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EFFECT OF THE TRIBOLOGICAL BEHAVIOUR OF HEMATITE FILLED HYBRID COMPOSITES – A TAGUCHI APPROACH

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ABSTRACT

This paper reports the development and wear performance evaluation of a new class of polymer based composites filled with hematite ore. The ore particles 75-150µm are reinforced in polyester resin to prepare particulate filled composite of three different compositions (with 0,3,6&9 wt.% of ore). Dry sliding wear trials are conducted following a well planned experimental schedule based on design of experiments (DOE) using a standard pin on disc test setup. Significant control factors predominantly influencing the wear rate are identified. Effect of Fe_2O_3 *content on the wear rate of polyester composites under different test conditions is studied. ANOVA approach taking into account training test procedure to predict the dependence of wear behavior on various control factors is implemented. This technique helps in saving time and resources for large number on experimental trails and predicts the wear response of* Fe_2O_3*filled epoxy composites within and beyond the experimental domain.*

Key words:- *Taguchi,* Fe_2O_3*, ANOVA,E-glass fiber, polyester resin, sliding wear.*

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1. INTRODUCTION

An informal number of papers dealing with the tribological behaviors of polymer materials have been published. That is why the polymers are extending over a great area used in sliding components like such as gears, cams, breaks, clutches, bearings, wheels and bushes. Adhesive wear includes galling, fretting, scuffing and surface fatigue. This refers to the damage produced when two mating surfaces move relative to each other under a normal load. Surface asperities interact and very high stresses, strain, and strain rates are generated in localized regions [1].

The improved performance of polymers and their composites in industries and many other applications by the addition of particulate fillers has shown great advantages and so has lately been the subject of considerable interest. The mechanical and tribological behavior of particulate fillers CaCO3 and CaSO4 filled vinyl ester composites have been studied. Wear tests were carried out in dry sliding conditions on a pin-on-disc friction and wear test rig.

(DUCOM) at room temperature under sliding velocity (1.57, 2.62 and 3.67 m/sec.), normal load (20, 40 and 60 N), filler content (0, 10 and 20 wt.%) and sliding distance (1000, 3000 and 5000 m).

The plans of experiments is based on the Taguchi technique, was performed to acquire data in a controlled way. An orthogonal array and analysis of variance (ANOVA) were applied to investigate the influence of process parameters on the coefficient of friction and sliding wear behavior of these composites. The coefficient of friction and specific wear rate were significantly influenced with increase in both the filler content. The results show that for pure vinyl ester the coefficient of friction and specific wear rate increases with the increase of normal load, sliding velocity and sliding distance. The coefficient of friction and specific wear rate for CaCO3 filler decreases with the increase of filler content. But, for filler CaSO4 the coefficient of friction and specific wear rate decreases at 10 wt.% and then increases at 20 wt.%. It is believed that a thin film formed on stainless steel counter face was seems to be effective in improving the tribological characteristics. The worn surfaces examined through SEM to elucidate the mechanism of friction and wear behavior.[2]

Epoxy composites reinforced with organo-modified montmorillonite (oMMT) and alumina (Al_2O_3) particles were prepared by incorporating nanoparticles into epoxy via high shear mixing followed by liquid molding. The effects of loading of nanoparticles on the mechanical and wear properties were studied. The results showed that the incorporation of nano- Al_2O_3 with nano-oMMT could effectively enhance the tensile properties of the composites. The tensile strength decreased and Young's modulus of the epoxy increased with the increasing nano-oMMT content. The enhancement effect of the nanoparticles was more significant in the hybrid reinforced composites. The compounding of the two fillers also remarkably improved the wear resistance of the composites under higher load. The average coefficient of friction also decreased in Al_2O_3 filled oMMT-epoxy hybrid composite. It was revealed that the excellent wear resistance of the oMMT+ Al_2O_3 -epoxy hybrid composite was due to a synergistic effect between the oMMT and Al_2O_3 . Nano- Al_2O_3 carried the majority of load during the sliding process and prevented severe wear of the oMMT-epoxy. Further, the specific wear rates of the hybrid composites decreased with the increasing applied load and sliding distance. Nanoparticles distribution and their influence on properties were emphasized. Different wear mechanisms were observed on the worn surfaces of the composites, including pitting, micro-and/or macro-cracks, as well as crack propagation of the matrix in the transverse direction[3].

The E-glass woven fabric-epoxy (LY 556) (GE) composites have been fabricated with varying amounts of silicon oxide (SiO_2) particulate filler viz., 3, 6 and 9 wt % by compression molding followed by hot curing. The fabricated composites were characterized by mechanical properties such as tensile behaviour, flexural behaviour and interlaminar shear strength (ILSS). The effect of silica content on the sliding wear properties such as wear loss, specific wear rate and coefficient of friction of GE composites have been investigated at velocity of 5m/s and constant abrading distance of 1200 m with different loads viz., 30N, 60N and 90N by using pin-on-disc machine. Wear out surface of all the composites were studied using scanning electron microscopy (SEM)[4].

Frictional performance of glass-epoxy composite with influence of Granite and fly ash filler are experimentally investigated under constant load and sliding velocity, varying sliding distance using a pin-on-disc apparatus. Composites were fabricated by standard hand layup technique followed by hot pressing. The wear behaviour of the composites have been performed at varying abrasive distances viz., 5, 10, 15 20 and25 m at a constant load of 10 N. The experiment has been conducted using two different water proof silicon carbide (SiC) abrasive papers of 320 and 600 grit size at a constant speed of 200 rpm under multi-pass condition. The results show that wear loss of the composites was found increasing with the increase in abrading distances. A Significant reduction in wear loss and specific wear rates were noticed after incorporation of SiC and fly ash filler into GE composite [5].

The friction and wear behavior of glass-epoxy (G-E) composites with and without silicon carbide particles (SiCp) filler content as a function of sliding distance, keeping the sliding velocity and applied load constant it is seen that the wear rate increases with increasing sliding distance, but the gradient is not maintained the same all through. An attempt has also been made to correlate the wear loss of the worn surfaces using scanning electron microscopic (SEM) observations. The coefficient of friction is found to be almost same over a wide range of sliding distance employed. Further, the study indicates that the SiCp-G-E composites show lower coefficient of friction and lower slide wear loss compared to G-E composites irrespective of the sliding distance employed. It is found that during the running in wear, the wear of the resin mix as well as very few broken fibers are noticed. The breakage of fibers, the matrix debris formation and interface separation take place at a much later stage (i.e., in the severe wear region). In the steady state region some of the broken fibers are getting disoriented in the matrix and also agglomerations of the debris are seen. Other interesting SEM features have been noticed and discussed taking into account the addition of SiCp filler content (2.5 & 5.0 wt.%)[6].

2. MATERIAL DETAILS AND SPECIMEN PREPARATION

E-glass fabric (300 GSM) of plain weave construction, procured from New tech suppliers of polymers, Bangalore, was used for the study polyester resin matrix with methyl ethyl ketone peroxide catalyst and cobalt octet accelerator were used. The filler were Hematite is one of the most common minerals. The sandstone is most red and brown in color because of hematite presence. Non-crystalline forms of Hematite may be transformations of the mineral Limonite that lost water, possibly due to heat chemical formula Fe_2O_3. The filler used was hematite passed through 75-150 µm. In this work there are four types of composite is being prepared of diameter of 6mm and length of 150mm, by using hand layup technique with help mould.The table (1) show the details of the composites constituents proportion mixed.

Table: 1 composition of filler on specimens

composites	% of filler	Matrix volume %		Reinforcement volume%	
A	0	polyester	50	Glass fiber	50
B	3	polyester	47	Glass fiber	50
C	6	polyester	44	Glass fiber	50
D	9	polyester	41	Glass fiber	50

3. EXPERIMENTAL PROCEDURE

To evaluate the performance of these composites under dry sliding condition, wear tests are carried out in a pin-on-disc type friction and wear monitoring test rig (supplied by DUCOM) as per ASTM G 99. The experimental set up is shown in Figure 1. The counter body is a disc made of hardened ground steel (EN-32, hardness 72 HRC, surface roughness 0.6 Ra). The specimen is held stationary and the disc is rotated while a normal force is applied through a lever mechanism. A series of test are conducted with three sliding velocities of 210, 261 and 314 cm/sec under three different normal loading of 10N, 20N and 30N. The material loss from the composite surface is measured using a precision electronic balance with accuracy ± 0.1 mg and the specific wear rate (mm^3/N-m) is then expressed on 'volume loss' basis as

$$WS=\Delta m/\rho t \ VS. \ FN \text{ ----Eqn1}$$

Where;

Δm is the mass loss in the test duration (gm).

ρ is the density of the composite (gm/mm^3).

t is the test duration (sec).

VS is the sliding velocity (m/sec)

FN is the average normal load (N).

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

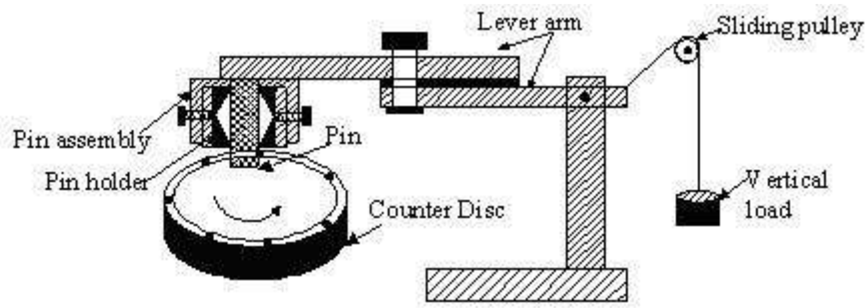


Figure 1 Schematic diagram of a Pin-on-Disc set

4. PLAN OF EXPERIMENTS

The experiments were conducted using L16 orthogonal array (OA) and the output is measured in terms of volumetric wear rate and frictional force as shown in Table 3. The process parameters and their levels selected for the experiment is presented in Table 2. This analysis is carried out to optimize the process parameter levels within the selected range to attain minimum volumetric wear rate and frictional force to attain defect controlled wear of non laminated composites. Analysis of variance was determined for the experimental data obtained for volumetric wear rate and frictional force to study the relative significance of process parameters. In this analysis, "smaller the better" characteristics has been applied to calculate the S/N ratio volumetric wear rate and frictional force. A higher the value of S/N ratio, better the fit for the combined objective.

Table 2 Process parameters and their levels

Process Parameters	Units	Code	Level 1	Level 2	Level 3	Level 4
% iron ore	-	A	0	3	6	9
Load	N	B	19.62	29.43	49.05	68.67
Speed	RPM	C	100	300	500	700

Table 3 L16 orthogonal array with the assigned values

Expt. Run	% of iron ore	Load (N)	Speed (RPM)	Volumetric wear rate (mm^3/m)	Frictional Force (N)	S/N Ratio for Volumetric wear rate (db)	S/N Ratio for Frictional Force (db)
01	0	19.62	100	0.0015924	2.4	55.9592	-7.6042
02	0	29.43	300	0.0014862	3.1	56.5585	-9.8272
03	0	49.05	500	0.0010191	18.2	59.8356	-25.2014
04	0	68.67	700	0.0015924	33.2	55.9592	-30.4228
05	3	19.62	300	0.0019108	9.8	54.3756	-19.8245
06	3	29.43	100	0.0010616	10.8	59.4810	-20.6685
07	3	49.05	700	0.0010828	30.0	59.3090	-29.5424
08	3	68.67	500	0.0007279	13.4	62.7582	-22.5421
09	6	19.62	500	0.0038217	11.9	48.3550	-21.5109
10	6	29.43	700	0.0063694	17.0	43.9180	-24.6090
11	6	49.05	100	0.0019108	10.0	54.3756	-20.0000
12	6	68.67	300	0.0005005	21.4	66.0127	-26.6083
13	9	19.62	700	0.0012739	10.9	57.8974	-20.7485
14	9	29.43	500	0.0005308	13.8	65.5016	-22.7976
15	9	49.05	300	0.0007006	23.1	63.0901	-27.2722
16	9	68.67	100	0.0005460	27.6	65.2569	-28.8182

5. EXPERIMENTAL RESULTS AND DISCUSSION:-

5.1 Analysis of Control factors

The influence of control factors like % of iron ore, Load (N) and speed (RPM) on volumetric wear rate and frictional force was been criticized using S/N ratio response analysis. The ranking of control factors using S/N ratio obtained for different parameters levels for volumetric wear rate is given in Table 4 & Table 5 and for frictional force is given in Table 6 & Table 7. Figure 2 (a&b) shows main effects plots of S/N and mean for volumetric wear rate of Hybrid laminated composite. Figure 3 (a&b) shows main effects plots of S/N and mean for frictional force of Hybrid laminated composite. It suggests that the optimum condition for minimum volumetric wear rate and frictional force is the combination of $A_4B_4C_2$ and $A_1B_1C_1$ respectively.

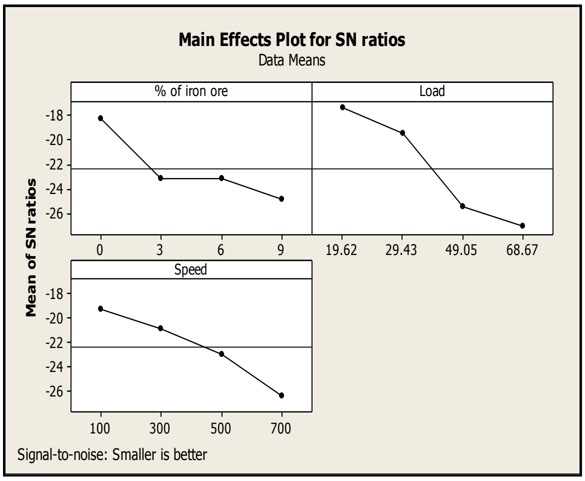
Table 4:- Response Table for Signal to Noise Ratios

Level	% of iron ore	Load	Speed
1	57.08	54.15	58.77
2	58.98	56.36	60.01
3	53.17	59.15	59.11
4	62.94	62.50	54.27
Delta	9.77	8.35	5.74
Rank	1	2	3

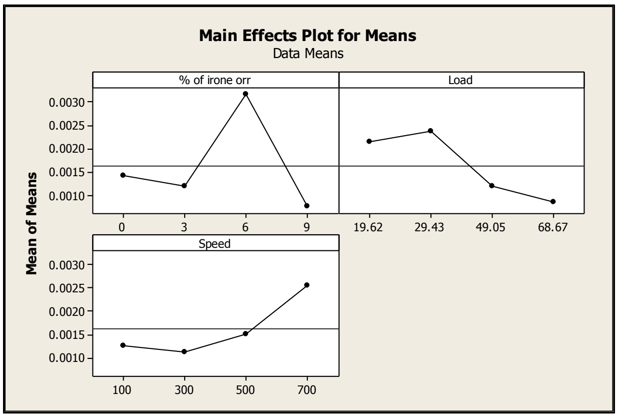
Table 5:- Response Table for Means

Level	% of iron ore	Load	Speed

1	0.001423	0.002150	0.001278
2	0.001196	0.002362	0.001150
3	0.003151	0.001178	0.001525
4	0.000763	0.000842	0.002580
Delta	0.002388	0.001520	0.001430
Rank	1	2	3



(a)



(b)

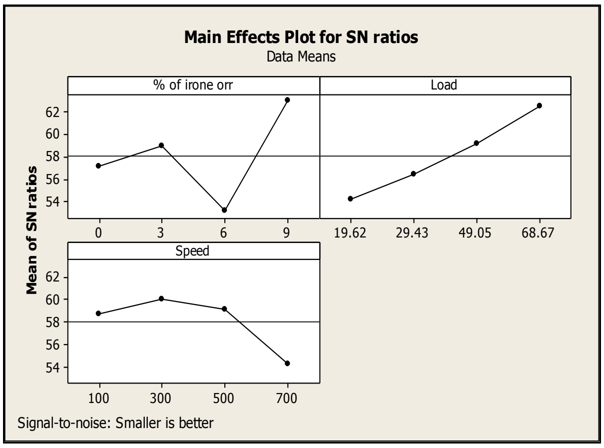
Fig 2: Main effects plots for volumetric wear rate of (a) S/N Ratios (b) Mean

Table 6:- Response Table for Signal to Noise Ratios

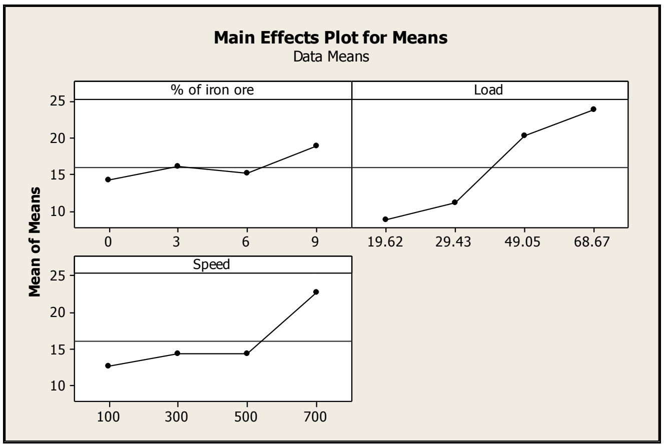
Level	% of iron ore	Load	Speed
1	-18.26	-17.42	-19.27
2	-23.14	-19.48	-20.88
3	-23.18	-25.50	-23.01
4	-24.91	-27.10	-26.33
Delta	6.65	9.68	7.06
Rank	3	1	2

Table7:- Response Table for Means

Level	% of iron ore	Load	Speed
1	14.225	8.750	12.700
2	16.000	11.175	14.350
3	15.075	20.325	14.325
4	18.850	23.900	22.775
Delta	4.625	15.150	10.075
Rank	3	1	2



(a)



(b)

Fig 3: Main effects plots for frictional force of (a) S/N Ratios (b) Mean

5.2 ANOVA

The conducted experimental results were analyzed by using Analysis of Variance (ANOVA) which is used to examine the influence of wear parameters like Normal Load and Sliding speed. By using ANOVA, it can be decided which independent factor dominates over the other and the percentage contribution of that particular independent variable. This analysis was carried out for a level of 5% significance that is up to a confidence level of 95%. Sources with a P-value less than 0.05 were considered to have a statistically significant contribution to the performance measures. Tables 8 and 9 show the results of ANOVA analysis of Hybrid composite of volumetric wear rate and frictional force. It can be noticed from the table 8 % of iron ore has significant influence on specific wear rate and in table 9 Normal Load has significant influence on frictional force.

Table 8:- Analysis of Variance for volumetric wear rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% of contribution
% of iron ore	3	0.0000132	0.0000132	0.0000044	2.89	0.124	38.39
Load	3	0.0000065	0.0000065	0.0000022	1.43	0.324	19.17
Speed	3	0.0000051	0.0000051	0.0000017	1.11	0.415	15.04
Error	6	0.0000091	0.0000091	0.0000015			27.40
Total	15	0.0000339					100.00

Table 9:- Analysis of Variance for frictional force

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% of contribution
% of iron ore	3	48.49	48.49	16.16	0.33	0.804	3.98
Load	3	627.81	627.81	209.27	4.28	0.062	51.49
Speed	3	249.25	249.25	83.08	1.70	0.266	20.44
Error	6	293.50	293.50	48.92			24.09
Total	15	1219.06					100.00

5.3 REGRESSION ANALYSIS

The Regression analysis is used to develop the correlation between the effective factors (% of iron ore, Normal Load and speed) and the volumetric wear rate and frictional force (quality characteristic) to observed data.

The Regression equations for volumetric wear rate is

Volumetric wear rate = 0.00210314 - 8.08816e-007 (A) - 3.17277e-005(B)
+ 2.14058e-006 (C) ---- Eqn 2

R-sq = 73.08%

The Regression equation for Frictional Force is

Frictional Force = -5.57742 + 0.431667 (A) + 0.326975 (B) + 0.0151(C) ---- Eqn 3

R-sq = 75.92%

6. CONCLUSIONS:-

In this research work, the study is to optimize the process parameter levels within the range analyzed based on minimum of volumetric wear rate and frictional force and thereby attaining defect controlled wear of non laminated Hybrid composites. Based on the result obtained, the following conclusions were expressed as follows.

1. Taguchi method has been applied to analyze the specific wear rate and frictional force of non laminated Hybrid composites.
2. In volumetric wear rate, the % of iron ore (38.39%) has significant effect followed by load (19.17%) and speed (15.04%).
3. In frictional force, the load (51.49%) has significant effect followed by speed (20.44%) and % of iron ore (3.98%).
4. The optimal tribological testing combination for minimum volumetric wear rate and frictional force are found to be $A_4B_4C_2$ and $A_1B_1C_1$ for non laminated Hybrid composites.

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