ISSN 2319-5991 www.ijerst.com

Peer Reviewed, Referred & Indexed Journal

Research Paper

Evaluation of Tribological Properties of Composite Nanomaterial by Taguchi Method

Kalpana G. Joshi[1], Noorul Ameen[2], Sumedh S. Ingle[3], Shivnarayan B. Bajaj[4], Nilkanth N. Kapse[*5]

[1]Integrated B. Tech Department School of Engineering and Technology, Sanjivani University, Kopargaon , India

[2]Department of Mechanical Engineering, Maulana Mukhtar Ahmad Nadvi Technical Campus, Malegaon, 423203 India

[3]Department of Mechanical Engineering, SRES, Sanjivani College of Engineering, Kopargaon 423603, India

[4]PG Department of Physics, J.E.S College, Jalna, India

[5]B.Raghunath ACS College, Parbhani, 431401 India

***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.**

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

I. 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_3 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

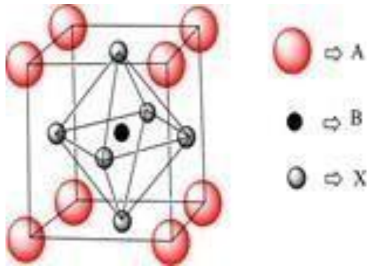

Fig. 1.Pervoskite Structure

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]

II. Literature Review

Yasmin Choudhury et al discussed wear behavior of Fe–Al2O3 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_2O_3), 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_2 nanoparticles and short pitch- based carbon nanotubes (CNTs) They found that addition of TiO_2 nanoparticles and short pitch-based carbon nanotubes (CNTs) shows positive effect on tribological properties.

Pure polyimide (PI) containing 4 wt% TiO2 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. Girishaet 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 $CaCO_3$, 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-B4C Composite Using Taguchi Technique. Their study shows that wear rate is highly depends upon Load followed 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 Pervoskite nanocompsite for various tribological applications.

III. 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_2O_5) (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 450^0 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 90^0C. After it small amount of pervoskite 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 600^0C 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

PARAMETERSOFEXPERIMENT

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

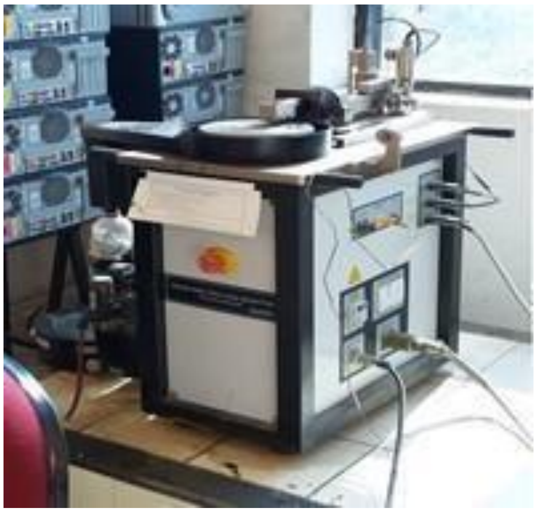

Fig. 2. Pin on Disc Apparatus

TABLE II

SPECIFIC ATION OF PIN ON DISC APPAR ATUS

Description	Specification
Sliding Speed Range	Min 0.5m/s to max10m/s
Disc Rotation Speed Range	200 to 2000rpm
NormalLoad	5N to200N
Friction Force	0 to200N
Wear Measurement Range	2mm
PinSize	2 mm to 12 mm dai.
Mean Wear Track Diameter	50mm to100mm
Temperature:	Max 400oC
Timer	Max 99hrs,59 min,59 sec

Objective of the experimentation should be smaller is better as coefficient of friction and wear are the response therefore $S/N = -10 log10 \{ 1/n \sum_{i=1}^{n} y_i^2 \}$[27]

Where n = number of tests in a trial.

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

TABLE III

LEVELS OF PARAMETRES

Factors	Code	Units	Level1	Level2	Level3
Load	L	N	9.81	19.6	29.4
Speed	S	RPM	200	400	600
SlidingDistance	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 27tests.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]

IV. RESULT AND DISCUSSION

TABLE IV

EXPERIMENTAL RESULT OF TAGUCHI DESIGN DATA

Sr. No.	Load (N)	Speed (rpm)	Sliding Dis-tance (m)	Wear rate (mm3/m)	COF	S/N Ratio (dB) Wear Rate	S/N Ratio (dB) COF
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

TABLE V

S/N RATIO RESPONSE FOR WEAR RATE

Smaller is better Level	Load	Speed	Sliding Distance
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

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

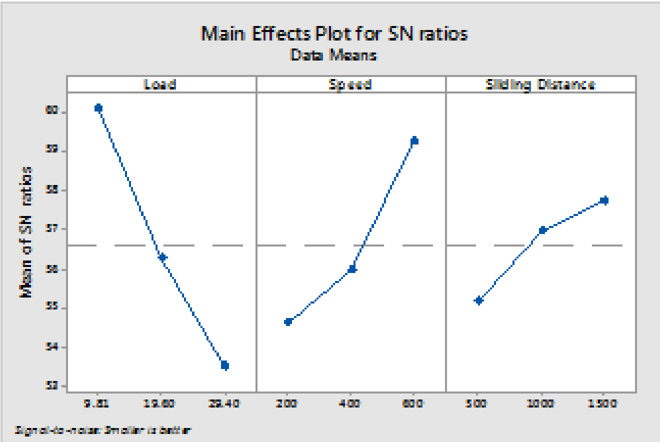

Fig. 3. Main Effect plot for S/N Ratio for wear rate

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 par 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 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 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

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.

V. 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.

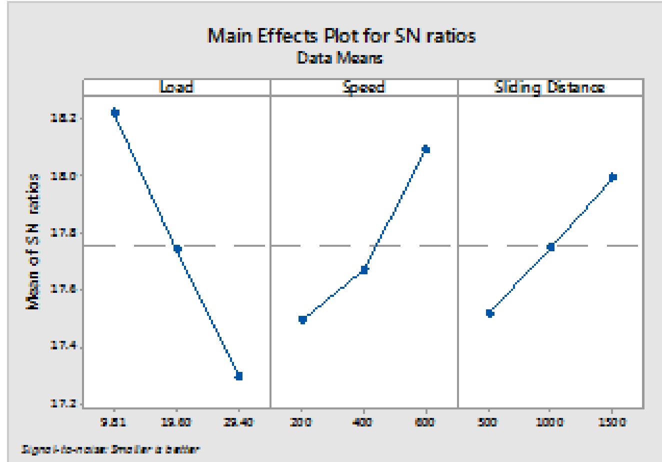

Fig. 4. Main Effect Plot for S/N Ratio for COF

TABLE VII ANOVA FOR WEAR RATE

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	Contrib-ution
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%

TABLE VIII ANOVA FOR COF

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					100.00%

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

VI. 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 pervoskite 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.

Acknowledgment

I would like to thank to Department of Nanotechnology, SRTMU, Nanded, Principal JES College Jalna for providing facilities required for my research work. I am also great thankful to Director, Sanjivani college of Engineering, and Management SRES.

VII. Refrences

[1] Yasmin Choudhury and Pallav Gupta, "Wear Behavior of Composites and Nanocomposites: A New Approach," in Re- cent Trends in Nanomaterials, Advanced Structured Materials, Z.H. Khan Ed. Singapore: Springer, 2017, pp. 29-48.

[2] Daniel Dornellas Athayde, "Synthesis and characterization of perovskite materials for production of mixed ionic and electronic conduction membranes," Chemical Engg. Of Universidade Federal de Minas Gerais, Belo Horizonte, January2015, pp. 10-13.

[3] Serafettin Demic, Ahmet Nuri Ozcivan, Mustafa Can, Cebrail Ozbek and Merve Karakaya "Recent Progresses in Per- ovskite Solar Cells," in Nanostructured Solar Cells, Narottam Das Ed., Intech open,Australia,2017, pp. 277-304.

[4] David Lawrence Burris, "Effects of Nanoparticles on the Wear Resistance of Poly tetra fluoro ethylene," The Graduate School of The Uni. of Florida, University Of Florida, USA, 2007, pp. 1-201.

[5] Kali Dass, S. R. Chauhan, And Bharti Gau, "Study on Mechanical and Dry Sliding Wear Characteristics of Meta- Cresol Novalac Epoxy Composites Filled with Silicon Carbide, Aluminum Oxide, and Zinc Oxide Particulates," Tribology Transactions, Vol. 57, Issue3, Nov. 2013, pp.157-172 .

[6] Joshi, K.G., Bajaj, S.B., Bajaj, R., & Ingle, S.S. (2017). Wear and Friction Study of Ferroelectric Composite Nanomaterial on Pin on Disc Machine *..

[7] Praveen Bhimaraj, "Effect of matrix morphology on the wear and friction behavior of alumina nanoparticle/poly(ethylene) terephthalate composites," Wear , vol258 ,Dec. 2005,pp.1437-1443.

[8] K.B.Girisha1, Dr. H.C.chittappa, "Preparation, Characterization And Wear Study Of Aluminium Alloy (Al356.1) Reinforced With Zirconium Nano Particles," IJIRSET, Vol. 2,Issue 8, Aug. 2013, pp. 3627-3637.

[9] Sunil Thakur and SR Chauhan, "Friction and sliding wear characteristics study of submicron size cenosphere particles filled vinylester composites using Taguchi design of experimental technique," Journal of Composite Materials,0(0),May 2013,pp.1-12.

[10] J Sudeepan, K Kumar, T K Barman, P Sahoo, " Study of tribological properties of ABS / CaCO3 polymer composites using Taguchi method," IOSR Journal of Mechanical and Civil Engineering ,2014, pp.38-42.

[11] Vishwanath Prasad et al. , "Optimization of Mechanical Properties and Wear Parameters of Al alloy-B4C Composite Using Taguchi Technique: A Review," IJSR, Vol. 4 Issue 3,March 2015, pp.238-241.

[12] ShuoYin, Zhao Zhang, Emmanuel J. Ekoi, Jing Jing Wang, Denis P. Dowling, Valeria Nicolosi, Rocco Lupoi, "Novel cold spray for fabricating graphene-reinforced metal matrix composites," Materials Letters, Vol.196, June 2017, pp. 172-175.

[13] Yecheng Xiao, Xiaoliang Shi, Wenzheng Zhai, Jie Yao, Zengshi Xu, Long Chen, and Qingshuai Zhu, "Tribological Performance of NiAl Self-lubricating Matrix Composite with Addition of Graphene at Different Loads," Journal of Materials Engineering and Performance, Aug. 2015, Vol. 24, Issue 8, pp. 2866–
2874.

[14] Fanyan Chen, Jiamin Ying , Yifei Wang , Shiyu Du, Zhaoping Liu, Qing Huang, "Effects of graphene content on the microstructure and properties of copper matrix compos- ites," Carbon, 96 , Jan. 2016,pp. 836-842.

[15] Meysam Tabandeh-Khorshid, Emad Omrani, Pradeep L. Menezes ,Pradeep K. Rohatg, "Tribological performance of self-lubricating aluminum matrix nanocomposites: Role of graphene nanoplatelets," Engineering Science and Technology, an International Journal , Vol. 19, Issue 1, Mar. 2016, pp.463- 469.

[16] H. G. Prashantha Kumar & M. Anthony Xavior, "Effect of graphene addition and tribological performance of Al 6061/graphene flake composite," Tribology - Materials, Surfaces& Interfaces, Vol. 11, Issue 2, 2017, pp. 88-97.

[17] Xiao-song Jiang, Nai-juan Wang, Degui Zhu, "Friction and wear properties of in-situ synthesized Al_2O reinforced aluminum composites," Trans.

Non ferrous Met. Soc. China–, 24, 2014, pp. 2352-2358.

[18] A. Chennakesava Reddy, “Significance of Testing Parameters on the Wear Behavior of AA1100/B4C Metal Matrix Composites based on the Taguchi Method,” 3rd International Conference on Composite Materials and Characterization, Chennai, Tamilnadu, India, 2001, pp.276-280.

[19] Bartosz Hekner, Jerzy Myalski, Nathalie Valle, Agnieszka Botor-Probierz, Małgorzata Sopicka-Lizer, Jakub Wieczorek, “Friction and wear behavior of Al-SiC(n) hybrid composites with carbon addition,” Composites Part B, Vol. 108, Jan. 2017, pp. 291-300.

[20] H.R. Akramifard, M. Shamanian, M. Sabbaghian, M. Esmailzadeh, “Microstructure and mechanical properties of Cu/SiC metal matrix composite fabricated via friction stir processing,” Materials and Design , Vol. 54, Feb. 2014, pp.838-844.

[21] G.H. Majzoobi, A. Atrianb& M.H. Enayatic, “Tribological properties of Al7075-SiC nanocomposite prepared by hot dynamic compaction,” Composite Interfaces, Vol. 22, Issue 7, pp.579-593.

[22] V. Ramakoteswara Rao, N. Ramanaiah, M. M. M. Sarcar, “Tribological properties of Aluminium Metal Matrix Composites (AA7075) Reinforced with Titanium Carbide (TiC) Particles,” International Journal of Advanced Science and Technology,Vol.88 , 2016, pp. 13-26.

[23] Debalina Bhattacharjee, Kamaraj Muthusamy, Sarathi Ramanujam, “Effect of Load and Composition on Friction and Dry Sliding Wear Behavior of Tungsten Carbide Particle- Reinforced Iron Composites,” Tribology Transactions, Vol.57,Issue 2, 2014, pp. 292-299.

[24] Kalpana G. Joshi1, S.B. Bajaj , Sumedh S. Ingle “Synthesis and Characterization of Nickel doped Barium Niobate Ba (Ni0.5Nb0.5)O3 (BNN) Nanomaterial”, Journal of Microelectronics and Solid State Devices, Volume 5, Issue 2, 2018, pp. 29-33.

[25] SrinivasAthreya1 , Dr. Y.D. Venkatesh, “Application Of Taguchi Method For Optimization Of Process Parameters In Improving The Surface Roughness Of Lathe Facing Operation,” International Refereed Journal of Engineering and Science (IRJES) ,Vol.1, Issue 3 , Nov. 2012, pp.13-19

[26] Jaswinder Singh and Amit Chauhan, “ Investigations on dry sliding frictional and wear characteristics of SiC and red mud reinforced Al2024 matrix hybrid composites using Taguchi’s approach,” ProcI Mech E Part L: J Materials: Design and Applications, Sep. 2018,pp.1-16.

[27] Vinod Kumar, Ashok Kr. Mishra, Dr. B.K. Roy, “ Application of Taguchi Technique to Optimize Tribological Behavior of Al6061T6/SiC/Al2O3 Metal Matrix Composite, IJSRP, Vol. 3, Issue 8, Aug. 2013, pp. 1-9.

[28] Mohammed Imran , Dr. A.R Anwar Khan, “Friction and Wear Properties of Al7075-BA-Gr Hybrid Composites,” IJSRST , Vol. 3 , Issue 7, pp.514-520.

[29] Shouvik Ghosh, Prasanta Sahoo, Goutam Sutradhar, "Friction Performance Optimization of Al-SiC Metal Matrix Composite," International Journal of Materials Chemistry and Physics, Vol. 1, No. 3, 2015, pp. 276-280.

[30] S. Baskaran, V. Anandakrishnan , Muthukannan Duraiselvam, "Investigations on dry sliding wear behavior of in situ casted AA7075–TiC metal matrix composites by using Taguchi technique," Materials and Design, Vol.60,2014,pp.184–192.

[31] Sandra Velickovic , BlazStojanovic, Miroslav Babic, IlijaBobic, "Optimization of tribological properties of aluminum hybrid composites using Taguchi design," Journal of Composite Materials, 2016, pp. 1–11.

[32] Radhika , R.Raghu, " Investigation on Mechanical Properties and Analysis of Dry Sliding Wear Behavior of Al LM13/AlN Metal Matrix Composite based on Taguchi's Technique," Journal of Tribology, Vol. 139, Issue 4, 2016, pp. 1-18.

[33] Deepak Mehra, Manas Mohan Mahapatra , Suraj Prakash Harsha "Optimizations of RZ5-TiC magnesium matrix composite wear parameters using Taguchi approach," Indus- trial Lubrication and Tribology, Vol. 70, Issue 5, pp.907-914.

[34] S Dhanalakshmi, N Mohanasundararaju, P G Venkatakrishna, V Karthik, "Optimization of friction and wear behavior of Al7075-Al2O3- B4C metal matrix composites using Taguchi method," in Int. Con. on Adv. in Metallurgy, Materials and Mfg., 2018, pp.1-10.

[35] B.M.Muthamizh Selvan et al. "Multi Objective Optimization of Wear Behavior of In Situ AA8011-ZrB2 Metal Matrix Composites by Using Taguchi-Grey Analysis," Materials Science Forum Submitted, Vol. 928, 2018, pp162-167.

[36] L.J. Raibagkar , S.B. Bajaj , "Poling effect on the dielectric, pyroelectric and electrical conductivity of ferroelectric ordered–disordered $Ba(Ni_{0.5} Nb_{0.5})O_3$ Solid State Ionics 108 (1998), pp. 105–108.