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Application of Taguchi Approache to Study the Effect of Filler Type on Tribological Behavior of Polymer Composite Under Dry Conditions

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ABSTRACT

The tribological behaviour of a G-P (glass-polyester) composite system and G-P composite systems interfaced with graded fillers were tested. The composite materials of G-P and G-P reinforced with SiC and Graphite particles as secondary fillers were experimentally investigated under varying loads, sliding velocities with dry surfaces by using a Pin-on-Disc test machine. A plan of experiments, based on the techniques of Taguchi, were performed to acquire data in a controlled way. An L9 Orthogonal array was selected for analysis of the data. Investigations to find the influence of additives, applied load, sliding speed on wear rate, wear resistance as well as the coefficient of friction during wearing process were carried out using ANOVA analysis and regression equation for each response. The model was chosen as "smaller is better" characteristics to analyse the dry sliding wear and friction while "larger is better" for sliding wear resistance. Results show that the additives have the highest influence followed by load and sliding speed. Finally, confirmation tests were performed to verify the experimental results foreseen from the mentioned correlations

Keywords: Glass-Polyester, Fillers, Taguchi's approache, Orthogonal array, Analysis of variance wear behaviour.

تطبيق طريقة تاكوشي لدراسة تاثير نوعية دقائق الحشو على سلوك الترايبولوجيا للراتنجات المقوى بالياف الزجاج تحت ظرف التشغيل الجاف

سلوك الترايبولوجيا لمركبات البولي استر المقوى بالياف الزجاج من جهة ومركبات البولي استر المقوى بالياف الزجاج متداخله بحشو دقائق الكرافيت وكاربيدات السليكون من جهة اخرى قد تم اختبارها عمليا تحت تاثير احمال وسرع انزلاقيه مختلفه وباستخدام جهاز المسمار والقرص.التجارب تم تصميمها والتحكم فيها اعتمادا على طريقة تاكوشي لغرض الحصول على البيانات البيانات بطريقة مسيطر عليها. المصفوفه

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القياسية L9 اختيرت لتحليل البيانات.التحقق لايجاد تاثير المضافات والاحمال والسرع الانزلاقية على معدل ومقاومة البليان وكذلك معامل الاحتكاك اثناء عملية التعريه قد تم تحليلها باستخدام ANOVA
مميزات نموذج " الاصغر – الافضل" لتحليل البليان والاحتكاك بينما مميزات نموذج "الاكبر- الافضل" لمقاومة البليان تم اختيارهما.اظهرت النتائج ان المضافات لها التاثير الاكبر يتبعها تاثير الاحمال والسرع الانزلاقيه واخيرا تم التحقق من نتائج التجارب باستخدام المعادلات المستنبطة من نتائج التجارب الحاصله .

INTRODUCTION

Wear is the most important yet at least understood aspect of tribology. It is certainly the youngest of the tri of topics, friction, lubrication and wear [1].The wear properties can be varied substantially through changes in the microstructure, the morphology, the mechanical properties of reinforcing phase and the nature of interface between matrix and reinforcement [2].Composites are multifunctional material systems composed of at least two elements working together to produce material properties chosen according to the desired mechanical properties and application [3]. The composites consist of a the matrix and a reinforcement of some kind, added to increase the strength and stiffness of the matrix. The matrix isolates the fibers from one another in order to prevent abrasion and formation of new surface flaws and possess ability to deform easily under applied load, transfer the load onto the fibers and evenly distributive stress concentration [4]. There are two main characteristics which make these materials attractive. They are relatively low density and ability to be tailored to have stacking sequences that provide high strength and stiffness in directions of high loading [5]. Due to their good combination of properties, they are used in advancing activities in aircrafts, aerospace and automotive industries [6].

The fillers dispersed in composites is increasing, since fillers do not reduce the cost only but improve the performance requirements which can not be obtained by using reinforcement and resins only.

In order to obtain perfect friction and wear properties many studies reported that the wear resistance with polymer sliding against steel improved when the polymers are reinforced with glass or aramid fibers. The modification of the tribological behavior of polymers by the addition of filler materials has shown a great promise and so has lately been a subject of considerable interest [5,7,8, and 9]. Kishore et al [10] studied the influence of sliding velocity and load on the friction and wear behavior of glass-polyester composites filled with either rubber or oxide particles and reported that the wear loss increased with increase in load and speed. Suresha et al [11] studied the influence of graphite particles on the wear of woven glass fabrics reinforced polyester composite they deduced that the filler contributed significantly in reducing friction and exhibited better wear resistance properties. Wang et al [12] studied the effect of solid lubricants such as MoS_2 when added to polymers S. Basvarajappay et al [13] carried out friction and wear behavior on FRP materials. Authors have compared the carbon epoxy (C-E) composite with that of glass epoxy (G-E) composites for tribological properties. It was found that, for optimization of tribological characteristics, moderate load and sliding velocity are the preferred choice irrespective of the type of the composite used.

The objective of this work is to apply the Taguchi method to investigate the friction, wear rate and wear resistance characteristics of a G-P composite system with chopped orientation of reinforcing fibers filled with different inorganic fillers of equal weight ratio against a hardened steel counter face.

Taguchi Technique

Taguchi technique is a powerful tool for the design of high quality systems [14]. The Taguchi technique to experimentation provides an orderly way to collect, analyze, and interpret data to satisfy the objectives of the study. Taguchi parameter design can optimize the performance characteristics through the setting of design parameters and reduce the sensitivity of the system performance to the source of variation [15]. Taguchi technique creates a standard orthogonal array to accommodate the effect of several factors on the target value and defines the plan of experiment[16]. The experimental results are analyzed using analysis of means and variance to study the influence of factors.

Starting Materials

Chopped strand mat (fiber) of 300 gsm, 11 µm diameter and 50 mm length has been employed (G). The matrix system used is unsaturated polyester resin (P) known commercially as TOPAZ -1110 TP medium reactive unsaturated polyster resin based on Phthalic Anhydride (KSA made). The polyster resin is mixed with hardner (Methyl Ethyl Ketone Peroxed MEKP) in the ratio 100:2 by weight. The fillers used are, graphite powders (no. 7782-42-5 Merck index 10,4410 Swiss) and silicon carbide powder 220 mesh (409-21-2 F.W.40.10) SiC.

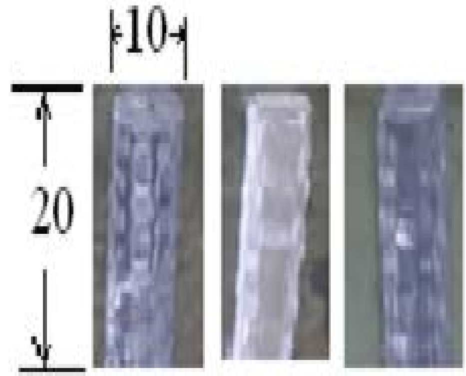
Composite Preparation

The composite specimens were prepared by dry hand lay up procedure. E-glass strand fibers, compatible with polyester resin, is used as the reinforcement. The unsaturated polyester resin is mixed with the hardener in the ratio 100:2 by weight. The stacking procedure of unfilled G-P composites consists of placing the chopped strand ply one above the other with the mixed well resin spread between the plies by using mould of 260x260x10 mm. The process was repeated till all the 16 plies were complete. The whole assembly was pressed to (0.25 MPa) and then released and allowed to cure for a 7 days at room temperature. The laminate so prepared has a size 200 x 200 x 10 mm. To prepare the filled G-P composites, fillers (SiC and Graphite) were mixed separately with resin until the color of mixture was changed uniformly with a known amount of polyester resin as shown in Table 1 and the above procedure for preparing the stacks was repeated. The test samples are cut to size 10 x 20 mm by a cutter and then polished using a polishing machine with fine paper and then tested to characterize the friction and wear properties. Figure (1) and figure (2) shows samples preparation.

Table (1). Samples details

Type	Polyester resin	Fiber glass	Filler type	Wt %
I	40	60	0	0%
II	35	60	Graphite	5%
III	35	60	SiC	5%

Figure(1): Wear test samples preparation



Figure(2) Samples according to ASTM D5963

Test Set up and wear run Procedure

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 and coefficient of friction. The experiments were developed based on an orthogonal array, with the aim of relating the influence of additives, sliding speed, and applied load . Taguchi recommends analysing the S/N ratio using conceptual approach that involves graphing the effects and visually identifying the significant factors.

The test set up used in this study is the well known Pin-on-disc machine . A G-P composite 10 mm diameter and 20 mm length to form the Pin assembly design for standard wear tests described in ASTM D 5963. This mounted G-P sample is made to come in contact with the rotating hardened (HRC 62) alloy steel disc counter surface of 200 mm diameter and 8 mm thickness. The load varies from 30 to 70 N .The mounting arrangement of the G-P samples is made in such a way that the thickness side of the laminate is made to come in contact with the disc, the sample surfaces were polished with fine SiC paper.

The initial weight of the pin assembly is measured in each test using suitable weighing balance of 10^{-4} g The test parameters are normal load, sliding velocity and additives. After the completion of each test the pin assembly is weighed accurately again using the same balance. Weight changes due to wear of the specimen were recorded. Care has been taken after each test to avoid entrapment of wear debris in the specimen. The specimens were cleaned by using atheline to remove the debris which adhere with the specimens. Load 30 –70 N , sliding velocity 2.67 - 5.34 m/sec were chosen . The weight loss of the sample was determined by noting the difference in initial and final weight readings of the sample. Three samples were run for each combination of the test parameters employed to ensure the taken data while the result reported are the average of the three readings . The coefficient of friction was obtained by dividing the frictional load which can be measured by using micro strain by the normal applied load. The sliding wear of the composite studied is function of the weight percentage of the reiforcement, sliding speed and applied load.The wear test is carried out with various sliding speed, load and additives.The level of these process variables is shown in table (2). The experimentations were conducted as per standard orthogonal array, so as to investigate which design parameter significantly affects the sliding wear for the selected combination of additives,sliding speed and load. Wear rate, wear resistance and coefficient of friction were calculated using following equations [17].

$$\mathbf{W_c = V_r / S_d} \qquad (1)$$

Where
W_c is wear rate ,V_r is volume of removed material While S_d is sliding distance.

$$\mathbf{V_r = \Delta m / \rho_c} \qquad (2)$$

Where
Δm is the wight loss (gm) and ρ_c is the composite's density

$$\mathbf{W_c = \Delta m / \rho_c\, v_s\, .t} \qquad (3)$$

Where
$\mathbf{v_s}$ is sliding speed and **t** is the sliding time

$$\mathbf{\mu = F_f / F_n} \qquad (4)$$

Where
F_f is the average friction force and F_n is the applied load

The wear resistance W_r is evaluated on the basis :

$$\mathbf{W_r = F_n\, S_d / \Delta m / \rho} \qquad (5)$$

Table 2 Variables factors and their levels

Factors	Unit	Symbol	Conditions levels		
			Level 1	Level 2	Level 3
Additives	%	A	0.0	5 % G	5 % Sic
Sliding speed	m/sec	B	3.2	4.27	5.3
Load	N	C	30.0	50.0	70.0

PLAN OF EXPERIMENTS

A dry sliding wear test was performed with three parameters: applied load, sliding speed, and additives and varying them for three levels. According to the rule that degree of freedom for an orthogonal array should be greater than or equal to sum of those wear parameters, a L9 Orthogonal array with 9 rows and 3 columns was selected as shown below .

The selection of Orthogonal array depends on three items in order of priority , the number of factors and their interactions, number of levels for the factors and the desired experimental resolution or cost limitations. A total of 9 experiments were performed based on the run order generated by the Taguchi model. The response for the model is wear rate , coefficient of friction and wear resistance. The objective of model is to minimize wear rate , coefficient of friction and maximize the wear resistance. The Signal to Noise (S/N) ratio, which condenses the multiple data points within a trial, depends on the type of characteristic being evaluated. The S/N ratio for wear rate and coefficient of friction using "smaller the better" characteristic given by Taguchi, is as follows:

$$S/N = -10 \log \frac{1}{n} \sum_{i=1}^{n} y_i^2 \qquad (6)$$

For the “larger is better” quality characteristic, the equation is:

$$S/_N = -10 \log \left(\frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2} \right) \qquad (7)$$

Where y_1, y_2...y_n are the response of friction and sliding wear and n is the number of observations.

Table (3) Experimental results and S/N calculated values

Exp .No	Parameters leve lcombination A B C			Output results			S/N ratio (dB)		
	Additive %	S.Speed m/sec	Load N	Wear rate mm^3/m $x10^{-9}$	Wear resistance Nm/m^3 $x10^{13}$	Cof. Friction µ	S/N Wear rate $x10^2$	S/N Wear rate $x10^2$	S/N µ
1	0.0	3.2	30	1.657	1.58	0.38	1.75614	2.63973	8.40433
2	0.0	4.27	50	2.47	2.3	0.47	1.72146	2.67235	6.55804
3	0.0	5.3	70	3.420	2.64	0.61	1.69319	2.68432	4.29340
4	5% G	3.2	50	1.361	3.49	0.33	1.77323	2.70857	9.62972
5	5% G	4.27	70	2.303	3.22	0.38	1.72754	2.70157	8.40433
6	5% G	5.3	30	1.13	3.0	0.33	1.78938	2.69542	9.62972
7	5% Sic	3.2	70	1.716	4.01	0.50	1.75310	2.72063	6.02060
8	5% Sic	4.27	30	0.718	4.4	0.38	1.82878	2.72869	8.40433
9	5% Sic	5.3	50	1.196	4.8	0.51	1.78445	2.73625	5.84860

RESULT AND DISCUSSIONS

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, coefficient of friction and maximum wear resistance . The experiments were developed based on an orthogonal array, with the aim of relating the influence of additives, sliding speed, and applied load. Taguchi recommends analysing the S/N ratio using conceptual approach that involves graphing the effects and visually identifying the significant factors.

Analysis of mean (ANOM)

Analysis of mean is a statistical method in which the optimum level of the process parameters is determined, depending on the results of the factor means. The average value of both S/N ratio and the experimental results for each factor A,B or C at each level I, II, and III had been obtained and tables (4-9) summerize them. The level that cooresponds to the highest S/N ratio value and the lowest value of the mean of μ and wear rate will be considered the optimum level.This is because the smaller is better used while the higher of S/N ratio and the highest of the mean of wear resistance were chosen to represent the optimum level because of choosing the "larger the better" to be the quality characteristic**.**

The results for various combinations of parameters were obtained by conducting the experiments as per the Orthogonal array**.**Table (3) shows the experimental results average of three repetitions for coefficient of friction,wear resistance and wear rate.To measure the quality characteristics, the experimental values are transformed into signal to noise ratio. The influence of control parameters such as additives, load, and sliding speed on coefficient of friction, wear resistance, and wear rate has been analysed using signal to noise response table. The ranking of process parameters using signal to noise ratios obtained for different parameter levels for coefficient of friction, wear resistance and wear rate are given in Tables (4-5), and Tables (6-7), respectively . The control factors are statistically significant in the signal to noise ratio and it could be observed that the additive is the dominant parameter on coefficient of friction and wear resistance followed by applied load and sliding speed. While Tables (8-9) show the control factors statistically significant in the signal to noise ratio and it could be observed that the load is the dominant parameter on wear rate followed by additives and sliding speed. Figures (3-5) show the influence of process parameters on coefficient of friction,wear resistance and wear rate graphically . The analysis of these experimental results using S/N ratios gives the optimum conditions resulting in minimum wear rate and coefficient of friction and maximum in wear resistance The results of ANOM were graphically plotted in figues (3-5). It can be seen from figure (3) that the optimum level for coefficient of friction each factor will be A_2 B_1 C_1, from figure 4 the optimum level for wear resistance is A_3 B_3 C_2 . While figure 5 shows the optimum level for wear rate is A_3 B_1 $C_{1.}$

COEFFICIENT OF FRICTION

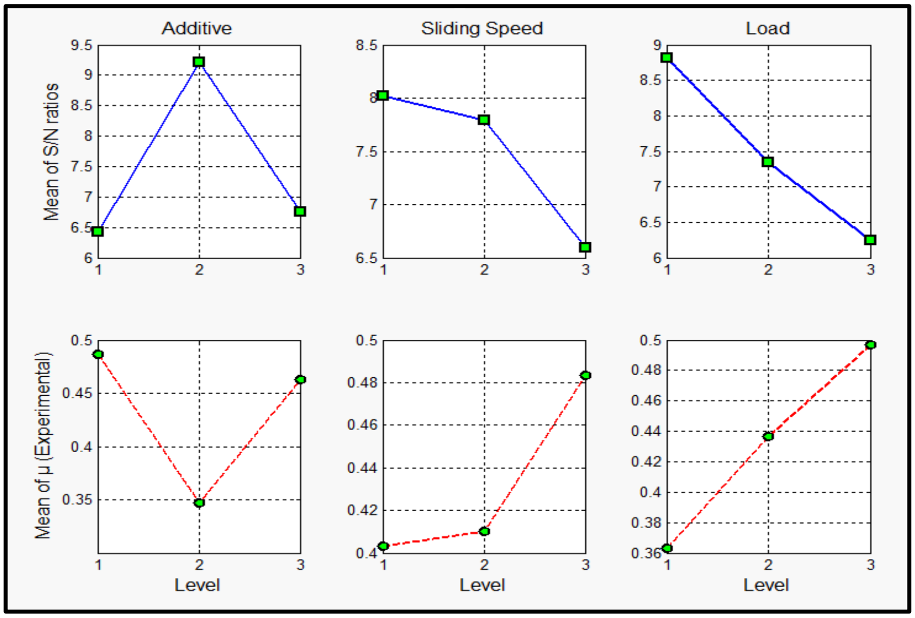
Table (4) Main effect for coefficient of friction

Factor	symbol	Average of levels for **μ**			Delta	Rank
		Level 1	Level 2	Level 3		
Additives (%)	A	0.48667	**0.34667**	0.46333	0.140	1
Sliding Speed (m/s)	B	**0.40333**	0.41000	0.48333	0.080	3
Load (N)	C	**0.36333**	0.43667	0.49667	0.133	2

The underlined value represents the optimum level

Table (5) Main effect of S/N ratio for μ

Factor	symbol	Average of levels for **μ**			Delta	Rank
		Level 1	Level 2	Level 3		
Additives (%)	A	6.41859	**9.22126**	6.75784	2.803	1
Sliding Speed (m/s)	B	**8.01822**	7.78890	6.59057	1.428	3
Load (N)	C	**8.81279**	7.34545	6.23944	2.573	2



The underline value represents the optimum level.

Figure.(3) Main effect plot for mean and S/N ratio- Coefficient of friction

WEAR RESISTANCE

Table (6). Main effect for wear resistance

Factor	symbol	**Average of levels for wear resistance**			Delta	Rank
		Level 1 ($x10^{13}$)	Level 2 ($x10^{13}$)	Level 3 ($x10^{13}$)		
Additives (%)	A	2.17333	3.23667	**4.40333**		1
Sliding Speed (m/s)	B	3.02667	3.30667	**3.48000**		3
Load (N)	C	2.99333	**3.53000**	3.29000		2

The underlined value represent the optimum level.

Table (7) .Main effect of S/N ratio for wear resistance

Factor	symbol	**Average of levels for wear resistance**			Delta	Rank
		Level 1 ($x10^{2}$)	Level 2 ($x10^{2}$)	Level 3 ($x10^{2}$)		
Additives (%)	A	2.66547	2.70185	**2.72852**		1
Sliding Speed (m/s)	B	2.68964	2.70087	**2.70533**		3
Load (N)	C	2.68795	**2.70572**	2.70217		2

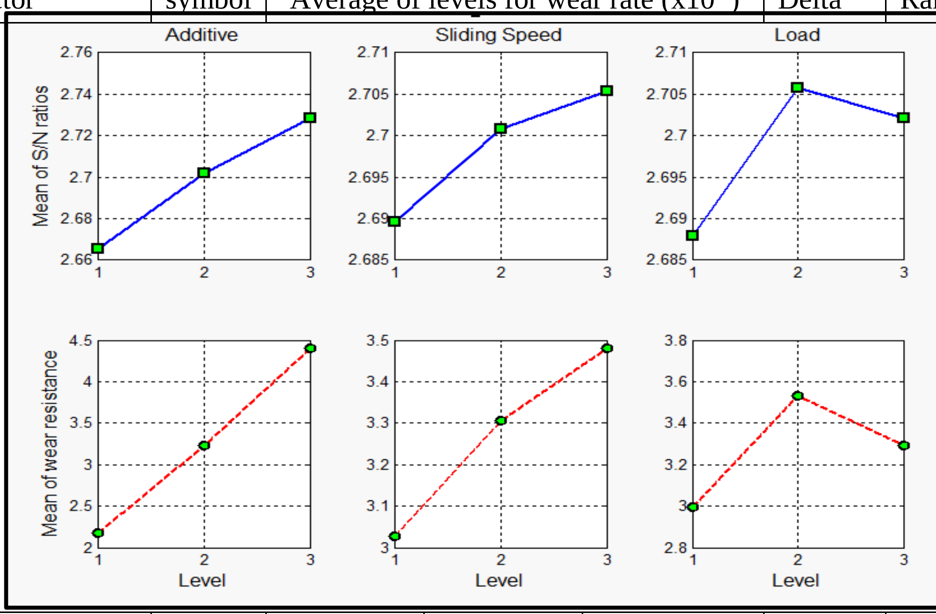
The underlined value represents the optimum level.

Figure.(4) Main effect plot for mean and S/N ratio- wear resitance

WEAR RATE

Table (8) Main effect for wear rate

Factor	symbol	Average of levels for wear rate ($x10^{-9}$)			Delta	Rank
		Level 1	Level 2	Level 3		
Additives (%)	A	2.51567	1.598	**1.210**		2
Sliding Speed	B	**1.57800**	1.83033	1.91533		3



(m/s)						
Load (N)	C	**1.16833**	1.67567	2.47967		1

The underline value represents the optimum level

Table (9) Main effect of S/N ratio for wear rate

Factor	symbol	Average of levels for wear resistance ($x10^2$)			Delta	Rank
		Level 1	Level 2	Level 3		
Additives (%)	A	1.72360	1.76338	**1.78878**		2
Sliding Speed (m/s)	B	**1.76082**	1.75926	1.75568		3
Load (N)	C	**1.79143**	1.75971	1.72461		1

The underline value represents the optimum level

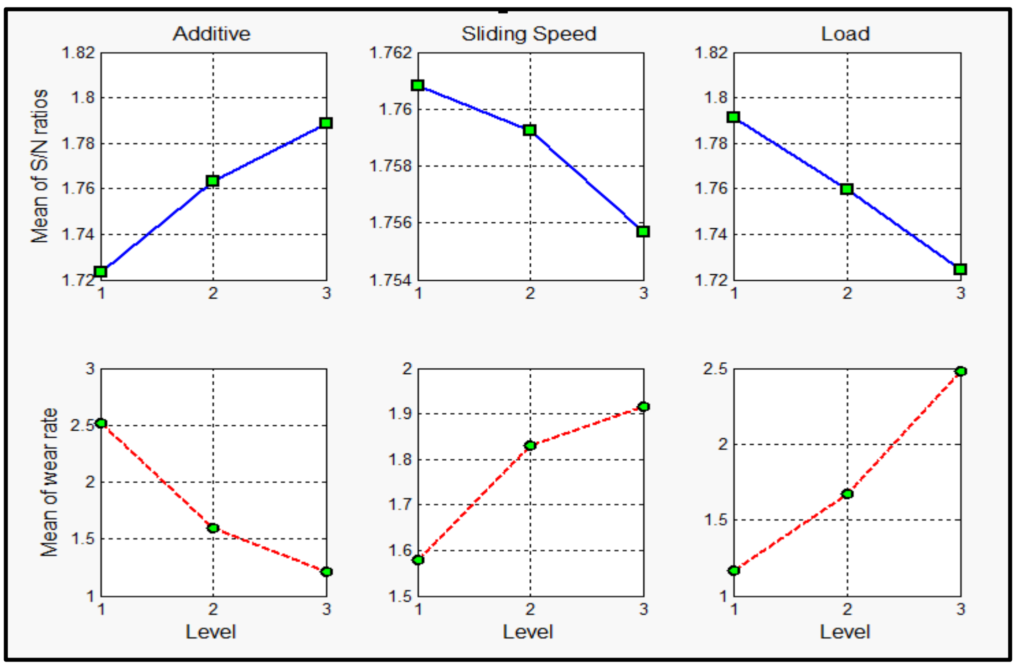


Figure. (5) Main effect plot for mean and S/N ratio - wear rate

Analysis of Variance (ANOVA)

The experimental results were analysed with Analysis of Variance (ANOVA) which is used to investigate the influence of the considered wear parameters namely,fillers additves, applied load, and sliding speed, that significantly affect the performance measures. By performing analysis of variance, it can be decided which independent factor dominates over the other and the percentage contribution of that particular independent variable. Tables 10 and 11 show that the dominant factor is the additives. That indicates the additives are more significant among others for the coeefficient of friction μ and wear resistance. It can be obsereved from these tables that the additives factor has the highest influence such that the contribution is 50.84% for coefficient of friction μ and 82.515 for wear resistance . Hence additives are an important control factor to be taken in considerations followed by load and sliding speed. In the same way from table 12 for wear rate , it can be observed that the load has the highest contribution of about 49.977% followed by additives 48.28% and sliding speed 0.311% This is because, whenever applied load increases the friction at the contact surface of the material and rotating disc obviously increases but when compared to material GP and GP with additives, the wear rate is less, since SiC is the harder material which is used as filler in the fabrication. Because of increase in the brittle property of the material the wear rate decreases obviously. The SiC particles which are highly brittle in nature will be crushed into small particles when coming in contact with the rotating disc. These small particles fill the voids formed during fabrication process. From the analysis of variance and S/N ratio,it is inferred that the additives has highest contribution on coefficient of friction and wear resistance followed by load and sliding speed. This is because additives like graphite filler act as a self lubricant or a solid lubricants which reduces the coefficient of friction while SiC filler tends to increase wear resistance. It is found that wearing initially controlled by the removal of graphite which acts as a self lubricating material due to less friction between the mat layer and rotating disc. But at higher applied loads and sliding speeds the matrix material is well spread and the graphite in the powder form smeared the surface. While for wear rate the load has the highest contribution followed by additives and sliding speed.

Table (10) ANOVA table for coefficient of friction (μ)

Symbol	Sum of squares SS	Degrees of freedom dof	Mean square MS	F value MS/error	Contribution %
Additives	14.0384	2	7.01922	389.41	50.864
Sliding speed	3.5267	2	1.76337	97.83	12.778
Load	9.9985	2	4.99923	277.35	36.227
Error	0.0361	2	0.01803		0.1308
Total	27.599	8			100

Table (11) ANOVA table for wear resistance

Symbol	Sum of squares SS	Degrees of freedom dof	Mean square MS	F value MS/error	Contribution %
Additives	60.1142	2	3.0571	17.14	82.515
Sliding speed	3.92	2	1.96	1.12	5.380
Load	5.3101	2	2.6551	1.51	7.288
Error	3.5081	2	1.754		4.815
Total	72.8524	8			100

Table (12) ANOVA table for wear rate

Symbol	Sum of squares SS	Degrees of freedom dof	Mean square MS	F value MS/error	Contribution %
Additives	64.762	2	32.3812	33.74	48.280
Sliding speed	0.418	2	0.2092	0.22	0.3116
Load	67.038	2	33.6551	34.92	49.977
Error	1.919	2	0.9597		1.4306
Total	134.138	8			100

Multipple Quadratic Regression

In order to establish the correlation between the wear parameters (i)additives (ii) load (iii) sliding speed and the wear rate, multiple quadratic regression model was used. A multiple quadratic regression model is developed using software **MATLAB R 2011 A** . This model gives the relationship between the independent / predictor variable and response variable by fitting a quadratic equation to an observed data. Regression equation thus generated establishes correlation between the significant terms obtained from ANOVA analysis namely additives, applied load, and sliding speed. The regression equations developed are:

1- Quadratic model for coefficient of ftricion :

$$C_f=0.07A+0.2779B-0.023C+0.00633A^2-0.0278B^2-0.00019C^2-0.0554AB+0.00267AC+0.00668BC$$

R= 0.992, Average error = 1.96% (8)

2- Quadratic model for Wear Rate

$$Wr=-1.893A+0.362B+0.268C+0.179A^2-0.252B^2+0.00634C^2+1.0317AB-0.08AC-0.111BC$$

R= 0.95, Average error = 12% (9)

3- Quadratic model for Wear Resistance

$$Wr=0.4347A-0.052B+0.0552C+0.0256A^2-0.0308B^2-0.00116C^2-0.0602AB-0.00062AC+0.015BC$$

R= 0.9997, Average error = 0.74% (10)

Where R is the coefficient of correlation. Substituting the recorded values of the variables into the above equations; the coefficient of friction, wear rate and wear resistance can be calculated. The positive value of the coefficients suggests the coefficient of friction, wear rate and wear resistance of material increases with their associated variables. Whereas the negative value of the coefficients suggest that the coefficient of friction, wear rate and wear resistance of the material will decreases with the increase in associated variables . It is observed from the multiple regressions equations derived above that the evaluation of the coefficient of friction, wear rate and wear resistance are correlated with reasonable degree of approximation.

Confirmation Test

A confirmation experiment (table 13) is the final step in the design process. A dry sliding wear test was conducted using a specific combination of the parameters and levels to validate the statistical analysis. After the optimal level of testing parameters have been found, it is necessary that verification tests are carried out in order to evaluate the accuracy of the analysis and to validate the experimental results.To predict the optimum value of the studied characteristics or the response in this study, the predicted mean of each response can be calculated by using general form of equation 11.

$$\boldsymbol{Response_{opt.}} = \overline{\boldsymbol{Resp}}_{\cdot\boldsymbol{Total}} + \left(\boldsymbol{A_{at\ optimum\ level}} - \overline{\boldsymbol{Resp}}_{\cdot\boldsymbol{Total}}\right) + \left(\boldsymbol{B_{at\ optimum\ level}} - \overline{\boldsymbol{Resp}}_{\cdot\boldsymbol{Total}}\right) + \left(\boldsymbol{C_{at\ optimum\ level}} - \overline{\boldsymbol{Resp}}_{\cdot\boldsymbol{Total}}\right) \quad (11)$$

Where $Response_{opt.}$ denotes the predicted mean of the response at optimum conditions. $\overline{Resp}_{\cdot Total}$ is the total average of response (corresponding to the experimental values). *A*, *B*, and *C* represent the response's average values at the optimum levels of the process parameters wear rate, wear resistance, and coefficient of friction (taken from main effect table).

Table 13 Confirmation experiment and prediction comparison

Response	Best initial combination	Confirmation	
		Experimental	Prediction
		Optimum Levels	Optimum Levels
Wear Rate	$A_2B_3C_1$ 1.13×10^{-9}	$A_3B_1C_1$ 0.703×10^{-9}	$A_3B_1C_1$ 0.604×10^{-9}
Wear Resistance	$A_3B_3C_2$ 4.8×10^{13}	$A_3B_3C_2$ 4.8×10^{13}	$A_3B_3C_2$ 4.87×10^{13}
Coefficient of Friction	$A_2B_1C_2$ 0.33	$A_2B_1C_1$ 0.25	$A_2B_1C_1$ 0.249

CONCLUSIONS

The following conclusions can be drawn from the study performed using Taguchi's technique:

a-Wear rate ,wear resistance and coefficient of friction of composite material under different load and sliding velocities can be successfully analyzed using Taguchi design of experiment.

b- The analysis of variance for coefficient of friction of composite material shows that the additives is the most significant factor 50.86% whereas load and sliding speed has little contribution 36.22% for load and 12.77% for sliding speed .
c- Analysis of variance for wear rate of composite material shows that the load is the most significant factor 49.97% followed by additives 48.28% whereas sliding speed has little contribution 0.311%.
d- The analysis of variance wear resistance of composite material shows that the additives is the dominant factor 82.51% whereas load and sliding speed has little contribution 7.288% for load and 5.38% for sliding speed .
e- Regression equation generated for the present model was used to predict the wear rate , wear resistance and coefficient of friction with reasonable accuracy.
f- A confirmation experiment was carried out for comparison between experimental values and predicted values with small error associated for coefficient of friction, wear resistance and wear rate of composite varying from 0.4% , 1.45 to 14.08% . Thus the design of experiment by Taguchi method was considered successful to be used to predict tribological behavior of composites.

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