

Research Paper

## Evaluation of Tribological Properties of Composite Nanomaterial by Taguchi Method

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### ABSTRACT

The current scenario of the modern material science and manufacturing technology is to develop new and advance materials with least wear and coefficient of friction for better working in tribological applications. Hence it is important aspect to find out the tribological properties of the material such as wear rate and coefficient of friction. The research work is carried out on pervoskite nanocomposite material and tribological analysis is done by Taguchi design of experiment and influence of each parameter is found out by ANOVA. The aim of the study is to find out which parameter is most influencing in wear rate and for COF. The optimum values of wear parameter also determined with the help of S/N ratio analysis. The objective of the model was selected as “smaller is better” for optimization of wear parameters. The result indicates that Load has maximum influence on wear rate as well as on COF followed by Speed and Sliding Distance.

**Keywords:** Index Terms: ANOVA, Co-efficient of friction, S/N Ratio, Taguchi design, Wear rate

### 1. INTRODUCTION

Whenever at least two materials are consolidated together to yield another material, they are known as composite materials. They vary from alloy since in composite material the individual constituents hold their self properties to form material with improved properties. Generally, the large constituent of composite is known in matrix. It combines and ties together fragments or fibers of the other material, which is known as reinforcement. Nanocomposites are those in which one or more phases are in the nanoscale dimensions. Nanoparticles Nanofibers, and Nanoclays are implanted in a metal, ceramic, or polymer matrix. Nanocomposites were made so as to beat the shortcoming occurs in composite materials. Nanocomposites have filler size in nanoscale and very less separation between fillers which leads to high surface-to-volume ratio. They have expanded malleability with no decline in quality and scratching opposition. Nanocomposite find very wide application in various fields.[1] Pervoskite having cubic structure as shown in Fig.1 The structure is described by the general formula ABO<sub>3</sub> where the where 'A' and 'B' are two cations of very different sizes, and X is an anion that bonds to both. The 'A' atoms are larger in size than the 'B' atoms. The A-site is generally engaged by elements from the rare earth, alkali or alkaline families such as La, Na, Ca, Sr or Ba.[2][3]

Moving parts of every machine is subjected to friction and wear. Friction consumes and wastes energy. Wear is

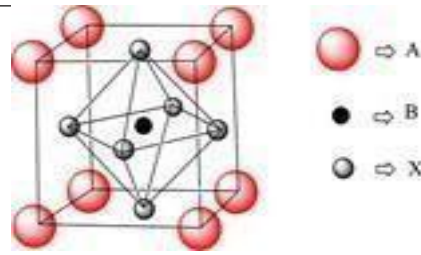


Fig. 1: Cauliflower foliar diseases

responsible for changes in dimensions and eventual breakdown of the machine element and the entire machine. Tribology is the science and engineering of interacting surfaces in relative motion. Tribology means It include study and application of the principles of lubrication, friction and wear. Wear is the process of removal of material from one or both of two solid surfaces in solid-state contact. It occurs when solid surfaces are in rolling or sliding motion relative to each other. In a well- designed tribological system, the removal of material is normally a very slow process, but it is very continuous and steady. Similar to friction, the wear behavior of a material is also a very complicated phenomenon in which various mechanisms and factors are involved.[4]

## 2. LITERATURE SURVEY

Yasmin Choudhury et al discussed wear behavior of Fe– Al<sub>2</sub>O<sub>3</sub> metal matrix nanocomposites synthesized via powder metallurgy technique.[1] Kali Dass et al. presented a paper in which the mechanical and dry sliding wear characteristics of synthesized m-cresol novalacepoxy composites filled with silicon carbide (SiC), aluminum oxide (Al<sub>2</sub>O<sub>3</sub>), and zinc oxide (ZnO) have been studied using a pin-on-disc apparatus. The influence of normal load, sliding velocity, filler content, and sliding distance on the coefficient of friction and specific wear rate of these composites have been studied under dry sliding conditions. They conclude that the co-efficient of friction decrease with increase in the sliding distance and filler content and the wear rate increases with an increase in, applied normal load, the sliding velocity and sliding distance and decreases with an increase in filler contents of the m-cresol novalac epoxy composites filled.[5] Yuan-fei Fu et al. worked on the tribological properties of polyimide composites filled with TiO<sub>2</sub> nanoparticles and short pitch- based carbon nanotubes (CNTs) They found that addition of TiO<sub>2</sub> nanoparticles and short pitch-based carbon nanotubes (CNTs) shows positive effect on tribological properties.

Pure polyimide (PI) containing 4 wt% TiO<sub>2</sub> and 6 wt% short CNT shows significantly lower coefficient of friction and wear rate.[6] Praveen Bhimaraja et al studied the effect of matrix morphology on the wear and friction behavior of alumina nanoparticle/poly (ethylene) terephthalate composites friction.[7] K.B. Girisha et al. carried research on Aluminum alloy (Al356.1) matrix composite reinforced with Zirconium Oxide nano particle with reinforcement of different weight percentage of filler. The addition of filler is done by stir casting method and wear characteristic are found. They concluded that addition of filler improve the wear characteristics of Aluminum. [8] Sunil Thakur et al. investigated the friction and wear behavior of vinylester composites filled with uniformly sized micron and submicron cenosphere particles on pin on disc apparatus. The design of experiment is done with the help of Taguchi method they have find out the influence of the parameters on co- efficient of friction and wear rate. According to their study applied load and filler content are the major factors affecting these properties. [9] J Sudeepan et al. investigated acrylonitrile

– butadiene – styrene (ABS) with different compositions of micron-sized CaCO<sub>3</sub>, composite material is prepared by compression moulding through melt compounding. The tribological properties (friction and wear depth) of the polymer composites are studied in a multi-tribo-tester using block- on- roller configuration in dry sliding conditions. Experiments are conducted based on Taguchi design of experiment they conclude that the most significant factor for coefficient of friction is normal load [10]. Vishwanath Prasad et al. studied Optimization of Mechanical Properties and Wear Parameters of Al alloy-B<sub>4</sub>C Composite Using Taguchi Technique. Their study shows that wear rate is highly depends upon Load fol- lowed by distance and sliding velocity whereas in case of co- efficient of friction, distance affects to a large extent followed by load and sliding velocity. They also show that optimum conditions for obtaining good tribological characteristics were low load along with high sliding velocity and distance.[11]

Various metal matrices reinforced with Graphene nano particles in different forms and tribological properties were evaluated. Different routes are used for manufacturing such composites such as Stir Casting, Powder Metallurgy

Spark Plasma Sintering etc. The results shows that improvement in the tribological properties due to addition of Graphene particles.[12][13][14][15][16]

Addition of Alumina, SiC, TiC, WC, B4C etc nanoparticles in metal matrix also reduce coefficient of friction and wear rate as shown by various studies with some specific weight % or volume % of filler material in the form of nanoparticle. [17][18][19][20]

The conclusion can be drawn from literature review that as particle size decreases up to nanoscale certain mechanical properties increased. As all papers concluded that reduction of tribological properties for the nanoparticles and nanocomposite materials. The aim of current study is to optimize tribological parameters using Taguchi method of design of experiment and based on result Perovskite nanocomposite for various tribological applications.

### 3. EXPERIMENTAL DETAILS

#### A. Synthesis of Perovskite composite nanomaterial

Perovskite Composite nanomaterial was synthesized by conventional solid state reaction method [24]. The raw chemicals used in this study are Barium oxide (BaO), Nickel oxide (NiO) and Niobium oxide (Nb<sub>2</sub>O<sub>5</sub>) (99% AR grade). The mixture of barium oxide, nickel oxide and niobium oxide (99% AR grade) were taken in the stoichiometric proportion for sample then it was crushed and mixed in mortar for 4 hours in presence of Acetone. This sample was then heated in the muffle furnace in the silica crucible at 1000 degree Celsius for 12 hours, and then cooled slowly. After cooling material is removed from the furnace and again crushed for four hours and then annealed in the muffle furnace at 450<sup>o</sup> C for two hours.[24]

#### B. Making pellet from the composite nanomaterial powder

For making pellets in laboratory scale processing normally make 4 % PVA solution in distilled water (4gm PVA in 100 ml water). For getting clear solution it is heated using magnetic stirrer for 40 minutes at about 90<sup>o</sup>C. After it small amount of perovskite powder (5-10 gm) to be pelletized is mixed with PVA solution in mortar. Grind the powder with the help of pestle for few minutes (5-10 minutes) till fine powder is obtained. Again added few drops of PVA and repeat the process. Now powder is ready for pellet making. The powder is now kept in the die cavity and compressed to make the pellet. The density depends upon the quantity of applied force. The force is applied by CTM which is about 5 Ton. The Pellet is then again sintered at 600<sup>o</sup>C for one hour to eliminate the binder.[36]

#### C. Design of Experiment

The Taguchi design of experiment limits the variety in a procedure through structure of experiment to conduct. The aim of the method is to produce high quality product at very less possible cost to makers. The Taguchi technique was created by Genichi Taguchi for designing experiments to examine of different parameters on mean and variance of the process performance characteristics that defines the functioning of the process. Taguchi design of experiment uses orthogonal arrays to arrange the parameters affecting the process and their different levels of variation. The parameters are grouped as Control Factors which can be controlled and Noise Factors which are out of control. The Signal to Noise Ratio (S/N Ratio) is utilized in this analysis which takes both the mean and the variance of the outcome into record. The S/N ratio relies upon the quality attributes of the item/process. S/N ratio analysis can be done for performance characteristics under three groups that is, the higher-the-better, the lower-the-better, and the nominal- the-better.[25][26][27]

It is important in Taguchi design of experiment to list out various parameters involved in the experiment and distinguish them as the control factors and noise factors. For the wear and friction experiment of composite nanomaterial using Pin on Disc apparatus, the control factors and noise factors are as follows

TABLE I  
PARAMETERS OF EXPERIMENT

Control Factors	Noise Factors
Load	Coefficient of friction Sliding distance
	Wear
Speed	Rise in temperature



Fig. 2. Pin on Disc Apparatus

TABLE II  
SPECIFICATION OF PIN ON DISC APPARATUS

Description	Specification
Sliding Speed Range	Min 0.5 m/s to max 10 m/s
Disc Rotation Speed Range	200 to 2000 rpm
Normal Load	5 N to 200 N
Friction Force	0 to 200 N
Wear Measurement Range	2 mm
Pin Size	2 mm to 12 mm diameter
Mean Wear Track Diameter	50 mm to 100 mm
Temperature	Max 400°C
Timer	Max 99 hrs 59 min 59 sec

Objective of the experimentation should be smaller is better as coefficient of friction and wear are the response therefore

$$S/N = -10 \log_{10} \left\{ \frac{1}{n} \sum_{i=1}^n y_i^2 \right\} [27]$$

Where n = number of tests in a trial.

27 tests. The columns were assigned with parameters. The first column was assigned to load (L), second column was assigned to Speed (S) and fifth column was assigned to sliding distance (D) and the remaining columns were assigned to their interactions [28]. For Taguchi design of experiment and analysis Minitab-18 software is used. [28][29][30]

#### 4. RESULT AND DISCUSSION

TABLE IV  
EXPERIMENTAL RESULT OF TAGUCHI DESIGN DATA

Sr. No.	Load (N)	Speed (rpm)	Sliding Distance (m)	Wear rate (mm <sup>3</sup> /m)	COF	S/N Ratio (dB)	S/N Ratio (Wear COF Rate)
1	9.81	200	500	0.00157	0.132	56.082007	17.58852
2	9.81	200	1000	0.00157	0.126	56.082007	17.99259
3	9.81	200	1500	0.00136	0.123	57.329222	18.2019
4	9.81	400	500	0.001413	0.133	56.997157	17.52297
5	9.81	400	1000	0.001099	0.125	59.180046	18.0618
6	9.81	400	1500	0.000732	0.121	62.709778	18.34429
7	9.81	600	500	0.000942	0.118	60.518982	18.56236
8	9.81	600	1000	0.000549	0.115	65.208553	18.78604
9	9.81	600	1500	0.000471	0.113	66.539582	18.93843
10	19.6	200	500	0.002041	0.138	53.80314	17.20242
11	19.6	200	1000	0.001884	0.132	54.498382	17.58852
12	19.6	200	1500	0.001622	0.125	55.798983	18.0618

13	19.6	400	500	0.001884	0.132	54.498382	17.58852
14	19.6	400	1000	0.001648	0.13	55.660856	17.72113
15	19.6	400	1500	0.001517	0.128	56.380288	17.8558
16	19.6	600	500	0.00157	0.129	56.082007	17.78821
17	19.6	600	1000	0.001099	0.133	59.180046	17.52297
18	19.6	600	1500	0.000942	0.121	60.518982	18.34429
19	29.4	200	500	0.002669	0.147	51.473029	16.65365
20	29.4	200	1000	0.002276	0.141	52.856555	17.01562
21	29.4	200	1500	0.002041	0.139	53.80314	17.1397
22	29.4	400	500	0.002041	0.142	53.80314	16.95423
23	29.4	400	1000	0.002041	0.132	53.80314	17.58852
24	29.4	400	1500	0.002904	0.135	50.740068	17.39332
25	29.4	600	500	0.002148	0.129	53.359314	17.78821
26	29.4	600	1000	0.00157	0.134	56.082007	17.4579
27	29.4	600	1500	0.001622	0.131	55.798983	17.65457

The out put obtained from experiment is analyzed in Table IV with the help of Minitab 18 software. Table IV shows the response for S/N ratio

The factors and their levels selected for the experimentation are as follows.

1	60.07	54.64	55.18
2	56.27	55.97	56.95
3	53.52	59.25	57.74
Delta	6.55	4.62	2.56
Rank	1	2	3

TABLE III  
LEVELS OF PARAMETRES

FACTORS	CODE	UNITS	LEVEL 1	LEVEL 2	LEVEL 3
LOAD	L	N	9.81	19.6	29.4
SPEED	S	RPM	200	400	600
SLIDING DISTANCE	D	M	500	1000	1500

The parameters selected for the experiment are speed in rpm, load in N and sliding distance in m. each parameter was analyzed at three levels. The experiment consists of

The analysis is done for specific wear rate and COF with smaller is better S/N quality characteristic because the goal of this experiment is to obtain minimum wear rate and minimum COF. Table V shows response of the S/N for wear rate. On that basis, the most influential parameter and optimum

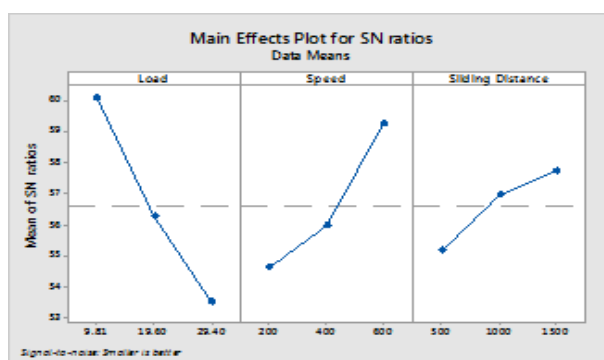


Fig. 3. Main Effect plot for S/N Ratio for wear rate

values for wear rate can be recognized. Fig 3 Influence of three factors for S/N ratio for wear rate is graphically represented. Based on the result obtained from Table V and Fig.3, The Load is most affecting parameter followed by Speed and Sliding Distance as per their ranking in Table V. Since parameters of the process with higher values of S/N ratio will give the optimum values.[31] Hence it is clear that from the table V and from Fig. 3 for minimum wear rate occurs when the value of load is 9.81

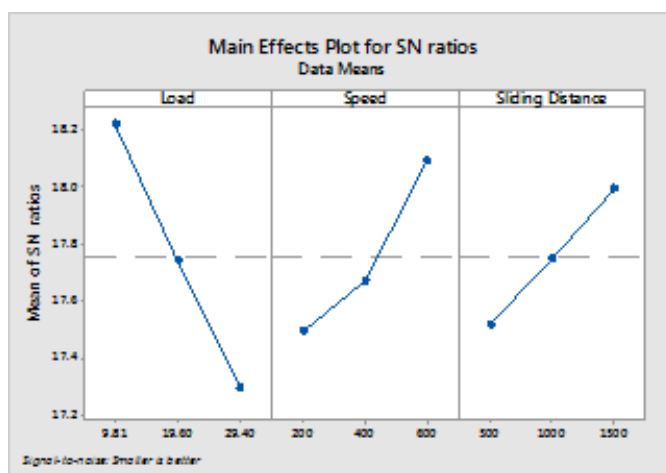


Fig. 4. Main Effect Plot for S/N Ratio for COF

TABLE VeII ANOVA FOR WEAR RATE

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	Contribution
L	2	0.000005	0.000005	0.000003	34.04	0	56.12%

S	2	0.000002	0.000002	0.000001	14.64		0.002	24.13%	
D	2	0.000001	0.000001	0	3.96		0.064	6.54%	
L*S	4			0	0	0	0.47	0.756	1.56%
L*D	4			0	0	0	0.72	0.605	2.36%
S*D	4			0	0	0	0.82	0.548	2.70%
Error	8	0.000001	0.000001	0					6.60%
Total	26	0.000009							100.00%

N, Value of Speed is 200 rpm and value of Sliding Distance is 1500 m. Levels of optimum parameter are L1S1D3 that is the first and Second factors on the first level and third factor on the third level.[32][33]

TABLE VIII ANOVA FOR COFTABLE VI  
S/N RATIO RESPONSE FOR COF

Smaller is better	Level	Load	Speed	Sliding Distance
	1	18.22	17.49	17.52
	2	17.74	17.67	17.75
	3	17.29	18.09	17.99
Delta		0.93	0.6	0.48
Rank		1	2	3

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	Contribution
L	2	0.000854	0.000854	0.000427	69.26	0	49.82
S	2	0.000372	0.000372	0.000186	30.18	0	21.71
D	2	0.000228	0.000228	0.000114	18.45	0.001	13.27
L*S	4	0.000092	0.000092	0.000023	3.71	0.054	5.34%
L*D	4	0.000042	0.000042	0.00001	1.68	0.246	2.42%
S*D	4	0.000078	0.000078	0.00002	3.17	0.077	4.56%
Total	26	0.001715				1	100.00%

For COF it is clear from the Table VI and Fig.4

the dependence of COF is mostly on Load followed by Speed and Sliding Distance as per ranking. The values of parameters for minimum COF will be load 9.81 N, Speed 600 and Sliding Distance 1500 m. Levels of optimal parameters for COF are L1S3D3 it means that the first level for the first parameter and third level for the second and third parameters.

**5. ANALYSIS OF VARIANCE(ANOVA)**

Analysis of variance (ANOVA) is used to analyze the influence of friction and wear parameters like speed, sliding distance and applied load on the tribological performance characteristics, wear and frictional force. The analysis

is done by using Minitab-18 software.

The Analysis of Variance (ANOVA) has been done for the confidence level of 95 % & significance level of 5 % to determine the significance of individual parameters and their interactions on wear rate and COF. Table VIII and Table VII indicate that the ANOVA result for wear rate coefficient of friction respectively. The last column of tables (VII & VIII ) indicates percentage contribution of each parameters and their interaction. [31][32][33]. The analysis of variance shows that the most effective parameter for wear rate is the load (L) with 56.12% contribution. Thus load is most valuable control factor for wear rate followed by speed(S) with 24.13% contribution. The sliding distance (D) has least effect on wear rate with 6.54% contribution. Among interaction of parameters

Speed\*Sliding Distance (S\*D) is most important with 2.70% contribution on wear rate.

Similarly for COF as indicated in Table VIII most influencing parameter is also the load (L) with 49.82% contribution followed by speed(S) with 21.71% and sliding distance(D) with 13%. Among interaction of parameter Load\*Speed (L\*S) is most affecting with 5.34% contribution

## 6. CONCLUSION

The design of experiment is done by Taguchi method with L27 orthogonal array. The results of experimentation are as follows

- According to analysis of S/N ratio and S/N graph it is clear that for both wear rate and COF, The Load is most affecting parameter followed by Speed and Sliding Distance. It means that for controlling wear rate and COF, the applied load is given prime importance and then speed and sliding distance for the tested composite material.
- ANOVA results also verify that Load is most affecting parameter with maximum percentage of contribution followed by speed and sliding distance for both wear rate and COF
- Among interaction of the parameters, the Speed\*Sliding Distance is most influential with maximum contribution on wear rate while Load\*Speed is most affecting with for COF.
- The perovskite nanocomposite can be used for application such as antifriction and anti-wear coating on bearing applications and other tribo components such as cylinder liners coating etc.

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