TAGUCHI APPROACH FOR THE DRY SLIDING WEAR BEHAVIOR OF GRANITE AND FLY ASH FILLED GLASS EPOXY COMPOSITES

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ABSTRACT

*In this present research the parameter optimization of the wear behavior of Granite filled Glass–Epoxy (G–E) composites has been evaluated by the addition of fly ash as a secondary reinforcement using pin-on disc equipment. By using Taguchi statistical design, the significant controlling factors along with the interactions influence on the specific wear rate of the composites were identified. The results indicate that the addition of Granite in G-E composite increases the wear resistance evidently. It was found that highest wear resistance of G-E composite was achieved by the addition of 10wt. % Granite and 5wt. %fly ash. The presence of different wear mechanisms were analyzed and supported by SEM-micrographic examinations.***

Keywords: Two-Body Abrasive Wear, Wear Mechanisms, Anova, S/N Ratio

I INTRODUCTION

Composites can be defined as new age materials that consist of two or more chemically and actually different phases estranged by a distinct interface. The different systems are combined judiciously to achieve a system with more useful structural or functional properties by any of the constituent alone. Polymer can be considered to be one of competitive materials for tribological applications owing to their strength, ease of processing and availability of wider choice of systems. The matrix materiel surrounds and supports the reinforcement material by maintaining their relative positions. The reinforcement imparts their mechanical and physical properties to enhance the matrix properties. The primary function of the matrix material is to transfer stresses between reinforcing fibers/particulate and to protect them from mechanical and/or environmental damages where as presence of fibers/particles in a composite improves its mechanical properties such as strength, stiffness etc.

Wear is defined as damage to a solid surface, generally relating progressive loss of material, due to relative motion between that surface, Abrasive wear is the most important among all the forms of wear. Abrasive wear is caused due to hard particles or hard protuberances that are forced against and move along a solid surface [9]. In two-body abrasion, wear is caused by hard protuberances on one surface which can only slide over the other.

Engineering materials and are invariably used in mechanical components, where wear performance in no lubricated condition is a key parameter in the material selection

Wear processes in composites are complex phenomena involving a number of operating variables, and it is essential to understand how the wear characteristics of the composites are affected by different operating conditions. Selecting the appropriate operating conditions is always a major concern because traditional experimental design would require many experimental runs to achieve satisfactory results. In any process, the desired testing parameters are either determined based on experience or by use of a handbook. However, it does not provide optimal testing parameters for a particular situation.

II MATERIALS AND EXPERIMENTAL WORK

2.1. Methodology

The specimen has to be fabricated by using hand lay-up technique. The proper volume fraction of fibers, epoxy, fillers and orientation of fibers are to be controlled. The laminates are cured for a period of about 24 hr. Then the sample is cut to a required size for the tests.

2.2. Materials

The matrix material used was medium viscosity epoxy resin (LAPOX-12) and room temperature curing polyamine hardener (K-6). Supplied by YUJE ENTERPRISES Bangalore, This matrix was chosen, since it provides good resistance to alkalis and good adhesive properties. The reinforcement material employed was 7-mill E-glass fiber. The filler used was granite and fly ash.

Epoxy resin was used in the present investigation, the most widely used matrix material for advanced composites have been the epoxy resin. Epoxy resin systems have achieved acceptance as adhesives, potting compounds, molding compounds and as matrices for continuous filament composites used in structural applications. Epoxy molecules in the pure state at room temperature normally do not react with each other and can sit for years in a dry container without mutual reaction. In the present work Hardener (K-6) is used. This has a viscosity of 10-20 poise at 25^{o}C. Depending upon the resin and hardener compressing the system, the amount of hardener can vary as low as one part of hardener per 100 parts of resin.

E-glass fibers are the most common basic material for reinforced plastics. They are also used in a lot of other applications, ranging from telecommunications to insulation materials. Of the various types of glass fibers, E-glass is by far the most important with a market share of about 99%. For special applications R-glass or S-glass are used which have a higher modulus and applicable in an alkaline environment.

Granite is a hard, tough, igneous rock that is widely distributed in the Earth's continental crust. It is medium to coarse-grained and consists of a number of minerals, especially members of the feldspar group and quartz. It varies in composition and comes in a range of colors, such as white, red, pink, gray, and black, often occurring in combination. Given its ruggedness and wide distribution, it has been used as a construction stone since antiquity

Fly ash is a derivative of the combustion of coal mainly in large electricity generating coal power stations. The production of cement requires quantities of clay or sand. Fly ash is used as an alternative raw material in the cement production process as substitute to base raw material

III PREPARATION OF COMPOSITES

The Glass–Epoxy- Granite and fly ash composite used in this work is made from the hand lay-up technique. The procedure consisted of placing the glass fibers-epoxy with granite and fly ash compatible finish on a substrate material which had a release coat applied on it. A curing agent (hardener) is mixed in the epoxy (1:10 ratio) with Granite and fly ash to polymerize the polymer and form a solid network cross-linked polymer. Weighed quantities of epoxy resin- Granite and fly ash plus hardener mix was taken and smeared over the glass fabric. On this, another layer of the glass fabric was laid and the process continued. The whole layup was covered with a mat finished fabric over which steel plate was placed with the necessary release coat applied on it. [1] The layup assembly was pressed in a press. The excess resin was allowed to squeeze out. The laminate was cured at ambient conditions for a period of about 24 hr. The composites are fabricated and cured as reported by Basavarajappa et al [1]. And Suresha et al,[2,3] and The laminates so prepared has a size of 300 mm × 300 mm × 3 mm to prepare the filled glass-epoxy- Granit and fly ash composites, fillers are mixed with a known amount of epoxy resin. The details of the composites prepared are shown in Table 1

Table 1. Filler Material Composition

Sl. No	Material Code	Matrix(Epoxy) %volume	Reinforcement (Glass fiber) % volume	Filler (Granite) % volume	Filler (Fly ash) % volume
1	A	50	50	0	0
2	B	50	40	5	5
3	C	50	35	10	5

3.1. Specimen Preparation

After the preparation of composite material, the cured composite materials have been cut by diamond tipped cutter to yield the testing specimens of dimensions 10mm×10 mm×3 mm. The geometry of two body wear testing specimen has been done. The surface of the sample (10mm × 10mm × 3mm) glued to a pin of 10X10 mm Bar and 45 mm height.

3.2. Experimental Procedure

A pin-on-disc test apparatus was used to investigate the two body wear characteristics of the composites as per ASTM G99-95 standards. The disc used is En-31 steel hardened to 60 HRC, 165mm track diameter and 8mm thick, with surface roughness of 10µm Ra. The tests were conducted by selecting test duration, load and velocity and performed in a track of 60mm diameter. The glass fabric layers in the composites are parallel to the contact surface and to the sliding direction. The surface of the sample (10mm × 10mm × 3mm) glued to a pin of 10×10mm cross section and 45 mm height of the composites specimen makes contact to the counter surface. Prior to testing, the samples are rubbed over a 150, 320 and 600 Grit Silicon carbide paper to ensure proper contact with the counter surface.

Fig.1: Schematic Diagram of Pin on Disk Apparatus

3.3. Statistical Design of Experiment

Design of experiment is the powerful analysis tool for modeling and analyzing the influence of the control factors on the performance output. The most important stage in the design of experiment lies in the selection of the control factors. Therefore, a large number of factors are influenced so that non significant variables can be identified at the earliest opportunity. The standard liner graph by Glen for the analysis as shown in figure is used to assign the factor and interaction to various column of the orthogonal array. The plan of the experiment is as follows: the first column is assigned to the applied Load (A), the second column is to Abrading distance (B), the fifth column to the filler content (C), the ninth column Abrasive paper grit size (D), For analysis of specific wear rate third and fourth column are assigned to $(A \times B)_1$ and $(A \times B)_2$, respectively , to estimate interaction between Load (A) and Abrading Distance (B), the sixth and seventh column are assigned to $(B \times C)_1$ and $(B \times C)_2$, respectively, to estimate the interaction between the Abrading Distance (B) and Filler Material (C), The eighth and eleventh column are assigned to $(A \times C)_1$ and $(A \times C)_2$, respectively to estimate the interaction between the Load (A) and Filler Material Content (C), The remaining columns are assigned to error columns respectively,

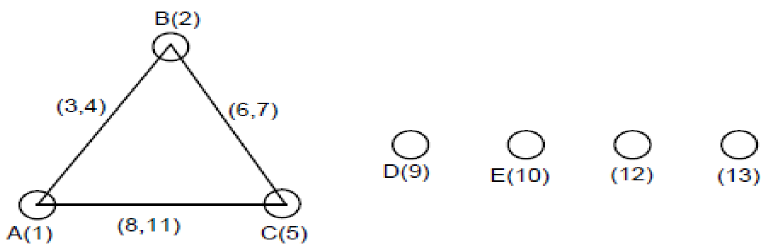


Fig.2: Linear Graph For L_{27} Array

Whereas for the analysis of coefficient of friction of third and fourth column are assigned to $(B \times C)_1$ and $(B \times C)_2$, respectively, to estimate interaction between Abrading Distance (B) and Filler Content (C), the sixth and seventh columns are assigned to $(C \times D)_1$ and $(C \times D)_2$, respectively, to estimate the interaction between the Filler Content (C) and Abrasive Grit Paper (D), the eighth and eleventh column are assigned to $(B \times D)_1$ and $(B \times D)_2$, respectively, to estimate the interaction between the Abrading Distance (B) and Abrasive Paper Grit Size (D) the remaining columns are assigned to error columns respectively,

IV RESULTS AND DISCUSSION

4.1. Taguchi Analysis of Specific Wear Rate

The analysis is done using MINITAB 16. Test result obtained are given in table 2

Table 2: Taguchi set of experiments

Sl no	Load (N)	Distance (m)	Composition	Grit size (μm)	Weight Loss TW	Wear volume loss (ΔV)m^3 $\times 10^{-9}$	Specific wear rate (k_S) m^3/Nm $\times 10^{-11}$	s/n ratio
1	5	25	A	150	0.0084	4.5652	3.652	-11.250
2	5	25	B	320	0.0123	6.9023	5.5218	-14.841
3	5	25	C	600	0.0051	2.8523	2.2818	-7.1655
4	5	50	A	320	0.0083	4.5108	1.8043	-5.1261
5	5	50	B	600	0.0052	2.9180	1.1672	-1.3429
6	5	50	C	150	0.0149	8.8333	3.3333	-10.4574
7	5	75	A	600	0.0042	2.2826	0.6086	4.3133
8	5	75	B	150	0.0126	7.0707	1.8855	-5.5085
9	5	75	C	320	0.0077	4.3064	1.1483	-1.2011
10	10	25	A	320	0.0201	10.9239	4.3695	-12.8086
11	10	25	B	600	0.0077	4.3209	1.7283	-4.75238
12	10	25	C	150	0.0682	38.143	15.257	-23.6693
13	10	50	A	600	0.0181	9.8369	1.9673	-5.8774
14	10	50	B	150	0.0576	32.3232	6.4646	-16.2108
15	10	50	C	320	0.0435	24.3288	4.8657	-13.7429
16	10	75	A	150	0.1835	99.7282	13.297	-22.4750
17	10	75	B	320	0.0305	17.1156	2.2822	-7.1670
18	10	75	C	600	0.0089	4.9776	0.66368	3.5608
19	15	25	A	600	0.0125	6.7934	1.8115	-5.16076

20	**15**	**25**	**B**	**150**	**0.1190**	**66.7789**	**17.807**	**-25.0118**
21	**15**	**25**	**C**	**320**	**0.0321**	**17.9530**	**4.7874**	**-13.6019**
22	**15**	**50**	**A**	**150**	**0.3180**	**172.82**	**23.040**	**-27.2496**
23	**15**	**50**	**B**	**320**	**0.0339**	**19.0235**	**2.5364**	**-8.0843**
24	**15**	**50**	**C**	**600**	**0.0130**	**7.2706**	**0.96942**	**0.2697**
25	**15**	**75**	**A**	**320**	**0.0322**	**17.5**	**1.5555**	**-3.83740**
26	**15**	**75**	**B**	**600**	**0.0144**	**8.0808**	**0.71829**	**2.87400**
27	**15**	**75**	**C**	**150**	**0.1532**	**85.6823**	**7.6162**	**-17.634**

The aim of the experimental plan is to find the important factors and combination of factors influencing the wear process to achieve the minimum wear rate. The experiments have been developed based on orthogonal array, with the aim of relating the influence of load, sliding distance, composition, grit size. These design parameters are distinct and intrinsic feature of process that influence and determine the composite performance. Taguchi recommends analyzing the S/N ratio using conceptual approach that involves graphing the effects and visually identifying the significant factors.

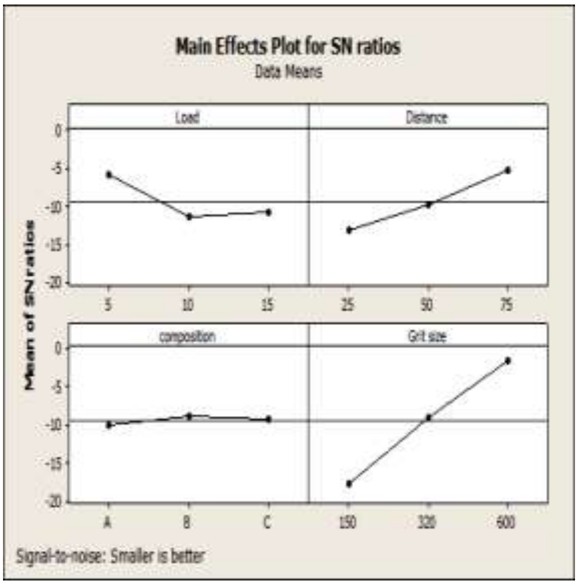
The investigational results and calculated values have been obtained based on the plan of experiment and then the results were analyzed with the help of commercial software MINITAB 15 specifically used for design of experiment application. The influence of controlled process parameters such as load, sliding distance, composition, grit size has been analyzed and the rank of involved factors like wear rate which supports signal to noise ratio response is given in table.

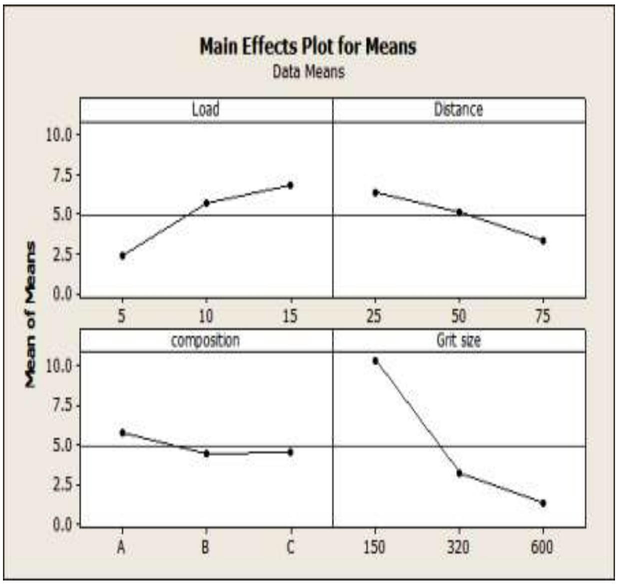
Table 3:Response for signal to noise ratio- smaller is better

Level	Load (N)	Distance (m)	Composition	Grit size
1	-5.816	-13.115	-9.941	-17.719
2	-11.46	-9.758	-8.894	-8.934
3	-10.826	-5.23	-9.268	-1.45
Delta	5.644	7.884	1.047	16.269
Rank	3	2	4	1

It is evident from the table3 that, among these parameters, Grit size is a dominant factor on the wear rate. Figure shows graphically the effect of the four control factors on wear rate of the composite specimens.

4.2. Main effect plots for means and S/N ratio





A main effect is seen when different levels of a factor affect the response differently. A main effects plot graphs the response mean for each factor level connected by line. When the line is horizontal, then there is no main effect present. Each level of the factor affects the response in the same way, and the response mean is the same across all factor levels. When the line is not horizontal, then there is a main effect present. Different levels of the factor affect the response differently. The steeper the slope of the line, greater is magnitude of the main effect on the wear rate. For each control factors, a level with maximum value of mean of S/N ratio will give maximum wear rate. In this case, material code B, with 5 N load, 75 m sliding distance and grit size of 600 µm will lead to a minimum wear rate.

When the effect of one factor depends on the level of the other factor, interaction plot can be used to visualize possible interactions. Parallel lines in an interaction plot indicate no interaction. The greater the difference in slope between the lines, the higher is the degree of interaction. From the interaction plot shown in figure it is observed that the interaction A x B x C i.e., load, sliding distance and percent filler shows significant effect on the wear rate of the composite samples.

4.3. Analysis of variance

Analysis of variance is a statistical tool used to compute the quantities and their significance in order to find out the effect of various factors like fiber loading, normal load, sliding distance and abrasive particle size on specific wear rate of granite and fly ash filled glass fiber reinforced epoxy composites, analysis of variance (ANOVA) is performed based on Taguchi experimental results. Table shows the results of the ANOVA with the specific wear rate of granite and fly ash filled glass fiber reinforced epoxy composition taken in this investigation. The analysis has been evaluated for a confidence level of 95%, that is for significance level of $\alpha=0.05$. The last column of table shows the percentage of contribution (P %) of each parameter on the response, indicating the degree of influence on the result.

Source	DOF	Seq SS	Adj SS	Adj MS	F	P	%
Load	2	170.41	170.41	85.207	7.58	0.023	8.547
Abrading distance	2	283.5	283.5	141.75	12.6	0.007	14.219
Filler material	2	5.03	5.03	2.515	0.22	0.806	0.252
Abrasive Grit size	2	1189.89	1189.89	594.947	52.9	0	59.68
Load x Distance	4	23.7	23.7	5.926	0.53	0.721	1.188
Load x Filler material	4	46.9	46.9	11.726	1.04	0.458	2.352
Load X Abrasive Grit size	4	206.84	206.84	51.71	4.6	0.049	10.374
Residual error	6	67.48	67.48	11.247			3.384
Total	26	1993.76					100

It has been observed from the from the result that Abrasive Grit size is the most significant parameter having the highest statistical influence (59.68%) on the dry sliding wear of composite followed by Abrading or sliding distance (14.219%). Among interaction terms, interaction between Load and abrasive grit size have a significant influence (P=10.374%) on wear rate of the composites. Other interactions are below the confidence level of 0.05. The pooled error is very low, accounting for only 3.38%. From the analysis of variance and S/N ratio, it is inferred that the Abrasive Grit size has the highest contribution on wear rate followed by abrading distance and load.

4.4. Multiple linear regression models

A multiple linear regression model is developed using statistical software MINITAB 15. This model gives the relationship between an independent/ predictor variable and a response variable by fitting a linear equation to observed data.

$$\text{Specific wear rate} = 10.2 + 0.438\ \text{Load} - 0.0610\ \text{Distance} - 0.0186\ \text{Grit Size} \quad (1)$$

The above equation has been used predict the wear rate of the composites. The constant in the equation is the residue. From regression equation it has been found that wear rate of composite is directly proportional to load and inversely proportional to sliding distance and grit size.

V CONCLUSIONS

The experimental and statistical analysis have been carried out for dry sliding abrasive wear test on glass epoxy, granite and fly ash reinforced composites the following conclusions have been drawn:

1. The wear testing experiment have been carried out at a sliding distance of 25, 50, 75 m at three different loads of 5, 10, 15 N for three different compositions of material A, B, C under three different Abrasive grit size of 150, 320, 600 µm.

2. From Signal to Noise ratio smaller the better have been chosen since the wear has to be reduced in the material composition.
3. From ANOVA it can be seen that Abrasive grit size and abrading distance are influencing the wear rate and also the percentage contribution of each factors that are affecting the responses.
4. Investigation on the effectiveness of granite and fly ash on the wear performance of composites has been reported. Specific wear rate decreases with abrading distance and increases with abrading grit size. Granite and fly ash reinforced glass epoxy composites shows better wear resistance as compared to that of unfilled G-E composite.

REFERENCE

1. S.Basavarajappa, Ajith G. Joshi, K.V.Arun, A. Praveen Kumar, and M.Prasanna Kumar, "Three body abrasive wear behavior of SiC filled glass epoxy composites" polymer –plastics technology and engineering, 2005, 44.
2. B. Suresha, Siddaramaiah, Kishore, S, Seetharamu and P, Sampath Kumaran Investigations on the influence of graphite filler on dry sliding wear and abrasive wear behaviour of carbon fabric reinforced epoxy composites, Wear, September 2009; Vol. 267(9-10): pp. 1405-1414.
3. Bhadrabasol Revappa Raju1, Bheemappa Suresha2, Ragera Parameshwarappa Swamy3, Bannangadi Swamy Gowda Kanthraju4 "Investigations on Mechanical and Tribological Behaviour of Particulate Filled Glass Fabric Reinforced Epoxy Composites" Journal of Minerals and Materials Characterization and Engineering, 2013, 1, 160-167
4. C. Anand Chairman1, S. P. Kumaresh Babu1*, Muthukannan DuraiSelvam2, K.R.Balasubramanian3. "Investigation on two-body abrasive wear behavior of titanium carbide filled glass fabric-epoxy composites- a Box-Behnken approach" International Journal of Engineering, Science and Technology Vol. 3, No. 4, 2011, pp. 119-129
5. B.Suresha, G.Chandramohan, "Three-body abrasive wear behavior of particulate-filled glass-vinyl ester composite", Journal of materials processing technology, 2008,200, 306-311.
6. S.Basavarajappa, Ajith G. Joshi, K.V.Arun, A. Praveen Kumar, and M.Prasanna Kumar, "Three body abrasive wear behavior of SiC filled glass epoxy composites" polymer –plastics technology and engineering, 2005, 44.
7. B. Suresha, Siddaramaiah, Kishore, S, Seetharamu and P, Sampath Kumaran Investigations on the influence of graphite filler on dry sliding wear and abrasive wear behaviour of carbon fabric reinforced epoxy composites, Wear, September 2009; Vol. 267(9-10): pp. 1405-1414.
8. Gaurav Agaraval,Amar Patnaik, Rajesh Kumar Sharma, "Parametric optimization of Three body abrasive wear behavior of Sic Filled Chopped Glass Fiber Reinforced Epoxy Composites", International journal of engineering and research,2013,3(2),32-38.

9. Suresha, BChandramohan, G Sadananda Rao, P R Sampathkumaran, P Seetharamu, S Venkateswarlu, Vartha “Friction and slide wear characteristics of glass-epoxy and glass-epoxy filled with SiCp composites” CSIR C03C 14/00 G01N 19/02

10. K.Naresh kumar ,M.Prashanth kumar ,V.Krishna , Experimental Investigation on Mechanical Properties of Coal Ash Reinforced Glass Fiber Polymer Matrix Composites