ENGINEERING RESEARCH JOURNAL (ERJ)

Vol. 1, No. 47 Jan. 2021, pp 57-65

Journal Homepage: http://erj.bu.edu.eg

"EXPERIMENTAL STUDY ON THE EFFECT OF TOOL ROTATIONAL SPEED AND WELDING SPEED ON SURFACE QUALITY OF FSW AA6063-O ALUMINUM ALLOY"

Fawzy. S. EL-Ghazawi[1], Amer. A. Abdelhakeem [1], S. S. Mohammed[2], Tamer. S. Mahmoud[2]

[1] Mechatronics department, High Institute of engineering Culture and science city, Egypt

[2] Mechanical department, Shoubra faculty of engineering, Benha university, Egypt

Abstract: Friction stir welding (FSW) is a modernistic solid-state welding technique which characterized by an environmentally friendly process. This paper focuses on the effect of tool rotational speed and welding speed on surface roughness of AA 6063 FSW joints. Four rotational speeds and three welding speeds were used in FSW trials. Surface roughness tests are carried out and reported at start, center and end of all weld joints. The surface roughness test results show that the tool rotational speed and welding speed are very important to control the surface quality of welded joints. The rotational speed had displayed a higher significant effect on the surface roughness of the weld joints than the welding speed. At high tool rotational speed 470 RPM and low welding speed 160 mm/min, the best surface roughness quality obtained as 7.990 µm.

Keywords: : Friction Stir Welding, Aluminum Alloys, Surface Roughness.

1. INTRODUCTION

FSW is a modernistic solid-state welding technique invented by The Welding Institute (TWI), Cambridge, UK in 1991 which is usually applied for the different grades of different ferrous and non- ferrous materials. FSW has a massive application potential in shipbuilding, aerospace, automobile, and other manufacturing industries [1-2]. The basic concept of FSW is remarkably simple and shown in the Fig.1 The basic concept of (FSW) is joining of two metals by solid state third body which heat treated to be wear resistant and it has a profiled pin and shoulder. This tool provides frictional heat and pressure due to its rotation and contact, friction between the welding tool and the welded metal and traverse along the welding line. The plasticized material transported from front to the back edge of the tool to make a permanent joint. [3-4].

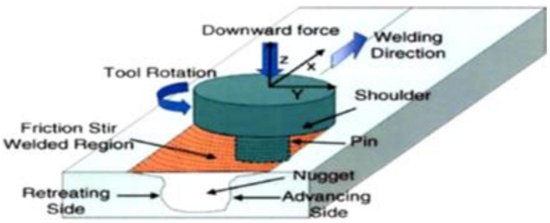

Fig.1. Schematic drawing of FSW working principle [4].

Hatamleh et al [5], they find that in the manufacturing industry the surface must be within certain limits of roughness to improve corrosion resistance and to reduce life cycle cost. Jolu et al [6], also suggested that surface roughness is a kind of irregularity in welding operation responsible of many cases of fatigue crack initiation due to generated stress concentrations.

Therefore, reaching an optimal surface roughness has become a goal for many researchers by identifying FSW welding parameters and tool geometry, which in turn improves quality of the welding joint.

Hasan I. Dawood et al [7], introduce a study on The Effect of the Surface Roughness on the Microstructures and Mechanical Properties of FSW AA 6061. They used The 6061 aluminum alloy with dimensions (210 mm × 200 mm) and 4 mm thick. They find that the reduction in surface roughness of the workpieces plays an important role in controlling the quality of the weld. Characterizations of microstructure revealed that the HAZ was narrow due to the effect of reduced workpiece surface roughness.

Khaled Boulahem et al. [8], observed that the optimum levels of the spindle speed, feed rate and tool shoulder diameter are 1700 rpm, 67 mm/min and 18 mm respectively and observed that when tool rotation speed increases the surface roughness of the FSW joint decreases but increases when traverse speed and tool shoulder diameter increases, respectively.

Bader A. Al-Ablani et al [9], concluded that the surface quality of AA6063 welded plates depends significantly on controlling the rotation speed with the traverse speed, the rotational speed showed a higher significant influence on the surface roughness when compared with the traverse speed, Low surface roughness with good surface quality is obtained at higher tool rotation speeds and medium traverse speeds. At the tool rotational speed of 800 rpm, the traverse speed does not affect the surface roughness of the welded AA6063 aluminum joint plates.

Cecile Langlade et al [10], observed that that the optimal conditions in terms of roughness for FSP process applied to this material are represented by test conditions for runs 8 (F=1000N, f=100 mm/min, n=900 rpm) and run 9 (F=1500N, f=50 mm/min, n=300 rpm) that provided the best combination between the cooling rate determined by the welding speed and the amount of heat produced by normal force and tool rotation speed. Too much heat and low cooling rates seem to affect negatively the surface quality.

Shigematsu et al [11], reported that the rotation speed tool and traverse speed tool are very important parameters in controlling the surface morphology of the joint. Also, Nejah [12], suggested that surface roughness is a result of the geometry of the tool and feed rate. The results indicated that an increase in the ratio (transverse speed/rotational speed) improves the surface state. Dwight et al [13], studied the welds produced by FSW using tools with various shoulders. They reported that shoulder design has a great effect on the surface roughness and metal deformation in the uppermost layers of welds.

The aim of this experimental study is to investigate the effect of tool rotational speed and welding speed on surface roughness of FSW butt joints and for selecting the best combinations of rotational speed and welding speed to produce a good surface quality joints with optimum surface roughness.

2. Experimental work.

2.1 workpiece material.

The base metal material used in this experimental investigation was AA 6063-O soft wrought aluminum alloy which considered heat treatable aluminum alloy and having good properties. Magnesium and silicon are the main elements in AA 6063-O aluminum alloy, its chemical composition is shown in table 1**.** The AA6063 rolled aluminum alloy plates were collected from "Egyptian Military Factory NO. 63" and the plates were cut into dimensions of 300 mm (length) × 50 mm (width) × 12 mm (thickness), as shown in fig.2**.**

Table 1 Standard and actual chemical composition AA 6063-O.

	Elements										
Weight wt%	Al	Cu	Fe	Mn	Mg	Si	Zn	Cr	Sn	Pb	Mo
Spec: BS EN 573-3: 2009	Max 97.5	Max 0.1	Max 0.35	Max 0.1	0.45:0.9	0.2:0.6	Max 0.1	Max 0.1	Other, total Max 0.15		
Actual	98.79	0.01	0.36	0.01	0.36	0.35	0.06	0.01	NIL	0.05	NIL

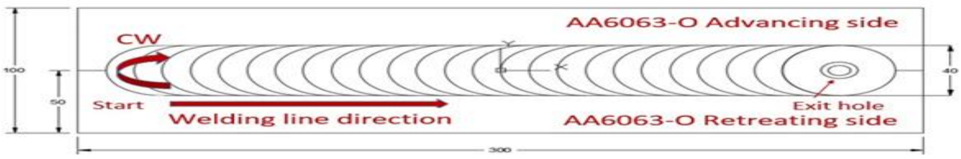

Fig.2. Dimensions of FSW specimen and joint, all dimensions in (mm).

2.2 FSW tool Material and design.

In this experimental study, the FSW tool used was fabricated from k110 tool steel round solid bars. The chemical compositions of k110 tool steel is presented in table 2.

Table 2 The chemical compositions of k110 tool steel.

Alloy	Chemical composition (wt.- %)						
	C	Si	Mn	Cr	Mo	V	Fe
K110	1.55	0.30	0.30	11.30	0.75	0.75	Bal.

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

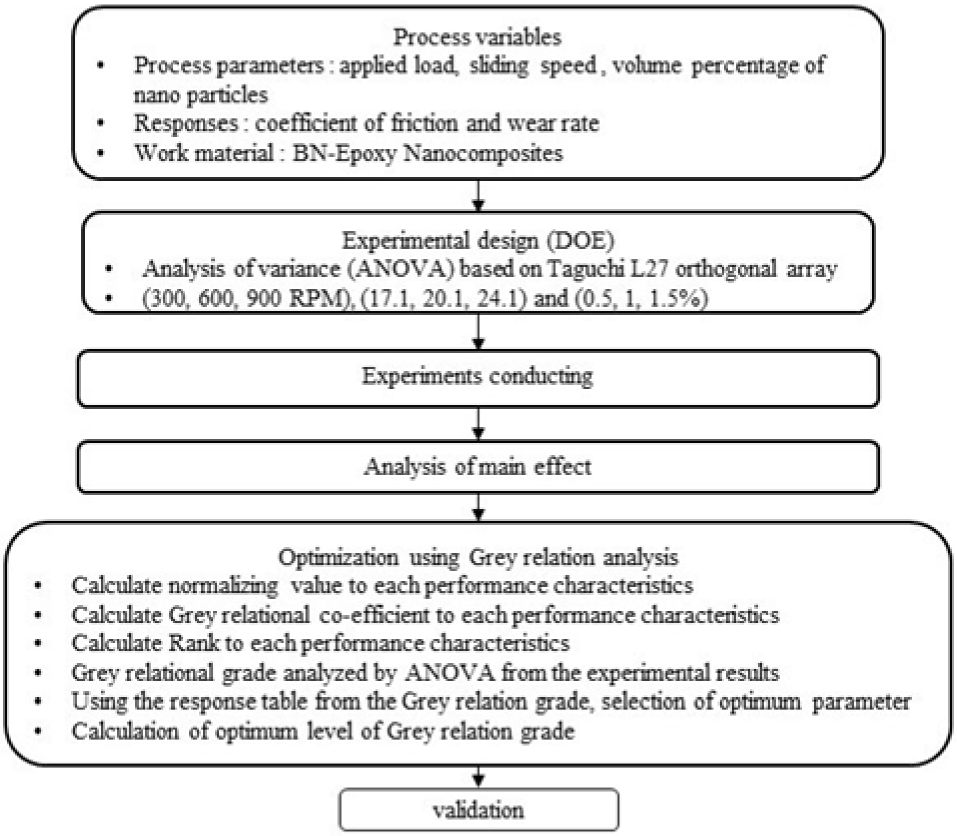

Fig 1 Flow chart of the present work

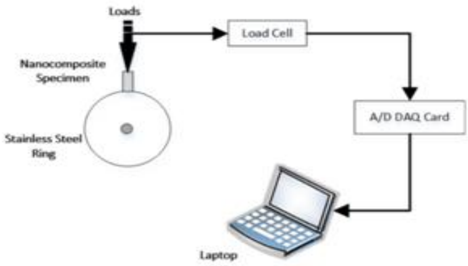

Fig 2 schematic illustration of the pin-on-ring wear tester.

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

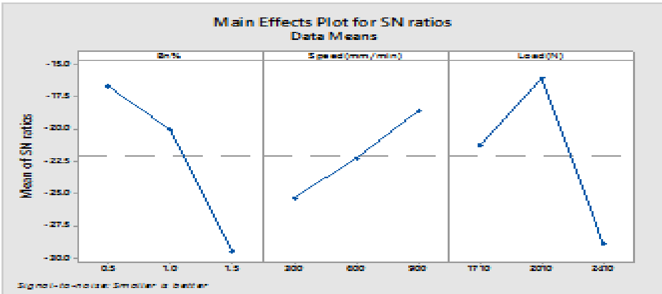

Fig 3. Main effects plot for SN ratio for wear rate.

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.

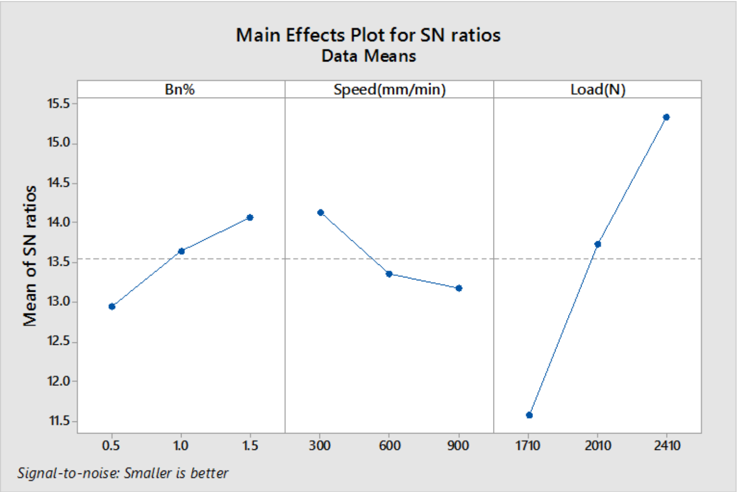

Fig 4. Main effects plot for SN ratio for coefficient of friction.

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:

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

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 (Δ0i). 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 $x0(k)$ and the given sequence $xi(k)$.

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.

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.