Most of the previous work puts lot of attention to homogeneous coating of layer [5]. Researchers used different nanoparticles to develop the wear resistance by adding, e.g. ZrO_2, Clay, Alumosilicate Nanoparticles, TiO_2, Fe_2O_3, ZnO, and SiO2 nanoparticles are the most used [7]. To obtain the maximum performance the suitable percentage of nanoparticles and proper homogeneousness of the polymer matrix with nanoparticles is necessary. And if the quantity is increased it worse the wear performance and can lead to embrittlement [8].

Many comparative studies of abrasive wear without using nanoparticles in coating and epoxy-based coatings with nanoparticles are conducted, the results from wear testing on pin on disc, showed that the loss of weight decreased with increasing the nanoparticles percentage [9]. Researchers also explained with the use of SiO_2 nanoparticles, with comparison to microparticles, improves the wear behavior of the epoxy coating. The study was also compared with normal epoxy powder coating it showed that the wear resistance has increased [10].

The tribological properties improved with the addition of nanoparticles in epoxy powder coating, aluminium silicate was added to improve wear resistance and to reduce the coefficient [11]. But most research are done on liquid coatings [10], there are studies which also deals with addition of nanoparticles in polyester powder which results in improving the loss of mass [11].

There is also a mixing method for resin with nanoparticles such as ultrasonic mixing, mechanical mixing homogeneous mixing of nanoparticles is important as it determines the final property of the product if it is not properly mixed defects may arise for organic powder coating, extrusion is used as a tradition mixing method.

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In this research, silica Nano-particles were used to determine the wear characteristics of the coating when hot mixed with the epoxy powder. Five different content of epoxy powder were hot mixed and coated on the substrate surface using electrostatic spray gun [12]. The mixture with higher content were not properly coated as they had low affinity towards charge which affected the powder deposition over the substrate and after curing the coating quality deteriorated and cause easy failure. But for content up to 10% hot mixing helped to homogenously mix the silica nanoparticles. Tribometer was used to study the wear of coating considering different parameter for testing. ASTM G133 guides for the sliding wear testing. This coating showing better tribological property can be used as protective coating of appliances, electronic instruments, automotive, aeronautic industry and marine infrastructure.

II. EXPERIMENTAL

A. *Material and Sample preparation*

The epoxy organic coating was provided by Amruta Powder coating industry Aurangabad and the Silicon Oxide Nanoparticles was provided by Nano research lab Jharkhand. The silicon dioxide nanoparticles with, average particle size 10-20nm, purity 99.5% molecular formula as SiO_2, density: 2.5g/cm^3 and melting point 1600 °C. To prepare epoxy powder coating, silicon dioxide nano powder was hot mixed using a hot mixer. The mixture were made at 72 ± 1 °C, 15 min and 40 rpm under dry condition [12]. Five types of powder were manufactured and designed but the OVAT analysis showed that coating with higher content of nanoparticles i.e. more than 15 % wt of reinforcement showed more wear rate so the material was prepared in the range of 0 %wt- 10 % wt of reinforcement as given in table.1. The coating was performed at Amruta powder coating industry. The coating was applied on mild steel substrates [30 mm×30 mm×5 mm]. It was deposited using an electrostatic powder spray gun. The curing of the deposited coating was done in an oven at 180 °C for 15 min [12], and the thickness was about 70-100 µm.

Table 1. Coating samples

Sample	Epoxy powder [wt %]	Weight [wt %]
A	100	0
B	95	5
C	90	10

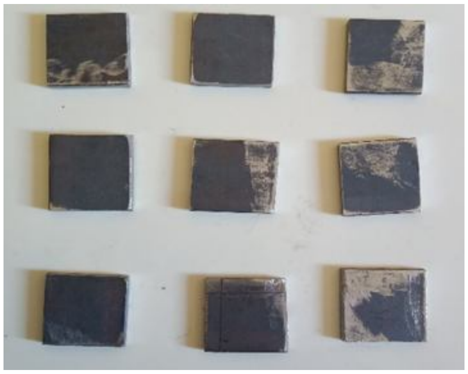

Figure 1: mild steel sample before coating

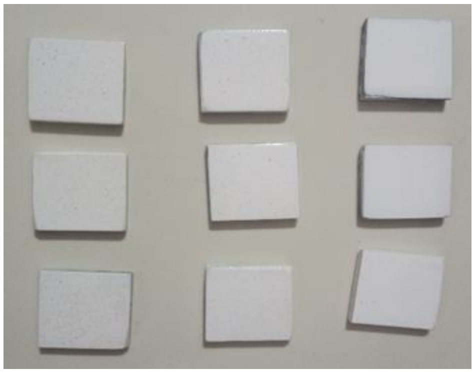

Figure 2: mild steel sample after coating

B. *Wear test*

The wear test [ASTM G133 Standards] was carried out using linear reciprocating Tribometer of DUCOM at government college of engineering, the substrate were prepared according to the requirement of the machine i.e. 30 mm×30 mm×5 mm was coated with the prepared epoxy resin powder mixed with nano SiO_2 particles with electrostatic gun and a EN31 pin of 4 mm diameter and 15 mm height was used as a tool to wear the coating. On the basis of pre experiment it was found that the coating showed substantial wear rate in a load between 2 N to 20 N and Frequency of 1 Hz to 5 Hz. After measuring the weight loss with help of eq [1] wear rate was calculated and the weight was measured before and after testing of the coated substrate with CONTECH electronic weighing machine [least count 1 mg] shown in figure [3] each test and weight of sample was done three times to improve the accuracy.

$$wear\ rate = \frac{\Delta m \times 10^3}{\rho LF}\ mm^3/Nm \qquad [1]$$

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Where,
Δm is weight loss in 'grams'.
ρ is density in 'grams/cubic centimetre'
F is Load in 'newton'.
L = 2 × frequency [freq] × time [t] × Stroke length [l] × 10^{-3}.
L is sliding distance in 'meters'.
Frequency in 'Hz'.
Time in seconds.
l is stroke length in 'mm'.

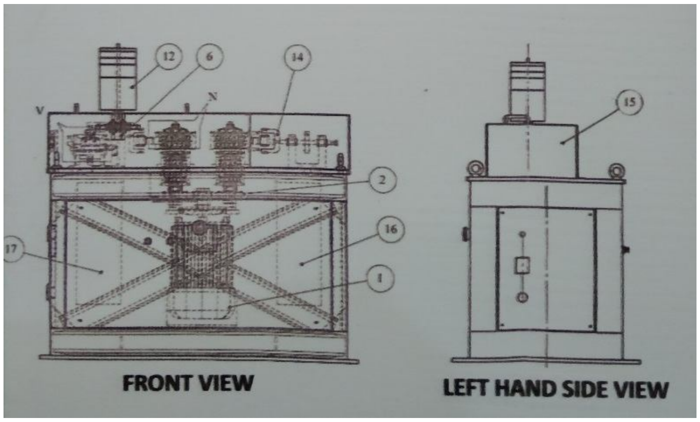

Figure 3: Linear reciprocating wear machine [Tribometer]

Figure 4: Electronic weighing machine

C. Scratch Test

To check the scratching hardness of the coating scratch testing is done. This test was carried out on [DUCOM] scratch testing machine at Government College of engineering using winducom software with parameters, stroke, Normal load, scratching speed, and the indenter was Diamond Rockwell c type with 200 micron nose radius. Constant load was applied while testing the coating and the width of the scratch was measured using scar view software which gives the width and the image of the scratch. The scratch hardness was calculated using equation [2]. Three scratch were take on each coating to obtain the accurate value.

$$HSp = \frac{24.98\, m}{x}\, GPa \qquad [2]$$

Where, m = Load applied in gms
x = average scar width in microns

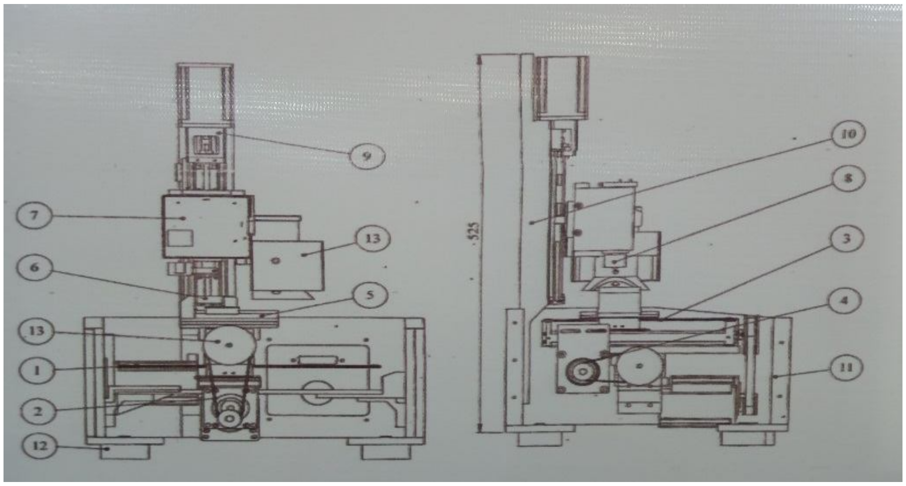

Figure 5: Scratch testing machine

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III. RESULTS AND DISCUSSION

The experimentation was design using taguchi L9 array for wear testing, considering three factors and three levels test were conducted in randomised manners. The output parameter was the wear rate and with the weight loss it was calculated by eq [1]. The percentage reinforcement of nanoparticles was up to 10 % wt, as it was found that the reinforcement at 15 % wt and 20 % wt has higher wear rate rather than lower, Due to this observation the 15 % wt and 20 % wt nanoparticles containing coating powder were eliminated to minimize the limits and the errors for finding the optimum parameters.

A. *Mean of Means*

This graph is plot by using minitab software it simply adds all the factor values and divide it by the no of values, which gives the optimum parameter. Smaller is better was selected for wear rate during the plotting of graph. The table [2] shows the S/N ratio and mean of experiment value using taguchi.

Table 2: L_{09} Orthogonal array [S/N ratio and mean]

%wt Reinforcement	Load [N]	Frequency [Hz]	Wear rate [mm^3/Nm]	SNRA1	MEAN1
0	5	1	0.042020	27.9155	0.04020
0	10	2	0.04666	26.6211	0.04666
0	15	3	0.05591	25.0502	0.05591
5	5	2	0.02950	30.6036	0.02950
5	10	3	0.03460	29.2185	0.03460
5	15	1	0.03400	29.3704	0.03400
10	5	3	0.03890	28.2010	0.03890
10	10	1	0.03260	29.7356	0.03260
10	15	2	0.04210	27.5144	0.04210

Figure 6: Mean of Means plot of result

From the above graph [1] it can be said that the Mean of Means shows the level of factor having lowest mean and it is considered as optimum response can be obtained from these level. The optimal level for lower wear rate was found to be at 5 wt % reinforcement SiO_2 nanoparticles, load of 5 N, and frequency of 1 Hz.

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B. ANOVA

It is arithmetical method used to understand the experiment outcomes and the factors influence on the output factor and its importance. This numerical technique used for testing null hypothesis for experimentation used for optimization, where more than one variables can be measured at the same time. It was analysed with 5 % level of significance and with 95 % of level of confidence. Result of analysis of variance shown in the table [2]. The p value is the possibility of getting a result at least as extreme as the one that was actually observed and the value is expected to be less than 0.05 in all parameters so the results shows that the factors % reinforcement of SiO_2 nanoparticles, Load, frequency are responsible for the wear rate. The percentage influence of each parameter is shown in the table.

Table 3. ANOVA table

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Wt % Reinforcement	2	0.00052994	0.00021497	5.17	0.0494	63.93
Load [N]	2	0.00014678	0.00007339	4.83	0.04817	17.70
Frequency [Hz]	2	0.00009286	0.00004643	2.48	0.0284	11.20
Error	2	0.00024931	0.00004155			
Total	2	0.00082889				

C. Confirmation test

Conformation test was performed on the optimized parameter observed from the graph i.e. on 5 % wt reinforcement, 5 N load and 1 Hz frequency the predicted value was derived from minitab and it was compared with the experimental value to check the wear rate.

Table 4: Confirmation test result

Parameters	Optimized value	Predicted wear rate	Experimental wear rate	Error %
% wt reinforcement	5	0.0257422	0.02373	9.07
Load [N]	5			
Frequency [Hz]	1			

D. Scratch hardness

This test was conducted using scratch testing machine under constant load of 20 N, scratching speed 1mm/sec and stroke length of 10 mm, all the coating samples were tested in same condition. From the experiment it was found that the scratch hardness of coating with 5 % wt of reinforcement has the average scratch width 542 µm and it was observed that the scratch hardness was improved for 5 % wt reinforcement. Coating with 0 % wt reinforcement has average scratch width of 614 µm and the lowest scratch hardness was found in 10 % wt reinforcement with average scratch width of 628 µm. The figure shows the scarview of the scratch.

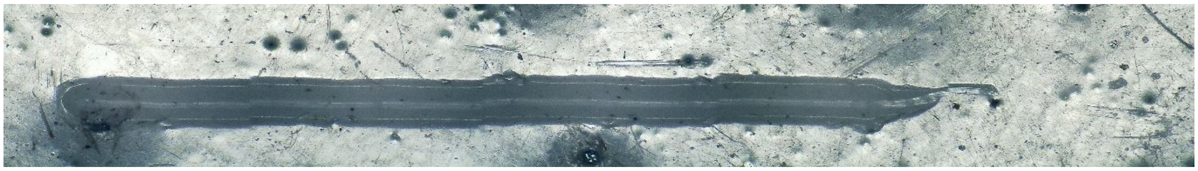

Figure 7: Scratch on the coating of 0 % reinforcement SiO_2

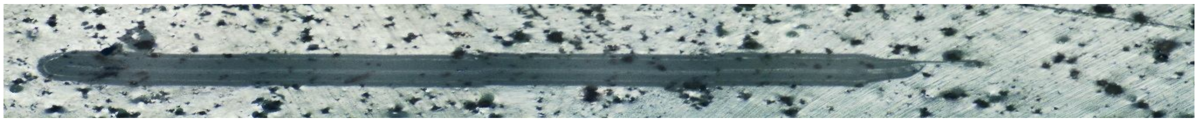

Figure 8: Scratch on the coating of 5 % reinforcement SiO_2

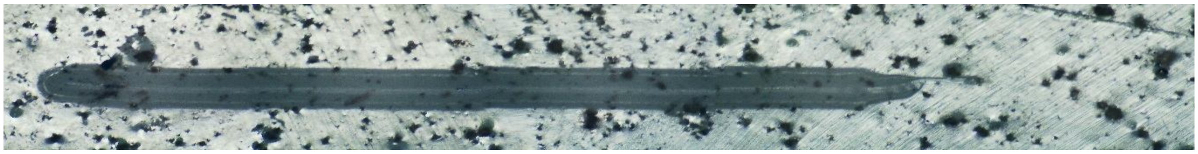

Figure 9: Scratch on the coating of 10 % reinforcement SiO_2

Table 5: Result of scratch hardness

Sample	Scratch hardness GPa
0 % wt reinforcement	82.99
5 % wt reinforcement	94.024
10 % wt reinforcement	81.14

IV. CONCLUSIONS

The taguchi technique used to analyse the optimum parametric nanoparticle content was determined experimentally under dry sliding wear and the wear characteristics was studied. The mean of means graph showed the optimum value for wear resistance of the coating which was at 5 % wt of reinforcement and above that the wear rate increases.it showed that the lower nanoparticles content has better wear resistance then the content above 5 % wt of reinforcement. ANOVA for means showed the % contribution for wear resistance and it was found that 63.93 % was contributed by the reinforcement, while load and frequency have the lower contribution and the hot mixing was significant method for preparing the mixture of nanoparticles and powder coating.

V. ACKNOWLEDGMENT

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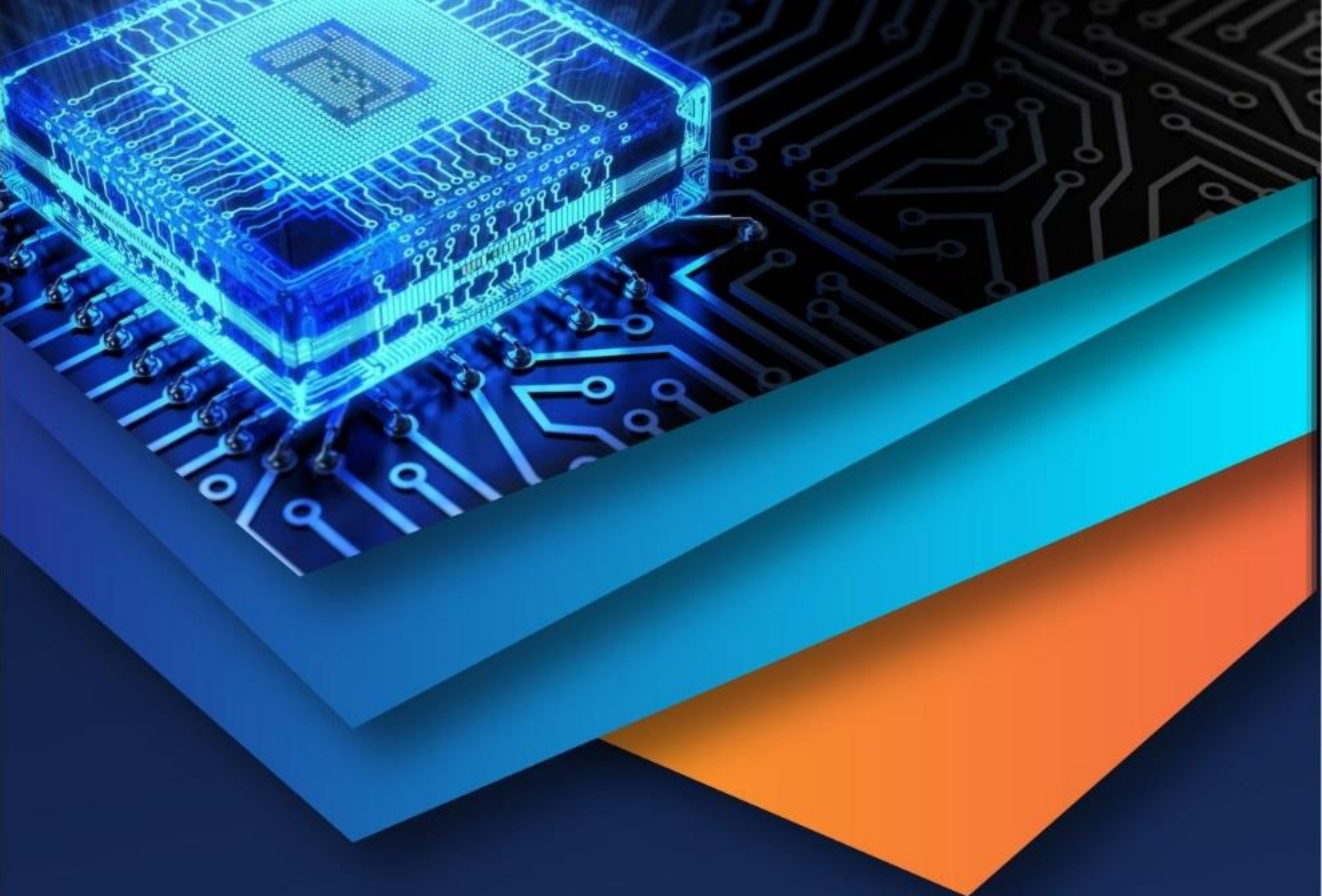

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