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Wear and Friction Behavior of Epoxy/BN nanocomposites

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Abstract: The effect of sliding conditions, typically, applied load, sliding speed and volume fraction of nano Boron nitride (BN)particles on coefficient of friction and wear rate of epoxy nanocomposites was evaluated and optimized. Experiments were carried out using pin on disc machine on cylindrical specimens of Bn/epoxy. The analysis and optimization via analysis of variance (ANOVA) based on Taguchi L27 orthogonal array design of experiments technique (DOE) were carried out to determine the most influential parameter on wear rate and coefficient of friction. The results of ANOVA analysis showed that parameters volume fraction of BN, sliding speed and load were significant factors on coefficient of friction and wear rate. The sequence of importance of process parameters on multi-responses by grey relation analysis (GRA) were BN%> speed %> applied load.

Keywords: Taguchi, grey relation analysis (GRA), epoxy matrix, wear behavior, BN.

1. INTRODUCTION

Nanocomposite materials are progressively important because of their exceptional characteristics. They show a combination of characteristics that no other typical material family could achieve[1].Epoxy resins commonly used in industrial applications due to their high mechanical, adhesion, and chemical resistance properties, and durability in a wide range of temperatures without the emission of volatile products[2]. They are commonly used in various applications, including paints and fabrics, adhesives, equipment manufacturing, and composites, electrical and electronics, consumer automotive, marine and aviation applications[3].Boron nitride (BN) nanomaterials synthesis and application are an exciting and rapidly growing field. Due to its unique characteristics, BN nanotubes have been applied in broad areas. They have shown reinforcement effects in structural and functional composites, including polymers, ceramics and metals[4]. As a distinguished example, BN nanotubes were added as fillers to the polymer matrix to improve thermal conductivity and mechanical strength, transparent super hydrophobic films and the development of medicines delivery systems, and many other applications, the BN nanostructures have attracted considerable interest. The development and production of BN composites for many structural, functional and medical applications was also of extensive scientific importance[5].In particular, BN nanomaterials can be used as intelligent platforms for drug delivery systems. The functioning of the surface is an essential interim step. Their successful success in chemotherapy. To mitigate the problem Toxic effects on healthy cells to improve efficacy and selectivity. The BN nanocarious tumor cell-specific small molecule legends should be associated for treatment with the cancer to affect tumor receptors. BN nanotubes showed good biocompatibility and functional biomedicine. This may contribute to demand for applications in orthopaedics. These can even hold and distribute deoxyribonucleic acid (DNA) oligomers or drugs such as doxorubicin, and even target cancer cells through a combination of magnetic aids like europium doped sodium fluoride[5], [6].Yaman and Calis[7]investigated the influence of boron waste addition and its particles size onphysico-mechanical and tribological properties of epoxy matrix composites. The results showed that wear resistance increased with increasing boron waste particle size.

The main objective of the present investigation is to study the effect of sliding wear conditions; applied load, sliding speed and sliding time on tribological properties (coefficient of friction and Wear rate) by using analysis of variance (ANOVA based on Taguchi L27 orthogonal array.

2. EXPERIMENTAL PROCEDURES

2.1. Samples preparation

Epoxy resin matrix was reinforced by boron nitride (BN). Epoxy resin was mixed with the hardener by 2:1 by weight. The mixing process was stirred mechanically for 20 minutes at room temperature at the rate of 1000 mm/min. The mixture poured in a silicon mold. Nanocomposites were prepared by adding0.5, 1 and 1.5 vol.% of BN nanoparticles separately to the resin and stirred mechanically for 20 minutes at room temperature, then the hardener was added to the mixture and then stirred mechanically again for 10 minutes. The epoxy/nanofillers slurry was poured in the molds and was hardened. Experiments have been conducting according to Taguchi L27 orthogonal array. The process parameters chosen are volume fraction of Bn, speed and applied load. The values and their levels are illustrated in Table1. The flow chart of present work is presented in Figure 1.

Table 1. The factors and their levels

Parameter	Unit	Level 1	Level 2	Level 3
Speed	RPM	300	600	900
Load	N	17.1	20.1	24.1
BN	Vol. %	0.5	1	1.5

The wear tests were performed using pin-on-ring machine apparatus shown schematically in Figure 1

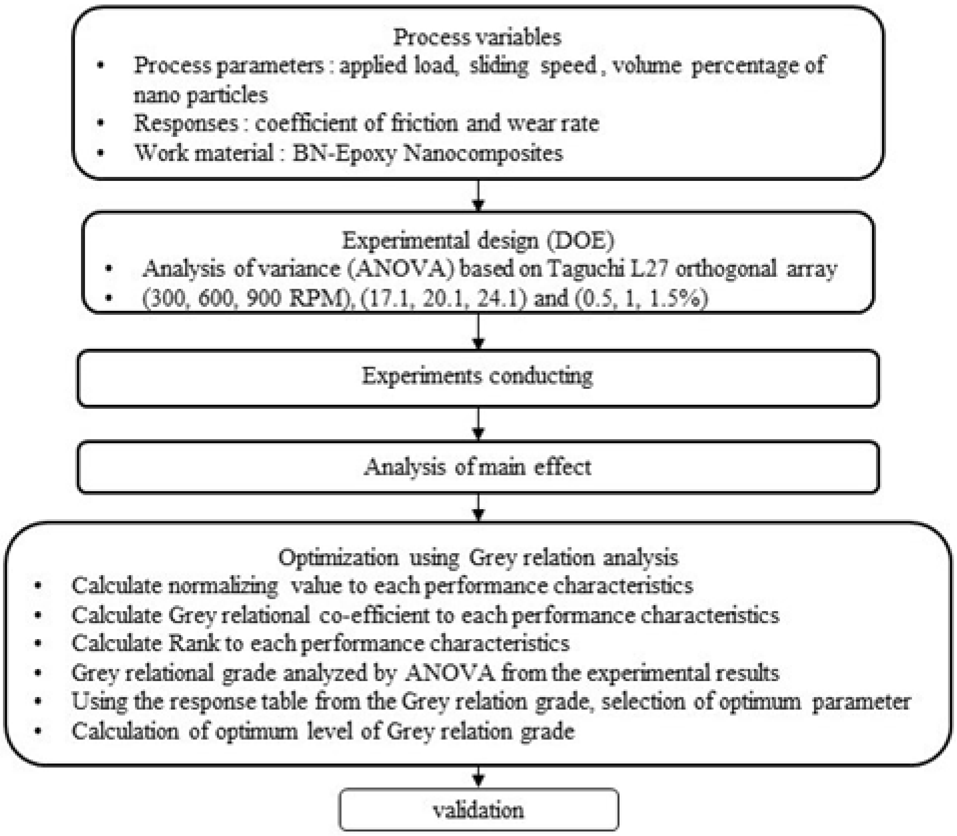

Fig 1 Flow chart of the present work

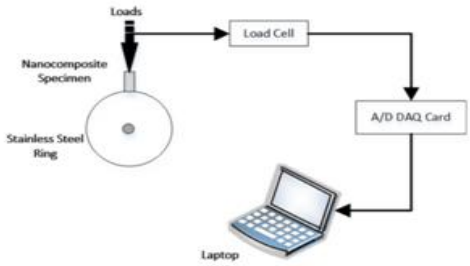

Fig 2 schematic illustration of the pin-on-ring wear tester.

3 Results and discussion

Table 2 measurement results of wear rate and coefficient of friction

No.	Bn, %	Speed RPM	Applied load, N	Wear rate(mg/min)	Coefficient of friction
1	0.5	300	300	12.075	0.285975
2	0.5	300	300	11.550	0.292796
3	0.5	300	300	8.675	0.292796
4	0.5	600	600	9.550	0.201661
5	0.5	600	600	8.750	0.219575
6	0.5	600	600	7.400	0.237236
7	0.5	900	1000	1.100	0.187971
8	0.5	900	1000	10.175	0.193021
9	0.5	900	1000	13.150	0.153460
10	1	300	600	5.725	0.177944
11	1	300	600	6.750	0.172141
12	1	300	600	8.250	0.183999
13	1	600	1000	29.700	0.173241
14	1	600	1000	24.750	0.197861
15	1	600	1000	25.725	0.197861
16	1	900	300	15.250	0.244158
17	1	900	300	17.775	0.272036
18	1	900	300	12.500	0.278857
19	1.5	300	1000	311.725	0.143570
20	1.5	300	1000	126.400	0.148410
21	1.5	300	1000	232.275	0.148410
22	1.5	600	300	41.400	0.230219
23	1.5	600	300	12.100	0.223101
24	1.5	600	300	15.450	0.258097
25	1.5	900	600	13.075	0.231433
26	1.5	900	600	9.175	0.201661
27	1.5	900	600	13.200	0.231433

3.1 Analysis of main effect for wear rate

According to input parameters, measurement of mean and SN ratio of wear rate are studied here. The main effect plot for wear rate and main effect plot for SN ratio can be visualized corresponding to volume fraction of BN, speed and load form Figure3.The results revealed that parameters BN vol.%, speed and load were significant factors on wear rate

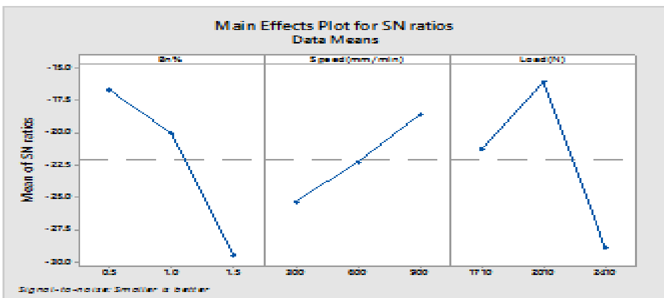

Fig 3. Main effects plot for SN ratio for wear rate.

In this study, analysis of variance for the response surface were performed. Results of ANOVA for each parameter are shown in Table3. From the table, BN%, sliding speed and applied load seem to have most dominance influence. The model of high F-value indicate to this model is significant. P-values less than 0.0500 indicate model terms are significant. thus, the most significant model terms are load, sliding speed and BN vol.%.

Table3. The results of ANOVA for wear rate

Source	DF	Adj SS	Adj MS	F-Val	P-Val
Bn, %	2	32531	16265.4	7.13	0.005
Speed, RPM	2	25472	12735.9	5.58	0.012
Load, N	2	32567	16283.4	7.14	0.005
Error	20	45615	2280.7		
Lack-of-Fit	2	27682	2280.7	13.89	0.000
Pure Error	18	17933	13841.0		
Total	26	136184	996.3		

3.2 Analysis of main effect for Coefficient of friction

Figure 3. Shows the main effects plots for coefficient of friction with respect to process parameters and Table 4 summaries the results of ANOVA analysis of coefficient of friction. The results from Figure4 andTable 4 revealed that parameters load, speed and BN% were significant factors on coefficient of friction.

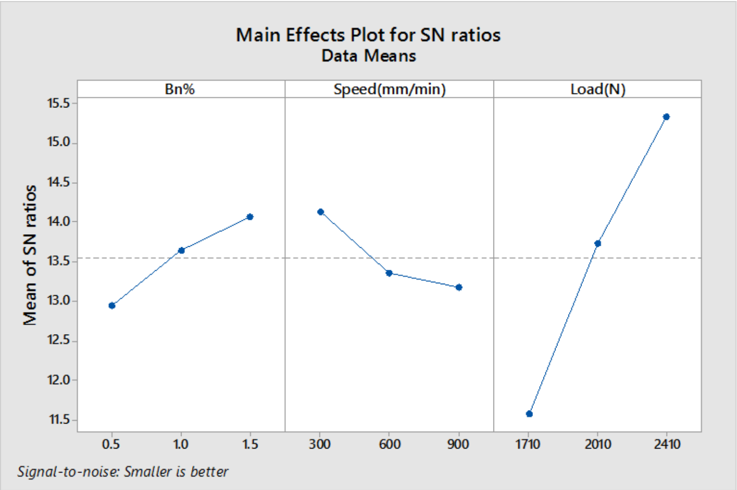

Fig 4. Main effects plot for SN ratio for coefficient of friction.

Table4. The results of ANOVA for coefficient of friction

Source	DF	Adj SS	Adj MS	F-Val	P-Val
Bn, %	2	0.003554	0.001777	3.53	0.049
Speed, RPM	2	0.001243	0.000621	1.23	0.313
Load, N	2	0.039462	0.019731	39.15	0.000
Error	20	0.010079	0.000504		
Lack-of-Fit	2	0.006047	0.003023	13.50	0.000
Pure Error	18	0.004032	0.000224		
Total	26	0.054337			

3.3 Multi optimization response usingGRA

The optimization of complex multi-response features can be converted to optimization of a single response feature through the Gray relational grade as the objective function by using GRA associated with the Taguchi process. The objectives of the present work are to minimize the wear rate and coefficient of friction during the experimental work. Thus, the wear rate and coefficient of friction as multi-response are combined by the Gray relational grade using the Gray relational analysis.

3.3.1 Grey relational generation:

GRA is the most appropriate technique for obtaining the optimal process parameters for multi-response characteristics, the first step is normalized the results of the wear rate and friction coefficient experiments corresponding to the lower-the-better criterion can be expressed as:

$$X_i(k) = \frac{\max Y_i(k) - Y_i(k)}{\max Y_i(k) - \min Y_i(k)} \quad (1)$$

k = 1, 2, ..., *n*, i = 1, 2, 3, ..., *m*; *m* is the number of experimental data and, *n* is the number process responses. Y_i (k) the original sequence, Min Y_i (k) is the smallest value of Y_i (k). Max Y_i (k) is the largest value of Y_i (k). X_i (k) is the value after Grey relational generation. The normalized values of wear rate and coefficient of friction are calculated by Eq. (1) and are shown in Table 5

3.3.2 Grey relational coefficient (GRC)

The GRC shown in Table**6**is calculated by the followingequation (2):

$$\xi_i(k) = \frac{\Delta_{min} + \zeta\,\Delta_{max}}{\Delta_{0i}(k) + \zeta\,\Delta_{max}} (2)$$

where, $\Delta_{0i}$is the deviation sequence of the reference sequence and the comparability sequence. Δ max and Δ min aremaximum the and minimum values of the absolute differences (Δ0*i*). ζ is identification coefficient and the range is between 0 to 1.The GRC of each performance characteristic is shown in Table 5.

3.3.3 Grey relational grade (GRG)

The (GRG) shown in Table 5.is calculated by meaning the GRCmatching to each experiment as it shown from equation (3):

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) \; (3)$$

where, i = 1, 2, 3 ... 40, ,ξi(k) is the Grey relational coefficient and *n* is the number of responses.. The higher value of GRG matches to an intense relational degree between the reference sequence *x*0(*k*) and the given sequence *x*i(*k*).

Table5. Grey relational generation, GRC and GRG values

no	Normalizing value of response		Deviation sequences		GRC		
	Coefficient friction	Wear rate (mg/min)	Coefficient friction	Wear rate (mg/min)	Coefficient friction	Wear rate (mg/min)	GRG
1	0.04571	0.961046	0.95429	0.038954	0.34381	0.927723	0.635767
2	0	0.974004	1	0.025996	0.333333	0.950578	0.641955
3	0	0.961449	1	0.038551	0.333333	0.928417	0.630875
4	0.610717	0.953803	0.389283	0.046197	0.562251	0.91542	0.738835
5	0.490671	0.964588	0.509329	0.035412	0.495379	0.933859	0.714619
6	0.372317	0.870262	0.627683	0.129738	0.443387	0.79398	0.618684
7	0.702458	0.255775	0.297542	0.744225	0.626926	0.401856	0.514391
8	0.668614	0.59662	0.331386	0.40338	0.601405	0.553477	0.577441
9	0.933723	0	0.066277	1	0.88296	0.333333	0.608147
10	0.76965	0.9633	0.23035	0.0367	0.684603	0.931619	0.808111
11	0.808538	0.946318	0.191462	0.053682	0.723106	0.903045	0.813076
12	0.729072	0.954447	0.270928	0.045553	0.648569	0.916501	0.782535
13	0.801168	0.920724	0.198832	0.079276	0.71548	0.863147	0.789313
14	0.63618	0.923863	0.36382	0.076137	0.578825	0.867849	0.723337
15	0.63618	0.907928	0.36382	0.092072	0.578825	0.844491	0.711658
16	0.325935	0.976982	0.674065	0.023018	0.425871	0.95599	0.69093
17	0.139119	0.981811	0.860881	0.018189	0.367409	0.964899	0.666154
18	0.093408	0.985111	0.906592	0.014889	0.355469	0.971082	0.663276

19	1	0.961207	0	0.038793	1	0.928001	0.964
20	0.967566	0.970785	0.032434	0.029215	0.939084	0.944795	0.94194
21	0.967566	1	0.032434	0	0.939084	1	0.969542
22	0.419343	0.979718	0.580657	0.020282	0.462682	0.961018	0.71185
23	0.467041	0.975372	0.532959	0.024628	0.484046	0.953057	0.718552
24	0.232527	0.972797	0.767473	0.027203	0.394486	0.948401	0.671443
25	0.411205	0.975614	0.588795	0.024386	0.459223	0.953496	0.706359
26	0.610717	0.966358	0.389283	0.033642	0.562251	0.936958	0.749604
27	0.411205	0.964668	0.588795	0.035332	0.459223	0.934	0.696612

The effects of each variable at different levels and mean GRGis presented in Table6. The optimal parametric combination is chosen based on higher mean (GRG) values which calculated by take the average values for each level of process parameter from Table2 and its values are shown in Table 6. Rank indicate to the most influencing parameters during the process, the higher value of GRGindicates a sturdier correlation to the reference sequence and better performance. Thus, the optimal settings for multi-responses are applied load of 0.75553, speed 0.798645 mm/min and Bn% of 0.792211 higher values of mean GRG gives the minimum values of wear rate and coefficient of friction. The difference of maximum and minimum values of mean GRG were as 0.161021for Bn%, 0.146099for speed and 0.085441for applied load respectively (Table6). This result indicates that the Bn% has the most influencing effect on multi-responses compared to others factors during process. The sequence of importance of process parameters on multi-responses are Bn% > speed> applied load.

Table6. Main effects on mean grey relational grade.

Name	G R grade			Mean (max-min)	Rank
	Level 1	level 2	level 3		
BN, %	0.63119	0.73871	0.792211 *	0.161021	1
Speed, RPM	0.798645 *	0.710921	0.652546	0.146099	2
Load, N	0.670089	0.736493	0.75553*	0.085441	3
Total mean value of grey relation grade is				0.392561	

* corresponding to optimum level

3.4. Applying (ANOVA) analysis

Considering GRG, ANOVA) resultsare shown in Table 8. The significance of process parameters on multi-responses. From the ANOVA Table 7,it is noted that Bn%, speed and applied load were significant process parameters influencing multi responses as its p-value is less than 0.05 at 95% confidence level.

Table7. Results of ANOVA on grey relational grade

Source	DF	Adj SS	Adj MS	F-Val	P-Val
Bn, %	2	0.12105	0.060526	20.33	0.000
Speed, RPM	2	0.09734	0.048672	16.35	0.000
Load, N	2	0.03622	0.018108	6.08	0.009
Error	20	0.05955	0.002977		
Lack-of-Fit	2	0.03902	0.019509	17.11	0.000
Pure Error	18	0.02053	0.001141		
Total	26	0.31416			

3 Conclusions

The process parameters;applied load, sliding speed and volume fraction of nano BN particles were optimized via two different optimization approaches, Taguchi and multi-response technique via GRA with ANOVA. The wear rate and coefficient of friction were set as the control parameters during experimental work. Based on the results we can conclude:

1 Parameters BN vol.%, sliding speed and applied load were significant factors on coefficient of friction.
2 The parameters BN vol.%, sliding speed and applied load have significant factors on wear rate.
3 The sequence of importance of process parameters on multi-responses were BN vol.% > speed > applied load.

4 References

[1] "Tribological behaviour of polymer nanocomposites containing tungsten based nanoparticles A Thesis submitted to the Graduate School of Engineering and Science of in Materials Science and Engineering," no. July, 2007.

[2] P. Taylor, H. Düzcüko, Ş. Ekinci, Ö. S. Ş, A. Avc, and M. Ekrem, "Enhancement of Wear and Friction Characteristics of Epoxy Resin by Multiwall Carbon Nano Tube and Boron Nitride Nano Particles," no. February 2015, pp. 37–41, 2014, doi: 10.1080/10402004.2014.998358.

[3] Z. Ren, Y. Yang, Y. Lin, and Z. Guo, "Tribological Properties of Molybdenum Disulfide and Helical Carbon Nanotube Modified Epoxy Resin," 2019, doi: 10.3390/ma12060903.

[4] K. L. Firestein *et al.*, "Structural analysis and atomic simulation of Ag/BN nanoparticle hybrids obtained by Ag ion implantation," *Mater. Des.*, vol. 98, pp. 167–173, 2016, doi: 10.1016/j.matdes.2016.02.108.

[5] Q. Peng, W. Ji, and S. De, "Mechanical properties of the hexagonal boron nitride monolayer: Ab initio study," *Comput. Mater. Sci.*, vol. 56, no. January 2018, pp. 11–17, 2012, doi: 10.1016/j.commatsci.2011.12.029.

[6] S. Bernard, C. Salameh, and P. Miele, "Boron nitride ceramics from molecular precursors: Synthesis, properties and applications," *Dalt. Trans.*, vol. 45, no. 3, pp. 861–873, 2016, doi: 10.1039/c5dt03633j.

[7] B. Yaman and N. Çalış Açıkbaş, "Dry Sliding Behaviour of Boron Waste Reinforced Epoxy Matrix Composites," *J. Boron*, vol. 3, no. 2, pp. 63–70, 2018, doi: 10.30728/boron.343608.

[8] A. V. Prabu, M. U. Kumar, V. Manikandan, and N. Rajini, "Effect of Redmud on dry sliding wear behavior of polymer matrix composites: Taguchi approach," *J. Adv. Microsc. Res.*, vol. 9, no. 1, pp. 34–38, 2014, doi: 10.1166/jamr.2014.1183.

[9] M. Sudheer, K. Hemanth, K. Raju, and T. Bhat, "Enhanced Mechanical and Wear Performance of Epoxy/glass Composites with PTW/Graphite Hybrid Fillers," *Procedia Mater. Sci.*, vol. 6, no. Icmpc, pp. 975–987, 2014, doi: 10.1016/j.mspro.2014.07.168.

[10] H. D. Prashanthakuamr and N. Bhanuprakash, "Friction and Wear Behaviour of Polymer Matrix Composites – a Review," *Int. Res. J. Eng. Technol.*, vol. 4, no. 5, pp. 988–991, 2017.