A STUDY OF WEAR BEHAVIOUR AND EXPERIMENTAL DESIGN OF ACRYLONITRILE BUTADIENE STYRENE (ABS) / CARBON POWDER COMPOSITES

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Abstract - Mankind has been aware composite materials since several hundred years before Christ and applied innovation to improve the quality of life. Contemporary composites results from research and innovation from past few decades have progressed from glass fiber for automobile bodies to particulate composites for aerospace and a range other applications. In view of these, the present investigation is on the tribological testings of ABS thermoplastics with carbon powder under dry sliding conditions and lubrication condition. The experiments based on the technique of Design of Experiments (DOE). DOE technique usually facilitates the intended optimization of factors affecting a physical phenomenon. Acrylonitrile-butadiene-styrene (ABS) is a widely used thermoplastic. In ABS, acrylonitrile causes an improvement in chemical resistance and weatherability, butadiene has the character of rubber toughness, and styrene offers glossiness and processability. The compositions of the various components can be controlled to meet the requirements of a variety of applications.

Keywords: ABS, Friction and wear, Design of Experiments, Central Composite Design, Analysis of Variance.

1. INTRODUCTION

Composite materials have generally considerable research interest during recent times. They are replacing many conventional engineering materials due to their specific properties of strength and stiffness. The applications are either weight critical or performance critical as seen in automobile and aerospace industries. The concept of combining two or more constituent materials to form a composite and to make the best use of the more desirable properties of the constituents has opened up several avenues for intelligent exploitation of composite materials.

A composite material is made by combining two or more materials to give a unique combination of properties. The above definition is more general and can include metals alloys, plastic co-polymers, minerals, and wood. Fiber-reinforced composite materials differ from the above materials in that the constituent materials are different at the molecular level and are mechanically separable. In bulk form, the constituent materials work together but remain in their original forms. The final properties of composite materials are better than constituent material properties [1].

Based on the nature of matrix, the composites can be Ceramic Matrix Composites (CMCs), Metal Matrix Composites (MMCs) or Polymer Matrix Composites (PMCs). Polymer Matrix Composites have matrices of thermoplastic or thermosetting polymers. A large number of resin formulations, curing agents and fillers provide an extensive range of possible properties. PMCs are increasingly being employed as structural materials in civil, defense, aerospace, automotive and industrial applications where the weight reduction can contribute toward saving in fuel and other materials [1]. Many common thermoplastics are too stiff by themselves, limiting their commercial applications. ABS represents industrially the most important thermoplastic two-phase system with an amorphous structure. The ABS polymers are based on three monomers: Acrylonitrile, Butadiene, and Styrene.

Acrylonitrile-butadiene-styrene (ABS) is a widely used thermoplastic. In ABS, acrylonitrile causes an improvement in chemical resistance and weatherability, butadiene has the character of rubber toughness, and styrene offers glossiness and processability. The compositions of the various components can be controlled to meet the requirements of a variety of applications.

Acrylonitrile Butadiene Styrene is a common thermoplastic. It is a copolymer made by polymerizing styrene and acrylonitrile in the presence of polybutadiene. ABS polymers have a high toughness, satisfactory rigidity, and good resistance to heat, chemical, and environmental stress cracking. Molded articles with high dimensional stability and good surface quality can be produced by simple processing technique.

2. FRICTION AND WEAR

Friction and wear are terms that most people use in their daily lives. Most people accept the cost of sport shoes wearing out after 4 months of use; people accept wear of roadways and flooring; people accept 30,000 miles as the limiting use of an automobile before fan belts, brakes, and other components start to wear out. This guide reviews current friction and wears fundamentals and describes the bench tests that are most often used to study and solve tribology problems. Tests are compared and critiqued. Information is presented to help the reader select a test that he or she might use to address a tribology concern that they are responsible for solving. The overall objective of the guide is to lower the annual cost of wear, and unwanted friction through appropriate tribo testing.

A problem in dealing with friction is that people often say that a material is low friction. A material cannot have a co-efficient of friction. It is a system effect. This co-efficient is unique to a system. It takes into consideration factors such as

- Surface texture,
- Sliding speed,
- Contact geometry,
- Type of motion (reciprocity, continuous, etc.),
- Environment,
- Mating materials,
- Mechanical properties of mating materials,
- Separating films/particles and,
- Contaminants.

Wear refers to the progressive removal of material from a surface and plastic deformation of material on a surface due to the mechanical action of the other surface [2]. The necessity for relative motion between the operating surfaces and initial mechanical contact between asperities leads an important role between mechanical wear compared to other processes with similar outcomes [2].

The OECD (Organization for Economic Cooperation and Development) defines wear as "the progressive loss of substance from the operating surface of a body occurring as a result of relative motion a t the surface".

2.1 FRICTION AND WEAR TESTS

The Tribometer uses a pin-on-disk system to measure wear. It consists of a pin on disc, loading panel and friction & wear monitor. The sliding wear of pure ABS and carbon powder filled ABS are carried out with different loads by varying time and sliding distances. To evaluate the performance of these composites under dry sliding and lubrication conditions, wear tests will be carried out in a pin-on-disc type friction and wear monitoring test rig as per ASTM G 99-95a. The counter body is usually a disc made of hardened ground steel. The specimen is held stationary and disc is rotated while a normal force is applied through a lever mechanism.

Fig 1: Set up to Perform an Abrasive Wear Test on Pin-on-Disc

2.2 STANDARD METHODOLOGY

2.2.1 Design of Experiments

Design of experiments can be defined as "The simultaneous evaluation of two or more factors for their ability to affect the resultant average or the variability of the particular product or process characteristics" To accomplish this in an effective and statistically proper fashions, the level of the factors are varied in a strategic manner, the result of particular test combinations are observed, and the complete set of the results are analyzed to determine the influential factors and preferred levels, and weather increase or decrease of those levels will potentially lead to further improvement. It is important to note that this is an iterative process; the first round through DOE process will many times leads to subsequent rounds of experimentation. The beginning round often referred to as a screening experiment is used to find the few important influential factors out of many possible factors involved with a product or process design [4].

To use the statistical approach in designing and analyzing an experiment, it is necessary for everyone involved in the experiment to have a clear idea in advance of exactly what is to be studied, how the data are to be collected, at least a qualitative understanding of how these data are to be analyzed.

2.2.2Central Composite Design (CCD)

Design of experiment is a powerful analysis tool for modeling and analyzing the influence of control factors on performance output. The most important stage in the design of experiment lies in the selection of the control factors. Therefore, a number of factors are included so that non-significant variables can be identified at earliest opportunity**.** Two parameters viz., normal load and time each at two levels are considered in this study in accordance with central composite design (CCD) [5].

Central composite design (CCD) is one of the methods of response surface design. CCD is very effective experimental technique in studies involving large number of factors. A set of experimental design that can look at k factor an n observation with each factor at two levels is called two level factorial designs, which can prove good and efficient when a linear relationship prevails between the factors and response**.**

Fig 2 shows the geometric form of the design when it is rotated by 450. It can be noticed that the levels of each factor have been increased from three levels without increasing the total number of test combination (Tc) which is still equal to nine. The design as represented in geometric form in fig 3 is called central composite design (CCD) for it is made up of a central point and optimal joining of the 22 factorial designs with one factor-at-a-time design.

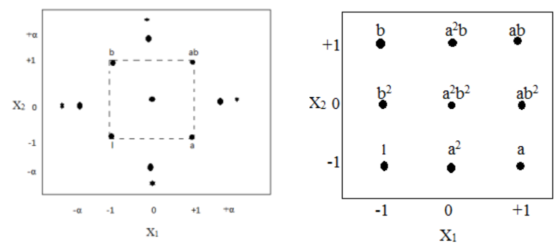

Fig 3: Two factorial designs with one factor-at-a-time design

The experimental design based on CCD allows investigation of factor up to fourth order quartics relationship due to the existence of five levels of each factor. The real value of the design is the increased scope of the experiment central composite design are easy to construct since they are based on two level factorials (2^k) and one-factor-at-a-time techniques. The general representation of CCD is:

No. of test combinations (Tc) = $2^{k-p} + 2*k + 1$

Here, k = no. of factors and p = the fractionalization element

Table.1 provides details of factors and their range considered in the present investigation.

Table 1: Details of factor and their range

FACTORS		RANGE
Load, N	X_1	10 to 80
Time, sec	X_2	500 to 1000

The distance (α) of the star (*) points from the centre is determined using equation

$$\alpha = 2^{k/4} = (2^2)^{1/4} = 1.414$$

These factors and their levels in CCD experimental plan are summarized on table 2.

Table 2: Factors and their levels in CCD experimental plan

FACTORS		LEVELS				
		-1.414	**-1**	**0**	**1**	**+1.414**
Load, N	X_1	10	20	45	70	80
Time, sec	X_2	500	573.2	750	926.8	1000

No. of test combinations (tc) = $2^{k-p} + 2*k + 5$

$$tc = 2^{2-0} + 2*2 + 5 = 13$$

3 RESULTS AND ANALYSIS

3.1 Analysis and Results of Carbon Powder filled ABS under Dry Sliding Condition

From table 2, CCD experimental plan and the wear test results of ABS thermoplastics are shown. Analyses are made using popular software specifically used for design of experiment applications known as Minitab. Before any attempt is made to use this simple model as a predictor for the measure of performance, the Regression models, Analysis of variance (ANOVA), main effects and the possible interactions between the control factors must be considered. Thus factorial design incorporates a simple means of testing for the presence of the interaction effects.

ABS is the main matrix material and reinforced with carbon powders. Prepare composites of composition such as matrix resin and filler percentage i.e., 90% matrix resin and 10% fillers. Details of materials and processing methods are described in chapter 4. CCD experimental plan and the wear testing results of carbon powder filled ABS are provided in table 3.

The analysis of variance is shown in table 4. Using α = 0.05, the critical value of F for load and time is $F_{0.05, 1, 9}$ = 5.12. Because 78.46>5.12 and 7.59>5.12, it can be concluded that the factors load and time significantly affects the wear. The p-value for the test is also quite small. The values of P less than 0.050 indicate model terms are significant. In this case factors A (load) and B (Time) are significant model terms, but the AB (load-time) interaction value greater than 0.050 indicates insignificant model terms.

The quantity "R-squared" explains about 90.70 percent of the variability in wear. Clearly, it must have $0 \leq R^2 \leq 1$, with larger values being more desirable. The "adjusted" R^2 is a variation of the ordinary R^2 statistic that reflects the number of factors in the model. The "predicted R-Squared" of 0.9070 is in reasonable agreement with the "adjusted R-squared" of 0.8760.

Table 3: CCD Experimental Plan and the Wear Test Results of Carbon Powder filled ABS

	Coded variables		Natural variables		Responses	
tc	**A**	**B**	**Load, N**	**Time, sec**	**Wear, g**	**COF**
1	-1	-1	20	573.2	0.0004	0.379
a	+1	-1	70	573.2	0.0096	0.315
b	-1	+1	20	926.8	0.0007	0.393
ab	+1	+1	70	926.8	0.0154	0.318
$-\alpha_a$	-1.414	0	10	750	0.0004	0.249
$+\alpha_a$	+1.414	0	80	750	0.0202	0.324
$-\alpha_b$	0	-1.414	45	500	0.0018	0.301
$+\alpha_b$	0	+1.414	45	1000	0.0089	0.314
zero	0	0	45	750	0.0067	0.321
zero	0	0	45	750	0.0049	0.318
zero	0	0	45	750	0.0056	0.277
zero	0	0	45	750	0.0062	0.276
zero	0	0	45	750	0.0072	0.307

Table 4: ANOVA – General Linear Model

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General Linear Model: Wear versus Load, Time

Factor  Type  Levels  Values


Analysis of Variance for wear, gms, using Adjusted SS for Tests

Source      DF     Seq SS     Adj SS     Adj MS      F      P
load         1  0.0003367  0.0003367  0.0003367  78.46  0.000
time         1  0.0000326  0.0000326  0.0000326   7.59  0.022
load*time    1  0.0000076  0.0000076  0.0000076   1.76  0.217
Error        9  0.0000386  0.0000386  0.0000043
Total       12  0.0004155

S = 0.00207162   R-Sq = 90.70%   R-Sq(adj) = 87.60%

Term            Coef   SE Coef      T      P
Constant    0.006769  0.000575  11.78  0.000
load        0.006488  0.000732   8.86  0.000
time        0.002018  0.000732   2.75  0.022
load*time   0.001375  0.001036   1.33  0.217

Unusual Observations for wear, gms

Obs  wear, gms       Fit    SE Fit  Residual  St Resid
  6   0.020200  0.015943  0.001184  0.004257    2.50 R

R denotes an observation with a large standardized residual.
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A normal probability plot of the standardized effect estimates from this experiment is shown in figure 4. The only large effects are A (load) and B (time) and the interaction AB. The effects that are negligible are normally distributed, with mean zero and variance and will tend to fall along a straight line, whereas significant effects will have non zero means and will not lie along the straight line.

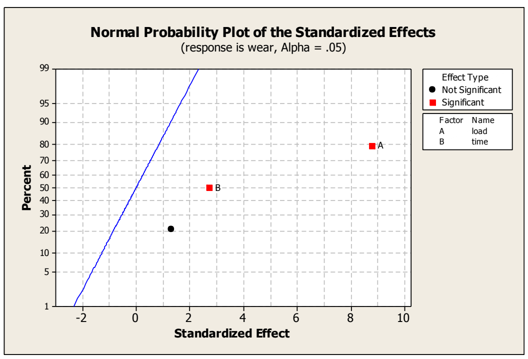

Fig 4: Normal Probability Plot of the Standardized Effects

The main effects of A (load) and B (time) are plotted in figure 5. All two effects are positive, and if considered only these main effects, it would run all two factors at a high level to minimize the wear. However, it is always necessary to examine interactions that are important.

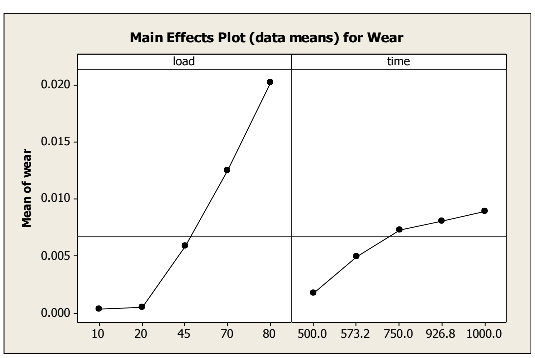

Fig 5: Main Effects Plot

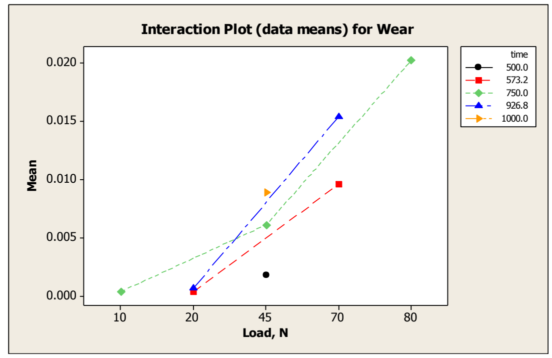

Fig 6: Interaction Plot

The AB (load-time) interactions are plotted in fig 6. These interactions are the key to solving the problem. Note from AB interaction that the time effect is fairly good when the load increases.

3.2 Regression Analysis

To fit linear regression models, it wishes to develop an empirical model relating to the wear of carbon powder filled ABS thermoplastics for factors of load and time. A model that might describes the relationship is

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + C$$

Where β_0, β_1 and β_2 are unknown parameters to be estimated and C is a random error term. The method often used to estimate the parameters in a model such as this is the method of least squares. This consists of choosing estimates of the β's such that the sum of the squares of the errors (the C's) is minimized. Table 5 shows the output obtained from Minitab to fit the wear regression model.

Table 5: Regression Analysis for Wear of Carbon Powder Filled ABS

Regression Analysis: Wear versus Load, Time

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The regression equation is
Wear, gms = - 0.0135 + 0.000261 load + 0.000011 Time

Predictor         Coef      SE Coef       T      P
Constant     -0.013522     0.003565   -3.79  0.004
Load        0.00026071   0.00003064    8.51  0.000
Time        0.00001141   0.00000431    2.65  0.024

S = 0.00215546   R-Sq = 88.8%   R-Sq (adj) = 86.6%

Analysis of Variance

Source           DF          SS          MS      F      P
Regression        2  0.00036901  0.00018450  39.71  0.000
Residual Error   10  0.00004646  0.00000465
Total            12  0.00041547

Source     DF      Seq SS
Load        1  0.00033644
Time        1  0.00003257
```

The least square fit, with the regression co-efficient has two significant factors, viz load and time is,

Wear = – 0.0135 + 0.000261 load + 0.000011 time

The equal-variance and normality assumptions are easy to check using a **normal probability plot.** To construct a probability plot, the general procedure is very simple and can be performed quickly with most statistic software packages. A computer generated normal probability plot of residuals and plot of residuals versus fitted value are shown in figure 7 and figure 8.

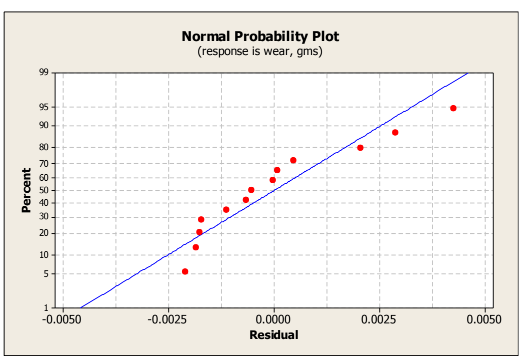

Fig 7: Normal Probability Plot of Residuals

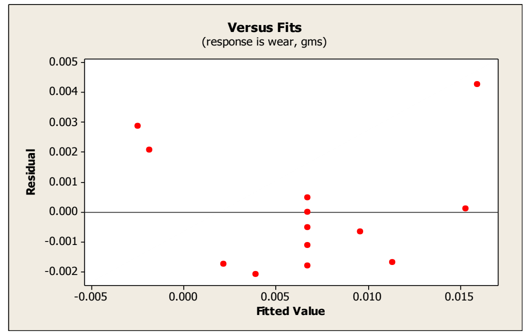

Fig 8: Plot of Residuals versus Fitted value

Figure 9 presents the three dimensional response surface plot of wear from this model, and figure 10 is the contour plot of response wear in the load, time plane. Because the model is first order (that is, it contains only the main effects), the fitted response surface is a plane. From examining the contour plot, it can be see that wear increases as load and time increases.

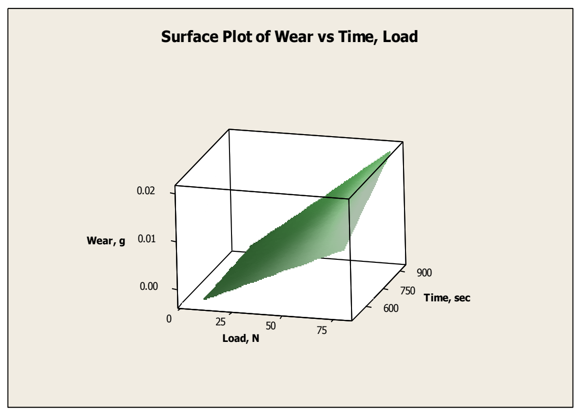

Fig 9: The Response Surface Plot

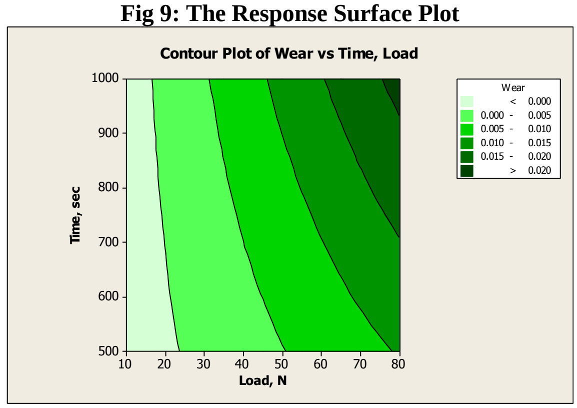

Fig 10: The Contour Plot

Exploration of response surfaces is a very important aspect of experimental design. From examination of the contour plot, we note the process may be slightly more sensitive to changes in time than to changes in load. Because the model is first order (that is, it contains only the main effects), the fitted response surface is a plane. From examining the contour plot, it can be see that wear increases as load and time increases.

4. CONCLUSION

The experimental and statistical analysis are carried out for the friction and wear behavior of carbon powder filled ABS composites under dry sliding leads to the following conclusions.

- Fabrication of a carbon powder filled ABS has been carried out by extrusion and injection molding processes.
- The experimental design has been planned using Central Composite Design (CCD) and statistical analysis has been carried for determining significant factors affecting the wear.
- Mathematical models for wear of carbon powder filled ABS in dry condition have been generated using statistical analysis.
- The following conclusions have been drawn from the experimental results obtained to determine the friction and wear of carbon powder filled ABS under dry and lubricating conditions. They are
  - It can be inferred that, carbon powder filled ABS under dry sliding condition exhibits inferior wear properties.
  - The co-efficient of friction in case of carbon powder filled ABS are minimum.

Besides this study concerning the influence of characteristic properties of ABS and carbon powder, these investigations will not only help in understanding friction and wear behavior but also assist in design and fabrication of materials for tribological applications based on ABS-carbon powder composites.

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