VITHAL RAO CHAVAN
VEERABHADRAPPA ALGUR
K R DINESH
and
K VEERESH

A comparative study on sliding wear behaviour of post-cured hybrid reinforced polymer composites

This endeavour also entails developing novel materials for composites that are superior to existing composites. Lapox L-12 resin, E glass fibre material, and cerium oxide, which are the rare earth material family member in the periodic table. The combination of these materials was utilised to investigate the wear loss, and surface roughness in a dry sliding wear in two conditions: with and without post-curing (at 100°C for 60 minutes) with process parameters such as percentage of filler material, normal load and sliding speed. The experiments were planned according to L16 orthogonal array based on Taguchi design. Results reveal that wear loss and surface roughness is minimum in post-cured glass fiber reinforced polymer (GFRP) composites compoared to without post-cured specimens. The optimum process parameters level for minimum wear loss of post-cured GFRP composites, optimum process parameters are percentage of filler material is 20%, load is 15N and sliding speed is 0.25 m/s.

Keywords: Post-curing, GFRP, wear loss, surface roughness, pin-on-disc testing machine.

1.0 Introduction

In recent days the polymers are replacing the metal and alloys by their promising property i.e. high strength-to-weight ratio and stiffness-to-weight ratio. As a reason, mechanical components such as gears, cams, wheels, brakes, clutches, bearings, and seals are being used consistently. The majority of these are impacted by tribological loading, when they are in service as a result the researchers are much interested in developing the newer material for the polymer system.

There are two methods to get the newer material, by varying the filler material and the proportion of the filler material in the polymer based matrix such as fillers/whiskers. The another method is by varying the type of reinforcement material and the geometry of the reinforcement such as woven/fibrous/unidirectional/bidirectional/random etc., (ASM Hand book, 1992, Pascoe, M.W, 1973) (B. Suresh et al., 2006) examined the wear properties by varying the three percentages of graphite filler in E-glass-epoxy composite, the comparison of wear behaviour is being carried with and without graphite filler, and concluded that the graphite filled composite poses higher value of resistance to sliding wear when compared to unfilled. (Gewen Yi and Fengyuan Yan, 2007). Tribological and mechanical characterization is being conducted on phenolic based composite with numerous inorganic fillers. Addition of petroleum coke in phenolic composite, increases bending strength and hardness characteristics. Talcum powder (5-10%) and hexagonal boron nitride (5-15%) of volume fraction acts as friction modifier, to increase the wear resistance of phenolic composite. Further addition leads to inappropriate results of wear resistance and decrease in strength. (S. Basavarajappa et al., 2007) an experiment approach using DOE (Taguchi) method for analyzing the wear characteristics of the composite with varying filler (SiC and graphite) material, sliding distance, sliding speed and load with aid of pin-on-disc test rig under dry condition. The result revealed that the wear resistance increased tremendously by the inclusion of SiC and graphite as fillers in the polymer composite.

Through above cited literature survey, shows an ample opportunity to conduct the experimentation on wear behaviour of polymer composite by varying the filler material i.e. one of the rare earth material lanthanum oxide. Taguchi approach helps to design a plan of experiments to get a good control on the variables opted to investigate the wear characteristics of particulate filled composites (B. Suresh et al., 2007).

2.0 Experimentation

2.1 Materials

To carry out the experimentation the random orientation e-glass fiber with density of 2.62 gm/cm^3, lapox L-12 resin with density of 1.120gm/cm^3, hardner with density of 0.954gm/cm^3 and secondary filler material lanthanum oxide with density of 6.51gm/cm^3 has been incorporated to get a newer polymer

Messrs. Vithal Rao Chavan, Research Scholar, Veerabhadrappa Algur, Associate Professor, K Veeresh, Professor, Department of Mechanical Engineering, Rao Bahadur, Y Mahabaleswarappa Engineering College, Ballari and K R Dinesh, Professor and Principal, Department of Mechanical Engineering, Government of Engineering College, K.R Pet, Mandya, Karnataka, India. E-mail: nrvithalchauhan@gmail.com / veereshalgur@gmail.com / kuppagalveeresh@yahoo.co.in / dineshkrpet@gmail.com

composite. Table 1 shows the proportionate use of fabricated composites (Chavan Rao Vithal et al., 2017, Chavan Rao Vithal et al., 2019.

Table 1: Proportionate combination of material used in the composite

Specimen	Composition		
	Resin	Fiber	Filler material
1	60%	40%	0%
2	60%	30%	10%
3	60%	20%	20%
4	60%	10%	30%

2.2 Fabrication of composite

The composites are fabricated as per the proportionate by hand layup method and further the composites are machined as per the required ASTM D G99 standard for wear test rig some sample are being post-cured for 30 min at 100ºC and specimens are furnace cooled. This was done to know the influence of post-curing on the wear characteristics (Chavan Rao Vithal et al., 2017, Chavan Rao Vithal et al., 2018, Chavan Rao Vithal et al., 2019).

2.3 Wear test

The whole test was carried on a "DUCOM" wear test machine at ambient conditions. The wear test was conducted for the samples without post-curing and with post-curing. The wear rate was monitored from the wear loss versus time plot. All the tests carried at constant track distance of 70mm (Algur Veerabhadrappa et al., 2017, Algur Veerabhadrappa et al., 2014, Algur Veerabhadrappa et al., 2022). The Fig.1 shows the picture of DUCOM test rig and Table 2 shows specifications of pin on disc.

2.4 Taguchi Approach

In this work, along all four different levels, the influence of three design variables was examined utilizing L16 experimental plan. The working conditions under which wear tests were performed are tabulated in Table 3.

Table 2: Specifications

	Parameters	Range
01	Load range	Up to 200N
02	Rotational speed	200-2000rpm
03	Frictional force Measurement	0-200N
04	Compound wear Measurement	0-1200µm
05	Wear	0-3mm
06	Disc size	160mm (Dia)
07	Pin size	3-10mm

Table 3: Levels for various control factors

Control variables	Units	Level I	Level II	Level III	Level IV
% of filler material	Wt.%	0	10	20	30
Load	N	5	10	15	20
Sliding speed	m/s	0.25	0.5	0.75	1

Fig.1: Pin-on-disc wear testing apparatus

3.0 Result and discussion

In this investigation, wear test and surface roughness were examined on modified particulate filled polymer composite and also the influence of post-curing on wear behaviour. In order to obtain the optimum result prediction, the obtained results need to transform into signal/noise ratio, because the S/N ratio greatly contribute, as objective function for optimization. The objective function for the wear loss and surface roughness obtained by the S/N ratio is smaller the better, which further can be equated as a logarithmic loss function.

3.1 S/N ratio analysis

The test carried out as per the plan of experiment obtained by the L16 orthogonal array and wear results are tabulated in the Table 4. To estimate the quality characteristics of obtained results, then the results need to transform into S/N ratio with the help of software MINITAB16, these ratios are tabulated in Table 4.

The main interest is to know the influence of the filler material, as it is the key factor for the modification of the composite. Signal/noise ratio responsive analysis need to carryout between percentage of filler and wear loss. To get the very high quality the process parameters are set to be optimum.

The higher and lower value of mean of S/N ratios difference leads to know the strongest impact parameter among the set parameters. If the difference is greater value of the averages of S/N ratios, would be the more prominent parameter.

The difference between the higher and lower values of the mean of S/N ratios was also used to determine the control parameter with the strongest recommendations. The control parameter would be more influential if the difference between the averages of S/N ratios was greater.

Table 4: Plan of experiment using L16 orthogonal array with and without post-cured composite

Trial	% of filler material	Load (N)	Sliding speed (m/s)	Without post-curing				With post-curing			
				Wear loss (mm^3/m)	S/N ratio (dB)	Surface roughness (Ra)	S/N ratio (dB)	Wear loss (mm^3/m)	S/N ratio (dB)	Surface roughness (Ra)	S/N ratio (dB)
1	0	5	0.25	0.15012	16.4712	4.140	-12.3400	0.0005	66.7039	3.88	-11.7766
2	0	10	0.5	0.11745	18.6029	2.380	-7.5315	0.0023	52.5916	3.41	-10.6551
3	0	15	0.75	0.00217	53.2708	2.450	-7.7833	0.0027	51.3824	2.66	-8.4976
4	0	20	1	0.0436	27.2103	1.580	-3.9731	0.0027	51.4040	2.25	-7.0437
5	10	5	0.5	0.11947	18.4548	2.860	-9.1273	0.0209	33.5998	4.89	-13.7862
6	10	10	0.25	0.09028	20.8882	3.723	-11.4179	0.0040	48.0673	4.46	-12.9867
7	10	15	1	0.09875	20.1093	2.920	-9.3077	0.0090	40.8985	2.93	-9.3374
8	10	20	0.75	0.00602	44.4081	2.670	-8.5302	0.0053	45.5418	2.29	-7.1967
9	20	5	0.75	0.00248	52.1110	6.560	-16.3381	0.0003	69.5012	5.20	-14.3201
10	20	10	1	0.00201	53.9361	4.680	-13.4049	0.0012	58.4558	2.51	-7.9935
11	20	15	0.25	0.02925	30.6775	2.593	-8.2761	0.0001	77.4609	8.06	-18.1267
12	20	20	0.5	0.04357	27.2162	7.143	-17.0776	0.0012	58.2771	8.68	-18.7704
13	30	5	1	0.06028	24.3965	2.110	-6.4856	0.0012	58.7753	2.50	-7.9588
14	30	10	0.75	0.09985	20.0130	1.890	-5.5292	0.0009	60.9917	1.87	-5.4368
15	30	15	0.5	0.21387	13.3970	3.220	-10.1571	0.0024	52.2674	2.28	-7.1587
16	30	20	0.25	0.02718	31.3150	2.380	-7.5315	0.0007	63.0914	3.30	-10.3703

Table 5: Response table for signal to noise ratios – smaller the better (without post-cured wear loss)

Level	% of filler material	Load	Siding speed
1	28.89	27.86	24.84
2	25.97	28.36	19.42
3	40.99	29.36	42.45
4	22.28	32.54	31.41
Delta	18.70	4.68	23.03
Rank	2	3	1

Table 6: Response table for signal to noise ratios –smaller the better (without post-cured surface roughness)

Level	% of filler material	Load	Siding speed
1	–7.907	–11.073	–9.891
2	–9.596	–9.471	–10.973
3	–13.774	–8.881	–9.545
4	–7.426	–9.278	–8.293
Delta	6.348	2.192	2.681
Rank	1	3	2

Table 7: Response table for signal to noise ratios –smaller the better (with post-cured wear loss)

Level	% of filler material	Load	Siding speed
1	55.38	57.12	64.27
2	42.00	55.01	49.29
3	66.82	56.17	57.06
4	58.71	54.60	52.28
Delta	24.83	2.52	14.98
Rank	1	3	2

Table 8: Response table for signal to noise ratios – smaller the better (With post-cured surface roughness)

Level	% of filler material	Load	Sidingspeed
1	-9.493	-11.960	-13.315
2	-10.827	-9.268	-12.593
3	-14.803	-10.780	-8.863
4	-7.731	-10.845	-8.083
Delta	7.072	2.692	5.232
Rank	1	3	2

Within the range of control parameters, the delta value will assign rank and average value of S/N ratio, which is tabulated in the Tables 5 to 8 for the composite with and without post-curing. The ranks to the control factors are assigned by the delta value, highest the delta value will be the 1st rank and highest delta value will be the 2nd rank and so on. The factor load is possessing highest value hence 1st rank is assigned to the load for without post-cured composite. 2nd rank is given to the percentage of filler material and 3rd rank is given to the sliding distance.

The optimum process parameters level for minimum wear loss of as without heat treatment for GFRP are percentage of

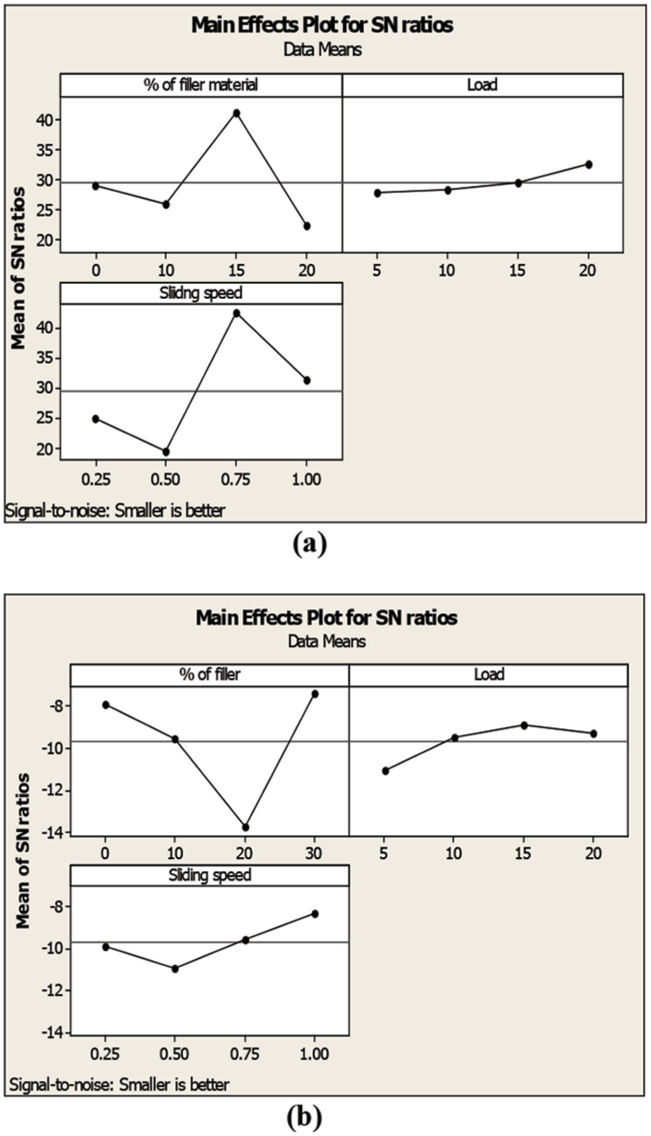

Fig.2: Main effects plot for S/N ratios-without post-cured specimens (a) wear loss (b) Surface roughness

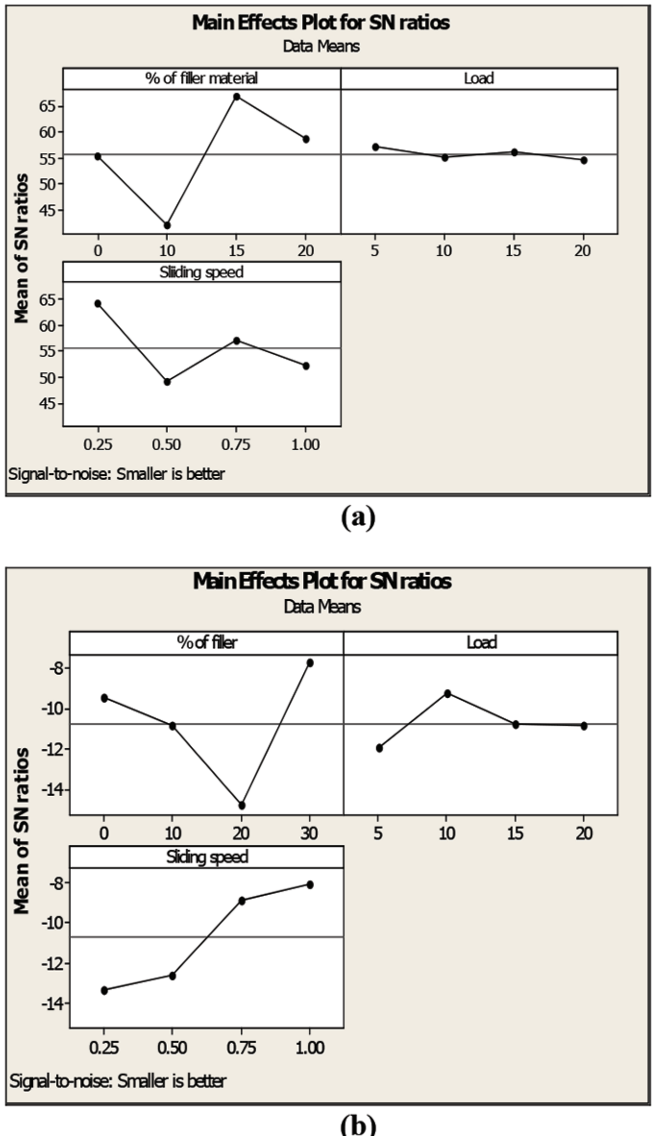

Fig.3: Main effects plot for S/N ratios-with post-cured specimens (a) wear loss (b) surface roughness

filler material is 0%, load is 15N and sliding speed is 0.75 m/s (A1B3C3. For post-cured GFRP composites, optimum process parameters are percentage of filler material is 20%, load is 20N and sliding speed is 0.5 m/s A3B4C1).

Figs.2 and 3 shows the main effects plots of S/N ratios with and without post-cured composites graphically. From the figures it is evident that the average means wear loss of without post-cured of GFRP is 0.089844, whereas for post-cured GFRP is 0.004064. This shows that wear resistance of heat treated GFRP composites is more than that of without post-cured.

4.0 Conclusions

The following conclusions were obtained as an outcome of the investigations:

1. Heat treatment of GFRP composites when comparing to specimens that have not been post-cured, there has been modest wear loss.
2. The optimum process parameters level for minimum wear loss of without post-cured for GFRP are percentages of filler material is 0%, load is 15N and sliding speed is 0.75 m/s (A1B3C3).
3. The optimum process parameters level for minimum wear loss of post-cured GFRP composites, optimum process parameters are percentage of filler material is 20%, load is 15N and sliding speed is 0.25 m/s (A3B3C1).
4. As the applied stress is increased, wear loss increases.
5. Wear loss is reduced as the sliding speed is increased..
6. Surface roughness is high for without post-cured specimens whereas for as post-cured composites, it is low.

7. With increase in normalized speed, normalized wear rate is increased and with increase in normalized pressure, normalized wear rate is decreased.

5.0 Reference

1. ASM Hand book, (1992): Materials Park, Ohio, USA, *ASM International*, Volume 18.
2. Algur Veerabhadrappa, Kabadi V R, Ganechari S M, chavan rao Vithal, (2017): Effect of Mn content on tribological wear behaviour of ZA-27 alloy, Materials today: *Proceedings*, vol.4, pp.10927-10934.
3. Algur Veerabhadrappa, Kabadi V R, Ganechari S M and Sharanabasappa, (2014): Experimental Investigation on Friction Characteristics of Modified ZA-27 Alloy Using Taguchi Technique, *Int. J. Mech. Eng. & Rob. Res,* vol.3(4), pp.24-32.
4. Algur Veerabhadrappa, Hulipalled Poornima, Lokesha V, Nagaral Madeva, Auradi V, (2022): "Machine Learning Algorithms to Predict Wear Behaviour of Modified ZA-27 Alloy Under Varying Operating Parameters", *Journal of Bio-and Tribo-Corrosion*, vol. 8(1), pp. 1-10.
5. B. Suresha, Chandramohan, G., J. N. Prakash, Balusamy, V., Sankaranarayanasamy K., (2006): The Role of Fillers on Friction and Slide Wear Characteristics in Glass-EpoxyComposite Systems. *Journal of Minerals & Materials Characterization & Engineering*, Vol. 5, pp.87-101.
6. B. Suresha, G. Chandramohan, P. Sampathkumaran and S.Sethuramu, (2007): Investigation of the friction and wear behaviour of glass-epoxy composite with and without graphite filler, *J. Reinforced Plastics and Comp*., 26:81.
7. Basavarajappa.S, Chandrmohan.G, Mahadevan.A, Mukundan, Subramanian.R,Gopalakrishan.P, 2007, Influence of sliding speed on the dry sliding wear behaviour andthe subsurface deformation of hybrid metal matrix composite, *Wear,* Vol.262, pp.1007-1012.
8. Chavan Rao Vithal, Dinesh .K.R, Veeresh K., Algur Veerabhadrappa, Shettar Manjunath, (2017): Taguchi's orthogonal array approach to evaluate drilling of GFRP particulate composites, AMMMT 2016 Materials Today: Proceedings 4, 11245–11250.
9. Chavan Rao Vithal, Dinesh K. R, Veeresh K., Algur Veerabhadrappa, Shettar Manjunath, (2018): Influence of post-curing on GFRP hybrid composite "MATEC Web of Conferences 144, 02011.
10. Chavan Rao Vithal, Algur Veerabhadrappa, Dinesh . K.R, Veeresh K., Gouda Sridhar, (2019): Effect of Post-curing On Rare Earth Particulates Filled Polymer Composite, *JETIR* May 2019, Vol.6, Issue 5 ISSN-2349-5162.
11. Gewen Yi and Fengyuan Yan (2007): Mechanical and tribological properties of phenolic resin based friction composite filled with several inorganic fillers. *Wear*, 262, 121-129.
12. Pascoe, M.W., (1973): Plain and filled plastics materials in bearing: a review. *Tribology,* Vol.6 No.5, pp.184-190.