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Research Article

Experimental investigation and prediction of wear behavior of cotton fiber polyester composites

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Abstract: The cotton fiber reinforced polyester composites were fabricated with varying amount of graphite fillers (0, 3, 5 wt.%) with a hand lay-up technique. Wear tests were planned by using a response surface (Box Behnken method) design of experiments and conducted on a pin-on-disc machine (POD) test setup. The effect of the weight percentage of graphite content on the dry sliding wear behavior of cotton fiber polyester composite (CFPC) was examined by considering the effect of operating parameters like load, speed, and sliding distance. The wear test results showed the inclusion of 5 wt.% of graphite as fillers in CFPC increase wear resistance compared to 3 wt.% of graphite fillers. The graphite fillers were recommended for CFPC to increase the wear resistance of the material. A scanning electron microscope (SEM) was used to study the wear mechanism. To predict the wear behavior of the composite material, comparisons were made between the general regression technique and an artificial neural network (ANN). The conformation test results revealed the predicted wear with the ANN was acceptable when compared with the actual experimental results and the regression mathematical models.

Keywords: wear; composites; cotton fiber reinforced polyester composites; artificial neural network; pin-on-disc

1 Introduction

Within the last few decades natural fiber reinforced polymer matrix composites (NFRPCs) were in boom due to their low cost, low weight, easy availability, and biodegradability. The natural fibers were in demand in automobile and structural sectors [1]. In the present work focus was placed on the cotton fiber due to its high strength, durability, biodegradability, and ease of blending with other fibers and resin. Failure due to wear was more common in automobile and failure of small parts leaded to the shut down in the industry. In this present investigation emphasis was placed on the wear behavior of the cotton fiber reinforced polyester composite (CFPC).

Many researchers have worked on different types of NFRPCs and have analyzed the effect of operating parameters (like load, speed, sliding distance, and temperature) and material parameters (like fiber length, fiber volume fraction, fiber orientation, and fiber treatment) on the wear behavior of NFRPCs. The work done of a few researchers is shown in the Table 1.

Table 1 reveals that most of the researchers have analyzed the wear rate of NFRPCs by varying different material parameters and different operating parameters. Very few have added fillers with the natural fiber and see the effect of fillers on the wear behavior of materials. Few studies show that use of proper wt.% of fillers with synthetic fiber helps to increase the wear resistance of the materials [16, 17].

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Table 1 Wear study by different researchers.

Research	Polymer	Fiber	Fillers	Variables	Observed wear rate
Chittaranjan Acharya [2]	Epoxy	Lantana camara	—	SD	Decrease
Chin Yousif [3]	Epoxy	Kenaf	—	*L*, FO, *S*	Decrease
Ganguluri et al. [4]	Epoxy	Pin wood dust	—	FVF	Decrease
Yousif et al. [5]	Polyester	Betelnut fruit	—	*L*	Decrease
Mishra and Acharya [6]	Epoxy	Sugar cane	—	FO, *L*	Decrease
Sayed et al. [7]	Polyester	Linen & Jute	—	FO	Decrease
Yousif et al. [8]	Polyester	Coir	—	FT	Decrease
Boopathi et al. [9]	Epoxy	Borassus fruit	—	*L*, *S*, SV, FT	Decrease
Yousif and El-Tayeb [10]	Polyester	Untreated & treated oil palm	—	FT, *L*	Decrease
Umar et al. [11]	Epoxy	Bamboo	—	FO	Decrease
Majhi et al. [12]	Epoxy	Rice husk	—	FT, *L*	Decrease
Dwivedi et al. [13]	Polyester	Bamboo powder	—	FVF, *L*	Decrease
Chandra et al. [14]	Epoxy	Coir	—	FVF, *L*	Decrease
Narish and Dirk [15]	Polyurethane (PE)	Kenaf	—	*L*, SD	Decrease

L: Load, *S*: Speed, SD: Sliding distance, FVF: Fiber volume fraction, FO: Fiber orientation, FT: Fiber treatment, SV: Sliding velocity

In the present investigation graphite fillers are used with the CFPC to analyze the effect of different wt.% of fillers on the wear behavior of CFPC.

The response behavior of material is implicit in the experiments. Usually, the behavior of materials is modeled analytically using mathematical expressions. However, it may not always be possible to have a simple expression. To create a complicated expression is difficult. The artificial feedforward neural network may be extremely helpful in terms of Refs. [18, 19]:

- The ability to implicitly detect complex nonlinear relationships between dependent and independent variables.
- The ability to detect all possible interactions between variables.
- The neural network is effective in terms of predicting the behavior of a new material before the material is produced. This may reduce the experiment cost and time.

An exhaustive literature review has been completed on the artificial neural network (ANN) to predict mechanical and tribological behavior of fiber reinforced polymer composites. Table 2 provides the summary of various studies for predicting the mechanical and tribological behavior of fiber reinforced polymer (FRP) composites with the ANN. In the present investigation

Table 2 Summary of various studies for predicting the properties of FRP composites with ANN.

Author	Study
Aymerich et al. [20]	Fatigue strength of composites
Velten et al. [21]	Wear volume prediction of polyamide 4.6 matrix composites reinforced with short carbon/glass fiber
Pleune et al. [22]	Fatigue life of carbon and low alloy steel
Haque et al. [23]	Corrosive fatigue behavior of steel
Allan et al. [24]	Predicting structural properties of polypropylene fiber
Hany and Yousif [25]	Fatigue life of glass fiber epoxy composite
Jia and Davalos [26]	Fatigue model for FRP wood composite
EI Kadi [27]	Mechanical modelling of FRP
Sha [28]	Machinability aspect of unreinforced and reinforced PEEK composites

predictions of wear behavior of the composite material comparisons are made between general regression statistical techniques with the ANN.

2 Experimental

2.1 Specimen preparation

Single wound 7 count cotton yarn procured from PBM Polytex Limited, Petlad, Gujarat was used as reinforcement. Unsaturated polyester resin, accelerator cobalt naphthenate and hardener were supplied by S K Enterprise, Surat, India. Matrix was prepared with a resin to hardener ratio 10:1. Graphite particles obtained from Heny Chemicals, Vadodara, India was used as filler with the average particle size 11.91 μm. Hand lay-up technique was used to prepare the composite plates of size 300 mm × 300 mm × 10 mm. The composition of fabricated composites with hand lay-up technique was listed in Table 3.

To determine graphite particle size distribution in the composites, the tensile test was carried out on the composites at Advance Metallurgical Services (AMS) Laboratory, Vadodara, Gujarat. The tensile test was performed according to the ASTM D 3039-M14 standard. A 10 kN load cell was used and three tests were repeated for each set of specimen and the average values were calculated and plotted in Fig. 1.

It was clear from the results that the addition of 3 wt.% graphite reduced the tensile strength of the cotton fiber polyester composites. The strength of the composite was even more deteriorated by increased graphite wt.%. This result was in agreement with Shalwan and Yousif [29] who concluded from their study that the addition of the graphite was highly recommended for the natural fiber composites which could enhance the wear characteristics of the polymer composites. However, the high content of the graphite deteriorated the mechanical properties. The micrograph of CFPC, 5 wt.% graphite filled cotton fiber reinforced polyester composite (5GCFPC), and 3wt.% graphite filled cotton fiber reinforced polyester composite (3GCFPC) were displayed in the Figs. 2–4, respectively.

Table 3 Formulation of fabricated graphite filled CFPC.

Material code	Resin content (wt%)	Cotton fiber (wt%)	Graphite (wt%)
CFPC	82	18	0
3GCFPC	79	18	3
5GCFPC	77	18	5

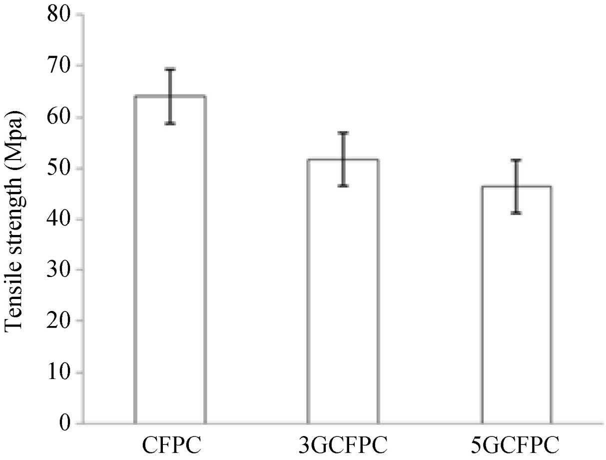

Fig. 1 Tensile strength of CFPCs.

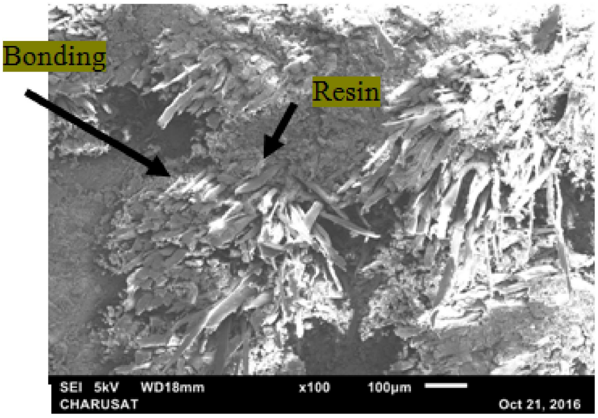

Fig. 2 Micrograph of CFPC after tensile test.

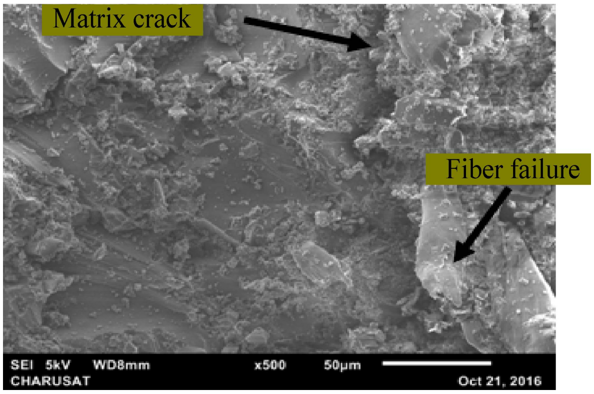

Fig. 3 Micrograph of 3GCFPC after tensile test.

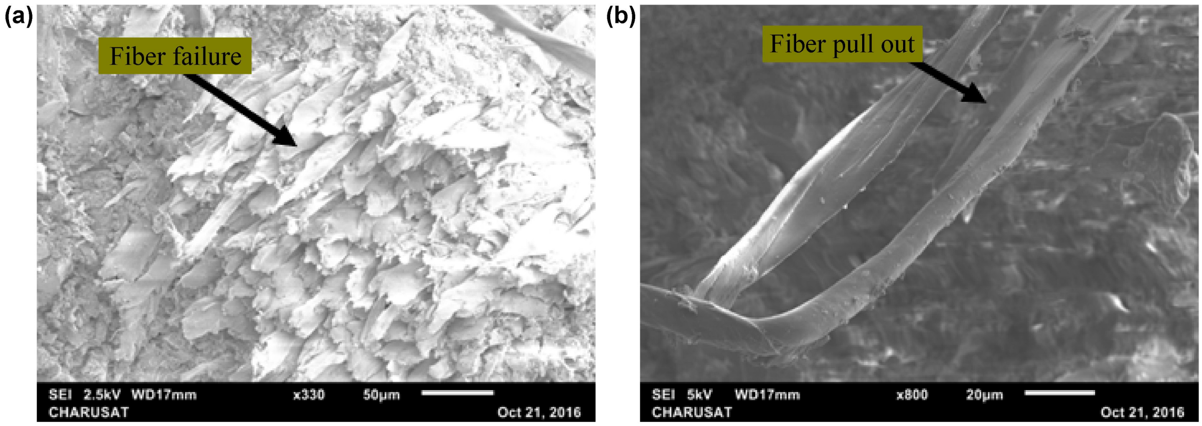

Fig. 4 Micrograph of 5GCFPC after tensile test: (a) low magnifacation and (b) high magnification.

From Fig. 2 good bonding between the resin and the fiber could be seen. This adhesion might be responsible for higher tensile strength. Figure 3 revealed that by adding 3% graphite in the CFPC, the first failure process was initiated from the matrix crack and then it was followed by the fiber failure in the direction of loading. Fiber pull out and fiber failure revealed from Figs. 4(b) and 4(a) for 5GCFPC that might be responsible for the low tensile strength of the material.

2.2 Test setup, test conditions, test parameters and design of experiments

To perform the wear test on the CFPCs, a pin-on-disc (POD) test setup (supplied by DUCOM, Bangalore) was used at CHARUSAT, Changa, Gujarat and it was shown in Fig. 5. The specimen was kept stationary against the disk and the counterface rotated. The load was functional through the lever mechanism.

The detailed experimental conditions were listed in Table 4. The specimen surfaces were prepared by rubbing them on different grade emery paper followed by acetone cleaning. The average surface roughness for the specimens before and after the test was measured with a Taylor Hobson Roughness tester and listed in Table 5.

Response surface methodology (Box Behnken method) was used to reduce the number of experiments in an organized way.

3 Results and discussion

3.1 Wear data from pin-on-disc machine

The operating parameters were set on the POD machine and experiments were performed. The wear response of composite materials was plotted from the POD machine and listed in Table 6.

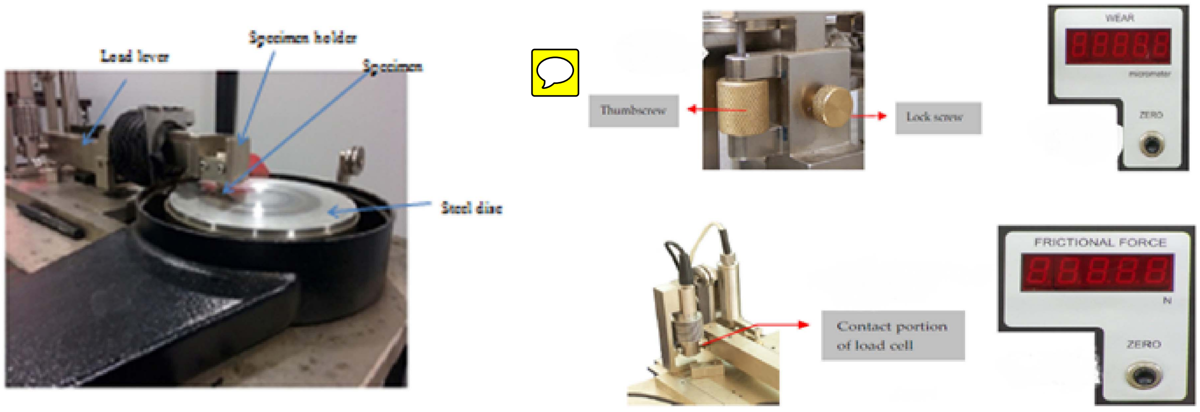

Fig. 5 Pin-on-disc wear test rig.

Table 4 Experimental conditions.

Parameters	Operating Conditions
Temperature	Ambient conditions (temperature: 29 °C)
Relative humidity	55(±5)%
Test disc	Hardened ground steel (EN-31, hardness 60 HRC)
Roughness of EN-31	1.6 m Ra
Duration of rubbing	600 s
Surface condition	Dry
Load	2 kg, 3 kg, 4 kg
Sliding speed	1.66 m/s, 2.49 m/s, 3.33 m/s
Sliding distance	1,000 m, 1,500 m, 2,000 m
Pin Material	Cotton fiber polyester composites (CFPC), 5 wt.% graphite cotton fiber polyester Composites (5GCFPC), 3 wt.% graphite cotton fiber polyester composites (3GCFPC).
Pin size (ASTM G99 Std.)	30 mm × 10 mm × 10 mm
The average contact pressure between the disc and specimen surface	0.3 MPa

Table 5 Surface roughness of test specimen.

Material	Average surface roughness Ra (μm)	
	Before test	After test
CFPC	1.45	1.7
3GCFPC	2.166	3.2
5GCFPC	1.7	2.2

Table 6 Observed data from POD.

Operating parameters					CFPC	3GCFPC	5GCFPC
Exp. No.	Sliding speed (m/s)	Load (kg)	Contact pressure (MPa)	Sliding distance (m)	Wear (micron)	Wear (micron)	Wear (micron)
1	2.49	2	0.2	1,500	42	54	36
2	3.33	4	0.4	2,000	23	56	34
3	3.33	2	0.2	2,000	37	30	28
4	2.49	3	0.3	1,500	37	38	40
5	3.33	3	0.3	2,000	40	66	30
6	1.66	3	0.3	1,000	42	47	31
7	2.49	2	0.2	1,500	30	24	43
8	1.66	2	0.2	1,000	28	23	48
9	2.49	3	0.3	1,500	29	47	32
10	2.49	4	0.4	1,500	41.2	53	26
11	1.66	3	0.3	1,000	30	25	17
12	3.33	3	0.3	2,000	22	37	25
13	1.66	4	0.4	1,000	35	35	39
14	2.49	3	0.3	1,500	29	47	32
15	2.49	4	0.4	1,500	44	69	39

3.2 Mean effects of operating parameters on response

The results of the mean wear for CFPC and graphite filled composites for different operating parameters were shown in Fig. 6.

Figures 6(a), 6(b), and 6(c) showed the effect of a normal load, speed, and sliding distance on the wear behavior of composite materials. The figures revealed by adding 5 wt.% graphite fillers wear resistance of the CFPC increased irrespective of operating parameters. Conversely, 3 wt.% of graphite fillers increased the wear of the CFPC. This finding was in agreement with Shivamurthy et al., Basavarajappa et al., and Rajesh et al. [30–32], who concluded from their studies that proper weight percentage of filler could improve the wear resistance of the materials.

To analyze the wear mechanism for the composite materials SEM analysis was performed on the wear surfaces.

3.3 Surface morphology

Figure 7(a) showed the SEM image for CFPC. It was clearly visible that good bonding between the fibers and matrix occurred. The fibers were not debonded normally from the matrix due to proper bonding. They were worn out during the wear process. Some fibers were peeled off during the wear process. Figure 7(b) revealed that 3GCFPC had undergone severe damage under the dry sliding conditions. Large

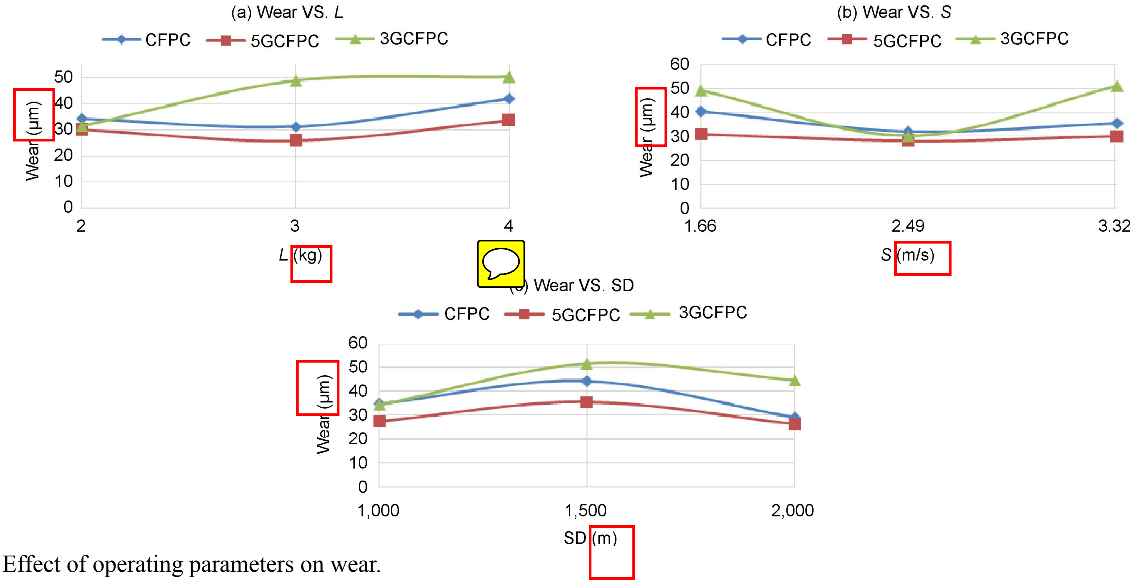

Fig. 6 Effect of operating parameters on wear.

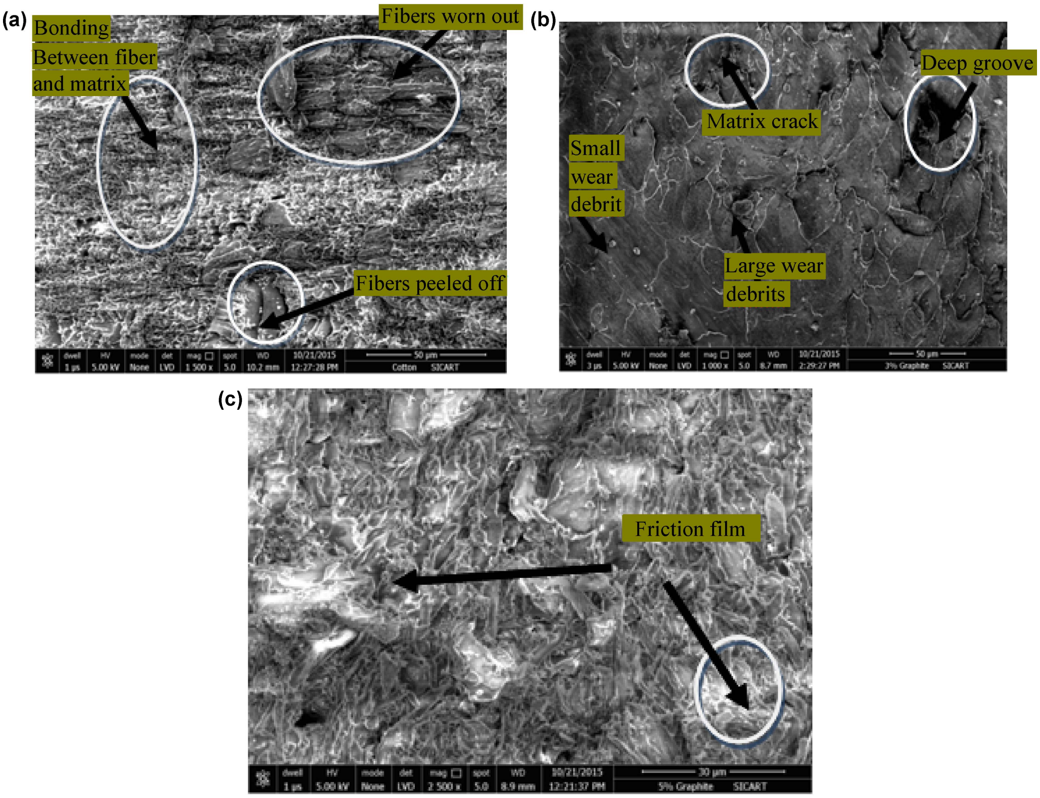

Fig. 7 Worn surface SEM analysis of (a) CFPC, (b) 3GCFPC, and (c) 5GCFPC.

and small wear debris was left over from the dry sliding condition on the worn surface of the specimen. The presence of this debris was mainly responsible for the large scale of wear. Matrix cracking was also found on the worn surface. These mechanisms were responsible for the high wear rate for 3GCFPC. Large scale disconnection of the matrix material and fibers produced several deep grooves on the specimen surface. Figure 7(c) indicated the formation of a friction film between two contact surfaces due to this less matrix cracks found and the tribological properties of a material improved in terms of less wear.

4 Regression mathematical models for wear

An ANOVA statistical tool was used with 95% confidence level with Minitab 17 software to quantify the influence of process parameters. Response surface methodology was used to create a mathematical model for wear of CFPCs. The second order general regression mathematical equations representing the relation between the wear and the input parameters (like load, speed, and sliding distance) for different materials were obtained and listed below.

CFPC

$$\text{Wear} = -22.883 - 0.108672 \times S - 19.25 \times L + 0.118664 \times \text{SD} - 0.012 \times S \times L - 0.013 \times L \times \text{SD} - 3.4 \times 10^{-5} \times \text{SD} + 0.000114 \times S^2 + 7.875 \times L^2 - 1.95 \times 10^{-5} \times \text{SD}^2 \tag{1}$$

3GCFPC

$$\text{Wear} = -243.0 + 61.13 \times L + 0.1095 \times S + 0.2080 \times \text{SD} - 0.05200 \times L \times S - 0.000090 \times S \times \text{SD} + 0.00650 \times L \times \text{SD} - 3.750 \times L^2 + 0.000132 \times S^2 - 0.000052 \times \text{SD}^2 \tag{2}$$

5GCFPC

$$\text{Wear} = -174.05 + 0.11238 \times S + 10.91 \times L + 0.11435 \times \text{SD} - 0.020800 \times S \times L - 0.000038 \times S \times \text{SD} + 0.000010 \times S^2 + 1.145 \times L^2 \times 0.000028 \times \text{SD}^2 \tag{3}$$

where L= load, S = Speed, and SD = Sliding distance.

The coefficient of determination (R^2) obtained for different models was listed in Table 7. It represented the ratio of variability explained by the model to the total variability in the actual data. Larger values of adjusted R^2 suggested models of greater predictive ability. Table 7 showed that all models satisfy this condition. All the response predicted R-sq values were in agreement with the adjusted R-sq values. This indicated the capability of the model was used effectively.

Table 7 Anova for the response surface.

	CFPC	3GCFPC	5GCFPC
R-sq	99.67%	99.82%	99.65%
R-sq (adjusted)	99.07%	99.57%	99.03%
R-sq (predicted)	94.69%	98.45%	94.44%

5 Configuration of artificial neural network (ANN)

The process of creating an artificial neural network (ANN) for the present research work was summarized in the following steps:

1. Collect the data and prepare the database: With the help of POD machine wear for the three different materials (CFPC, 3GCFPC, and 5GCFPC) was obtained. Box Behnken gave 15 design of experiments for the each material. Total 45 different wear values with one replica that is total 90 wear data were obtained for the three different materials.

2. Train the network: In this step network architecture, training functions and training algorithms for the network were required to select. The ANN model developed in the present research work was created using a MATLAB R13 software package. This package allowed the modification of the network architecture, such as generalized regression, Hopfield and feedforward backpropogation. Also the design parameters like number of neurons in each layer, number of hidden layers, neurons in the hidden layer, learning rate and momentum could be modified. Although this package offered a mixture of possible modification to the network design, not every modification was investigated. The work mainly focused on developing an ANN model for the wear instead of addressing an optimum network design. In the present work 72 data points (80%) were used for training/calibration and the remaining 18 data points (20%) were used for testing. The calibration/training data set and testing data set were selected randomly from the entire population. The schematic configuration of ANN was shown in the Fig. 8. Table 8 showed the design parameters used to train the network. The network was trained with a

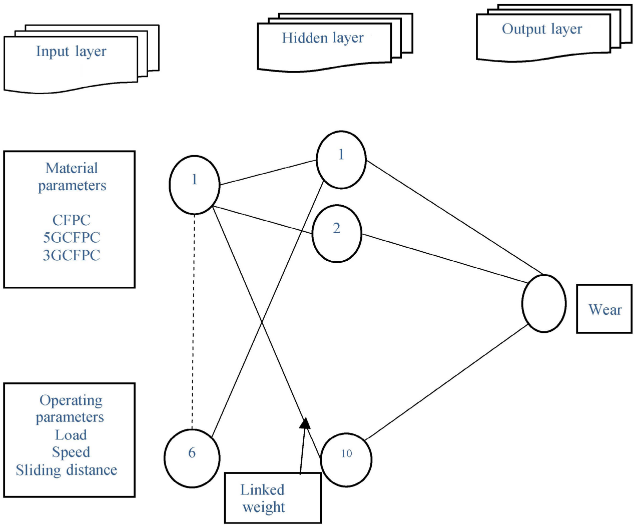

Fig. 8 Schematic configuration of ANN.

Table 8 Design parameters to train the network.

Design parameters	
Network type	Feed forward backpropogation algorithm
Training function	Train scaled conjugate gradient (TRANSCG)
Learning function	Gradient decent method (LEARNGDM)
Performance function	Mean square error (MSE)
No. of hidden layer	01
Neurons in the hidden layer	10

satisfactory coefficient of determination R = 0.99281 and was shown in the Fig. 9. For a better prediction the R value should be near 1. This network was used to simulate the test results.

3. Test the trained network: This was used to evaluate the network performance. After training the network, it was simulated for the test data in the same knowledge domain. For the testing total 18 data sets were used. Table 9 showed the simulated results with the ANN. A negative sign of the difference indicated underfitting the network while a positive sign indicated overfitting the network.

Table 9 Simulated results with ANN.

Exp. No.	Experimental wear	Predicted wear with ANN	Difference
1	39	32.594	6.406
2	29	28.9987	0.0013
3	52	43.9037	8.0963
4	39	42.6385	–3.6385
5	32	31.9995	0.0005
6	39	45.5757	–6.5757
7	35	44.6696	–9.6696
8	47	46.9988	0.0012
9	69	77.5934	–8.5934
10	39	32.594	6.406
11	29	28.9987	0.0013
12	52	43.9037	8.0963
13	39	42.6385	–3.6385
14	32	31.9995	0.0005
15	39	45.5757	–6.5757
16	35	44.6696	–9.6696
17	47	46.9988	0.0012
18	69	77.5934	–8.5934

4. Use the trained ANN for simulating and predicting the wear behavior for new domain data set: To simulate the network conformation experiments were performed. Table 10 showed the selected input parameters and wear test results obtained from POD, ANN and regression equations. The test results were evaluated in terms of mean fitting error and mean average percentage deviation. The mean fitting error showed the overfitting for the ANN model and underfitting for the regression model. From the mean percentage deviation the ANN was an effective tool to predict the wear behavior of the material compare to the regression model.

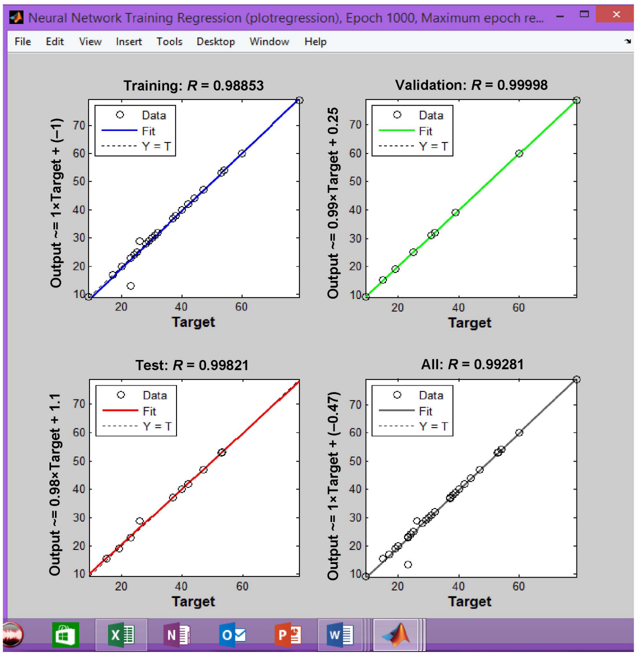

Fig. 9 Cofficient of Determination obtained by training a network.

6 Conclusion

Experimental investigation and prediction of wear behavior of CFPC were summarized in the following points:

- The experimental results indicated that proper wt.% fillers had a considerable effect on controlling the wear rate of the material. The objective of the study was to identify the effect of the filler weight percentage of wear response of materials. It was observed from the results that adding graphite

Table 10 Conformation test data set and test results.

Exp. No.	CFPC	3GCFPC	5GCFPC	S (m/s)	L (kg)	SD (m)	Actual wear from POD	Predicted wear from ANN	Predicted wear from regression
1	1	0	0	1.25	3	750	33	30	29
2	0	0	1	1.67	4	1,000	34	32	40
3	0	0	1	2.49	3	1,500	33	31	43
4	0	1	0	2.49	2	1,500	42	45	40
5	0	1	0	3.33	4	2,000	80	76	70
6	0	0	1	2.49	3	1,500	37	42	50
Mean absolute deviation $= \sum_{i=1}^{16}\left(\frac{\lvert M_i - P_i\rvert}{n}\right)$								3.166667	7.5
Mean fitting error $= \sum_{i=1}^{16}\left(\frac{\lvert M_i - P_i\rvert}{n}\right)$								0.6 (indicates over fitting model)	–2.16 (indicates under fitting model)
Mean average percentage deviation $= \left\{\frac{1}{n}\left(\sum_{i=1}^{16}\left(\frac{\lvert M_i - P_i\rvert}{M_i}\right)\times 100\right)\right\}$								9.336774	18.74

where M_i is measured wear and P_i is predicted wear.

5 wt.% wear resistance of the CFPC could increase. On the other hand, 3 wt.% graphite increased the wear of the CFPC.

- A welltrained ANN was created with a mean square error of 0.99281. The conformation test results revealed the ANN to be an effective tool that predicted the wear behavior of the material over a general regression model.
- Furthermore, the well trained neural network could be applied to predict the wear without performing long and costly experiments.

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