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**Research paper**

# Experimental evaluation and estimation of frictional behavior of polymer matrix composites

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**Abstract**

As the fiber-reinforced polymer matrix composites give good strength and can work in rigorous environmental conditions, nowadays, more focus is given to study the behavior of these materials under different operating conditions. Due to the environmental concern, the focus on the natural fiber reinforced polymer matrix composite is enhancing both in research and industrial sectors. Currently, the focus has been given to unifying solid fillers with the polymer matrix composite to improve their mechanical and tribo properties. Aligned to this, the present work discusses the effect of various weight fractions of fillers (Flyash, SiC, and graphite) on the frictional behavior of natural fiber (cotton) polyester matrix composites. The specimen prepared with a hand lay-up process followed by compression molding. A plan of experiments, response surface technique, was used to obtain a response in an organized way by varying load, speed, and sliding distance. The test results reveal that different weight concentration of fillers has a considerable result on the output. The frictional behavior of materials evaluated by general regression and artificial neural network. The validation experiment effects show the estimated friction by using the artificial neural network was closer to experimental values compare to the regression models.

## 1. Introduction

Polymer matrix composites (PMC) have shown a huge possibility due to their low cost, good lubricating properties, and low weight to strength ratio [1]. Many researchers have reported that the Tribo behavior of polymer materials is enhanced by adding natural fiber into the matrix; however, this behavior depends on the fiber orientation, length, volume fraction, fiber size, and test conditions like load, speed, and temperature [2]. The research work and applications of natural fiber polymer composite (NFPC) materials are gradually increasing mainly due to environmental concerns. The dimensional shape and friction behavior of NFPC can improve by adding fillers. The change in the friction behavior of NFPC by adding fillers has shown a great importance and research interest. Most of all mechanical elements in motion are experiencing friction, which leads to the mass loss of the materials. Many researchers worked on the NFPC to identify the friction behavior of the materials.

Hashmi et al. [3] worked on cotton fiber polyester resin with graphite filler composites with varying load and sliding distance. They observed that the coefficient of friction (COF) of the material is higher for the graphite filled material compared to the unfilled one. Yousif et al. [4] observed friction behavior of untreated and treated oil palm polyester composites and revealed that COF of the material decreases with increasing load for treated fiber. Yousif et al. [5] worked on coir fiber reinforced polyester composites and analyzed the COF of material with varying load and sliding distance. They revealed that the COF of the material increases with the increasing load condition. Nirmal [6] worked with the treated betel fiber reinforced polyester composites with varying load and sliding distance and proved that the COF of the material decreases with the increasing load condition. Narish et al. [7] observed that COF of treated kenaf fiber reinforced polyurethane with varying load, sliding distance, and fiber orientation. The study came to the conclusion that COF of the material decreases with the increasing load condition, and fiber orientation has a significant effect on the friction behavior of the material. Bajpai et al. [8] worked on the sisal fiber-reinforced polymer composites and revealed that the COF of the material decreases with the load. Shalwan and Yousif [9] and Ibrahem [10] worked on natural fiber reinforced polymer matrix composites and used graphite as filler material. Both the studies came to the same conclusion that with an increase in graphite filler, the COF of the material reduces.

The literature shows many studies on friction behavior of NFPC, but less work found natural fibers with the fillers. As friction process leads to material loss, this study focuses on the effect of fillers on the frictional performance of the natural fiber (cotton) polyester matrix composites.

To estimate the response performance of the composites, different techniques like Taguchi method, regression modeling, response surface methodology (RSM), artificial neural networking (ANN), particle swarm optimization (PSO), fuzzy logic, and gray-relations were used. There have been a number of researchers worked with different techniques to estimate the response behavior of composite laminates listed in Table 1.

Over the years, it has been a well-known fact that ANN has found substantial application in pattern recognition, function approximation, signal processing, and system identification [19]. Reports suggested that ANN is an effective tool for predicting the tribo performance of the composites [20, 21].

In the present work, evaluation and estimation of frictional behavior of the cotton fiber reinforced composite material, and comparisons were made between general regression statistical techniques and artificial neural network.

## 2. Materials and methods

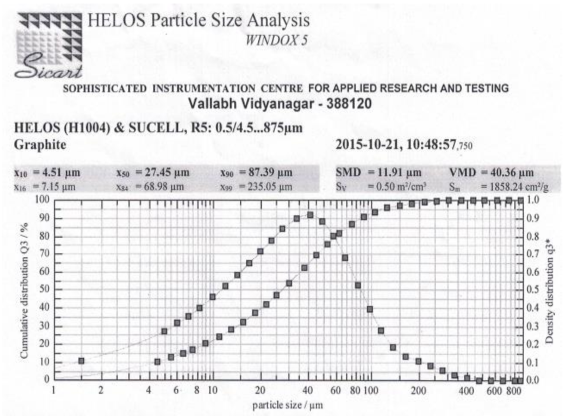
### *2.1. Specimen preparation*

Cotton yarns were used as reinforcement due to their wide application areas like bearings, gears, pulleys, rollers, and guides (Kamath et al. [22], Kamath [23]). The unsaturated polyester resin was used as the binder due to its low cost and ease of binding at room temperature. The graphite (11.91 µm), fly ash (4.42 µm), and SiC (166.51 µm) were used as fillers with 0 wt.%, 3 wt.%, and 5 wt.%, respectively.

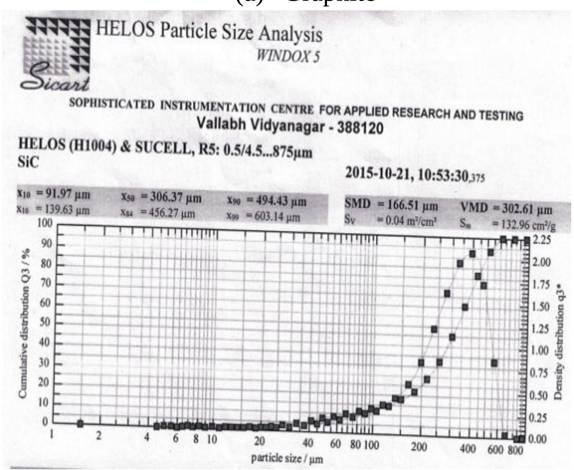
**Table 1.** Different researches for evaluating the behavior of FRP composites.

| Author | Study |
|---|---|
| Tharazi et. al. [11] | Tensile strength of kenaf fiber reinforced polylactic acid (pla) with a response surface approach |
| Mahesh et. al. [12] | Tensile, impact, and flexural strength of glass fiber reinforced composites with Taguchi approach |
| Vamsi Krishna et. al. [13] | Tensile strength of hybrid metal matrix composites with the SiC and graphite fillers with fuzzy logic. |
| Koronis et al. [14] | Strength of woven flax epoxy composites with the full factorial approach |
| Balak et al. [15] | Strength of synthetic fibers with chopped carbon fiber using Taguchi approach |
| Aymerich & Serra [16] | Fatigue strength of composites with artificial neural network |
| Haque & Sudhakar [17] | Corrosive fatigue behavior of steel using artificial neural network |
| Veeresh Kumar & Pramod [18] | Tribo behavior of SiC filled al matrix composites using artificial neural network |

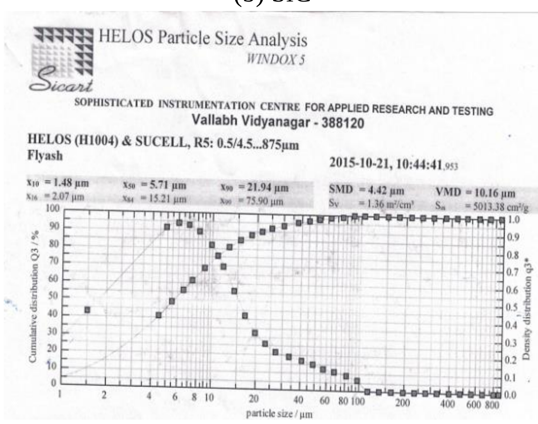
To determine the filler size, a particle size test was done on the fillers with the help of particle size analyzers, the test results were shown in Fig. 1.




(a) Graphite




(b) SiC



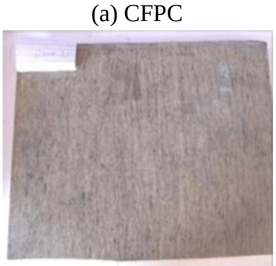

(c) Fly ash

**Fig. 1**. The results of particle size analyzer test on fillers.

The hand layup followed by the compression molding manufacturing process was used to prepare the composite material. The composition and weight fraction of the different fillers in the cotton fiber polyester composites are listed in Table 2. The composite was cured at room temperature under 50 KPa for 24 hrs. Composites of size 300 × 300 mm$^2$ were prepared using the hand lay technique and shown in the Fig. 2.
Coefficient of friction for all materials evaluated on pin-on-disc tribo apparatus. The disc body is made from EN - 31 steel with 62 HRC hardness and 0.62 Ra roughness. The tests were conducted by selecting load, speed, and sliding distance as the input variables.

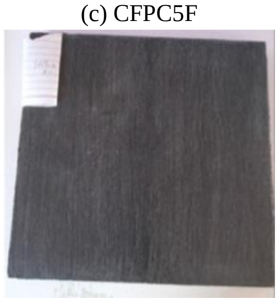
(a) CFPC

(b) CFPC5G

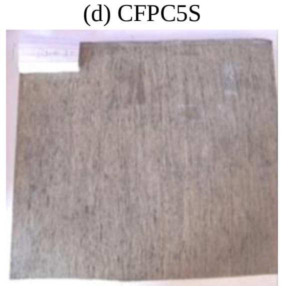


(c) CFPC5F

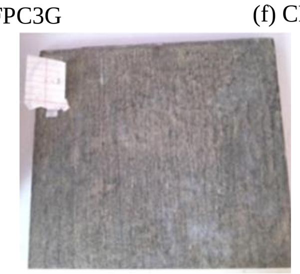
(d) CFPC5S



(e) CFPC3G



(f) CFPC3F



(g) CFPC3S

**Fig. 2**. Composite plates.

**Table 2**. Compositions of CFPC.

| Material | Fillers (wt.%) | Resin (wt.%) | Fiber (wt.%) |
|---|---|---|---|
| CFPC | 0 | 80 | 20 |
| CFPC5G | 5 | 75 | 20 |
| CFPC5F | 5 | 75 | 20 |
| CFPC5S | 5 | 75 | 20 |
| CFPC3G | 3 | 77 | 20 |
| CFPC3F | 3 | 77 | 20 |
| CFPC3S | 3 | 77 | 20 |

### *2.2. Pin on disc test setup and experimental conditions*

The cotton fibers kept in normal to the load condition, and the surface (10 mm ×10 mm) of the composites specimen rubbed over the counter surface. The specimen was rubbed on different grade emery paper for proper surface contact before performing each experiment.
Test conditions used for the experiments are listed below:
1. Temperature: 30 °C ambient conditions
2. Relative humidity: 50 (± 5) %
3. Time for rubbing of each specimen: 10 min
4. Pin size: 30 × 10 × 10 $mm^3$
The friction behavior of the materials noted as a function of load (L), velocity (S), and sliding distance (SD), as operating parameters, was studied as a function of different weight concentration of fillers, as material parameters. The operating parameters with their different levels are shown in Table 3. To cut down number of experiments in a systematic way, RSM was used with Minitab 17 software. The RSM method gives an advantage to include curvature effects in the response behaviour.

### *2.3. Design of experiments*

The experiments were planned as per the Box Behnhken (BB) design approach as there were three factors at the three levels, and the extreme limits of the factors were unknown. This method gives an advantage in terms of less number of experiments. A total of 15 numbers of experiments were selected, including 3 centre points shown in Table 4.

## 3. Results and discussion

All the experiments were performed on a pin on disc machine. On conducting the experiments as per Box-Behnken method, the coefficient of friction results for various materials was obtained and shown in Table 5.
By considering load as the most influenced parameters, the average COF for all the materials was calculated and plotted in Fig. 3. It reveals the COF of CFPC in the range of 0.3 to 0.4 (medium-range), which may be due to the fair bonding between the fiber and matrix, as the SEM image of CFPC (Fig. 4) reveals. In good bonding between fiber and matrix, high force is required to initiate the sliding process. By adding 3 wt.% graphite, COF was observed in the range of 0.9 to 1 (high range); on the other hand, by increasing the weight percentage of graphite, COF was noted in the same range as CFPC.
The SEM image of CFPC3G (Fig. 5) reveals a very hard structure. As the material has a hard structure, a higher amount of friction force is required to start the sliding process. This may be the reason to get COF in the higher range for CFPC3G.
The SEM image of CFPC5G (Fig. 6) shows the fair bonding between fiber and matrix and good spreading of graphite particles. As the graphite has well lubricating properties, the COF of the material was found in the medium range.

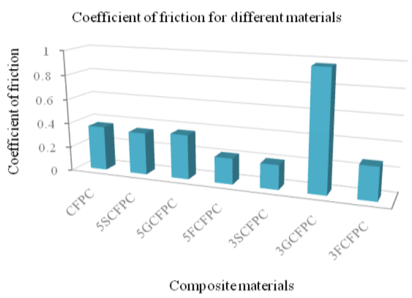



**Fig. 3**. Coefficient of friction of fillers filled CFPC.

**Table 3.** Operating variables with their three levels

| Parameters | Levels | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| S (m/s) | 1.7 | 2.5 | 3.3 |
| L (N) | 20 | 30 | 40 |
| SD (m) | 1000 | 1500 | 2000 |

**Table 4.** Design of experiments with box behnken

| Run | Load | Speed | Sliding distance |
|---|---|---|---|
| 1 | -1 | -1 | 0 |
| 2 | -1 | 1 | 0 |
| 3 | 1 | -1 | 0 |
| 4 | 1 | 1 | 0 |
| 5 | -1 | 0 | -1 |
| 6 | -1 | 0 | 1 |
| 7 | 1 | 0 | -1 |
| 8 | 1 | 0 | 1 |
| 9 | 0 | -1 | -1 |
| 10 | 0 | -1 | 1 |
| 11 | 0 | 1 | -1 |
| 12 | 0 | 1 | 1 |
| 13 | 0 | 0 | 0 |
| 14 | 0 | 0 | 0 |
| 15 | 0 | 0 | 0 |

By adding 3 wt.% SiC, COF of the CFPC reduced and was found in the lower range (0.1 to 0.2); conversely, with the addition of 5 wt.% SiC, COF showed in the same range as CFPC. The SEM image of CFPC3S (Fig. 7) shows the poor distribution of fillers due to less amount of filler content. This leads to the voids in the structure and gives less COF. While yhe SEM image of CFPC5S (Fig. 8) reveals good interfacial bonding with fair dispersion of particles. This bonding leads to higher COF of the material. By adding 3 wt.% fly ash, COF of the CFPC was found in the medium range (0.2 to 0.3); on the other hand, the addition of 5 wt% fly ash showed the COF in the lower range (0.1 to 0.2). As the fly ash weight percentage increased, COF reduced, which may be due to the good lubricating effect of fly ash. The SEM image of CFPC3F (Fig. 9) reveals good bonding between the fiber and the matrix, leading to quite a high friction force requirement, while that of the CFPC5F (Fig. 10) shows fair uniform dispersion of the fillers, which leads to a reduction in the friction force.

The influence of different weight concentration of fillers and the percentage contribution of each factor to the response was identified. The regression technique was used to form mathematical equations of the coefficient of friction for different materials.

## 4. Regression mathematical models for friction

ANOVA was performed to investigate the control of each variable and their interaction effect on the total variation of the results. Table 6 reveals the results of ANOVA for the COF of the different composite materials. The ANOVA was done with a 95% confidence level. The table reveals the percentage contribution of each variable and their interaction on the response.

**Table 5.** Experimental results of friction test

| Exp. No. | DOE (BB Method) | | | CFPC | CFPC3G | CFPC3S | CFPC3F | CFPC5G | CFPC5S | CFPC5F |
|---|---|---|---|---|---|---|---|---|---|---|
| | S | L | SD | Coefficient of friction | | | | | | |
| 1 | 2.5 | 20 | 1500 | 0.362 | 0.300 | 0.25 | 0.21 | 0.65 | 0.46 | 0.16 |
| 2 | 3.3 | 40 | 2000 | 0.443 | 0.272 | 0.22 | 0.28 | 0.47 | 0.39 | 0.06 |
| 3 | 3.3 | 20 | 2000 | 0.525 | 0.555 | 0.02 | 0.40 | 0.45 | 0.27 | 0.17 |
| 4 | 2.5 | 30 | 1500 | 0.306 | 0.570 | 0.24 | 0.07 | 0.36 | 0.37 | 0.16 |
| 5 | 3.3 | 30 | 2000 | 0.374 | 0.443 | 0.25 | 0.29 | 0.30 | 0.14 | 0.06 |
| 6 | 1.7 | 30 | 1000 | 0.262 | 0.276 | 0.16 | 0.30 | 0.27 | 0.21 | 0.13 |
| 7 | 2.5 | 20 | 1500 | 0.336 | 0.275 | 0.18 | 0.29 | 0.46 | 0.55 | 0.28 |
| 8 | 1.7 | 20 | 1000 | 0.392 | 0.300 | 0.30 | 0.21 | 0.33 | 0.24 | 0.27 |
| 9 | 2.5 | 30 | 1500 | 0.306 | 0.570 | 0.24 | 0.07 | 0.36 | 0.41 | 0.21 |
| 10 | 2.5 | 40 | 1500 | 0.410 | 0.350 | 0.25 | 0.46 | 0.32 | 0.50 | 0.29 |
| 11 | 1.7 | 30 | 1000 | 0.292 | 0.316 | 0.24 | 0.25 | 0.43 | 0.53 | 0.25 |
| 12 | 3.3 | 30 | 2000 | 0.499 | 0.266 | 0.22 | 0.06 | 0.52 | 0.16 | 0.45 |
| 13 | 1.7 | 40 | 1000 | 0.280 | 0.250 | 0.20 | 0.23 | 0.09 | 0.36 | 0.40 |
| 14 | 2.5 | 30 | 1500 | 0.306 | 0.570 | 0.24 | 0.07 | 0.36 | 0.41 | 0.41 |
| 15 | 2.5 | 40 | 1500 | 0.344 | 0.422 | 0.15 | 0.23 | 0.24 | 0.32 | 0.04 |

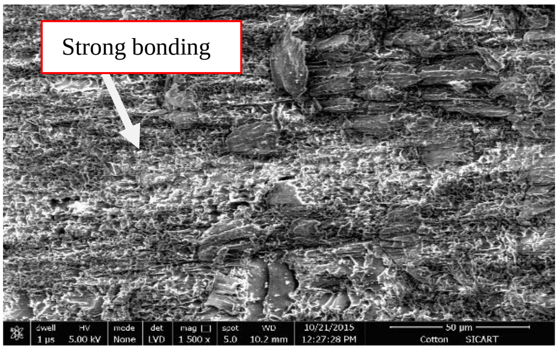


**Fig. 4.** SEM image of CFPC.

**Fig. 5**. SEM image of CFPC3G.

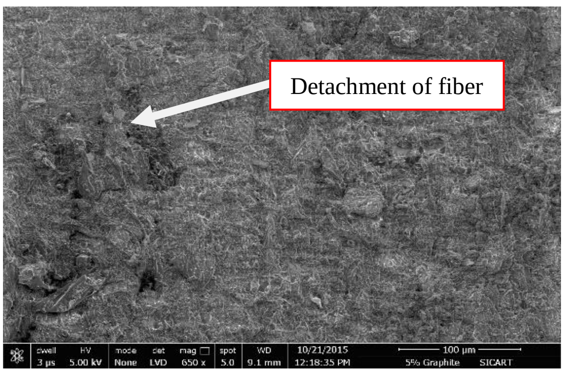


**Fig. 6.** SEM image of CFPC5G

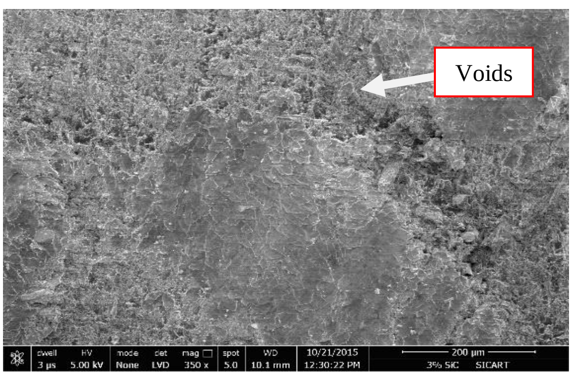


**Fig. 7.** SEM image of CFPC3S

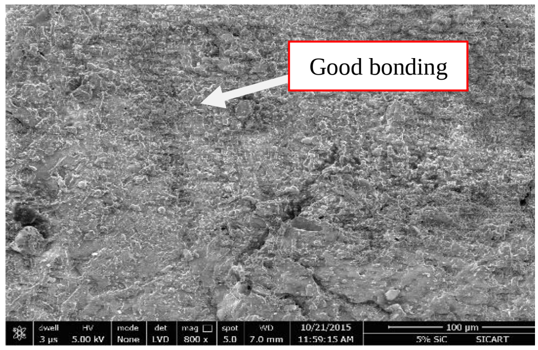


**Fig. 8.** SEM image of CFPC5S

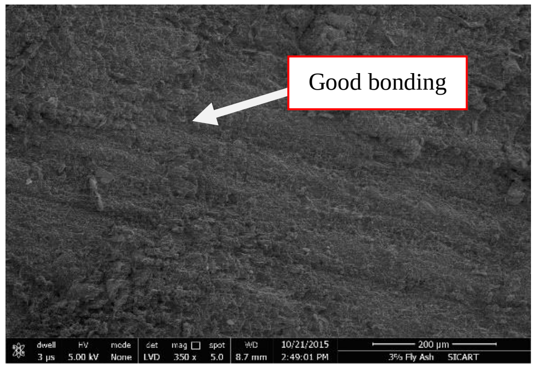


**Fig. 9.** SEM image of CFPC3F.

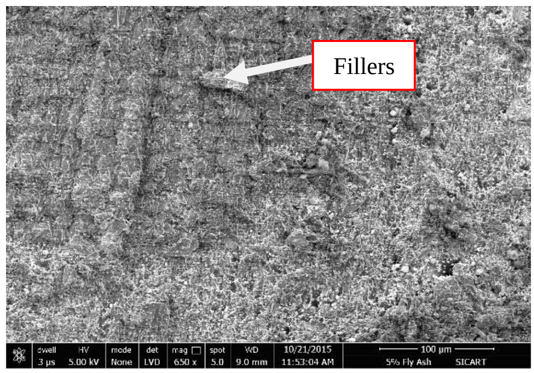


**Fig. 10.** SEM image of CFPC5F.

Table 6 also reveals that the main parameters and interactions between the parameters have a considerable effect on the COF of CFPCs. Load, speed, and interaction between the loads have a quite high percentage contribution on the COF for most of the materials compared to other parameters. It indicates that as the applied load increases, the COF also increases for most of the materials. This may be due to the fact that as the load increases, more asperities between two matching surfaces come in contact with each other, which leads to an increased friction force.

The ratio of changeability obtained by the model to the total changeability in the main data is called the coefficient of determination ($R^2$). The higher the value of $R^2$ adjusted, the higher the predictive ability. Table 7 shows the ANOVA for response surface for all the materials. The table shows that for all the materials, $R^2$ predicted values are in accord with the $R^2$ adjusted.

Second-order general regression mathematical model for the coefficient of friction with the different input parameters was obtained by Minitab software and listed below:

**CFPC**

COF = - 0.43796 + 0.001183 S + 0.19533 L+ 0.000034 SD - 0.000001 S*S + 0.000000 S*SD - 0.036276 L*L (1)

**CFPC5G**

COF = 0.590 - 0.001241 S - 0.1283 L + 0.000531 SD + 0.000000 S*SD + 0.000001 S*S - 0.000000 SD*SD + 0.000044 L*SD - 0.000067 S*L (2)

**CFPC5S**

COF = 0.53 - 0.000523 S - 0.005957 L + 0.002039 SD + 0.1014 L*L + 0.000000 S*SD - 0.000001 SD*SD (3)

**CFPC5F**

COF = 0.760 - 0.001109 S - 0.0633 L + 0.000024 SD + 0.000370 S*L – 0.000161 L*SD + 0.000001 S*SD – 0.000000 S*S (4)

**CFPC3G**

COF = -2.582 + 0.002132 S + 0.671 L + 0.001844 SD - 0.000002 S*S – 0.1135 L*L - 0.000001 SD*SD (5)

**CFPC3S**

COF = 0.3806 + 0.000407 S - 0.0211 L - 0.000334 SD + 0.000088 L*SD – 0.000000 S*S - 0.01953 L*L (6)

**CFPC3F**

COF = 2.999 - 0.002980 S - 0.670 L - 0.001117 SD + 0.000180 S*L + 0.000002 S*S + 0.0902 L*L + 0.000000 SD*SD (7)

where, L is the load, S is the speed, and SD is the sliding distance

## 5. Artificial neural network

The development of ANN for estimating frictional behavior of the cotton fiber-reinforced composites was shortened in following steps:

1. Collect the experimental output for the coefficient of friction for seven different materials (CFPC, CFPC5G, CFPC5S, CFPC5F, CFPC3G, CFPC3S, CFPC3F) using a Box-Behnken design approach, which gives 15 sets of experiments for the each composite.

**Table 6.** Percentage contribution of each factor on COF.

| Source | CFPC | CFPC5G | CFPC5S | CFPC5F | CFPC3G | CFPC3S | CFPC3F |
|---|---|---|---|---|---|---|---|
| | % Contribution of each factor | | | | | | |
| Regression | 99.98 | 99.08 | 97.61 | 99.12 | 90.28 | 97.93 | 91.53 |
| S | 29.83 | 12.52 | 2.56 | 8.88 | 8.63 | 32.07 | 0.01 |
| L | 14.23 | 45.74 | 0.59 | 5.69 | 0.48 | 1.14 | 0.33 |
| SD | 1.13 | 22.06 | 6.40 | 12.88 | 4.18 | 33.23 | 1.71 |
| S*L | No effect | 0.51 | No effect | 31.26 | No effect | No effect | 7.52 |
| L*SD | No effect | 0.91 | No effect | 23.08 | No effect | 25.62 | No effect |
| SD*S | 0.02 | 5.25 | 2.18 | 14.38 | No effect | No effect | No effect |
| S*S | 36.98 | 3.94 | No effect | 2.23 | 12.13 | 1.19 | 27.10 |
| L*L | 17.66 | No effect | 22.44 | No effect | 20.92 | 4.70 | 23.60 |
| SD*SD | 0.27 | 8.14 | 63.43 | No effect | 43.93 | No effect | 31.26 |
| Error | 0.02 | 0.90 | 2.39 | 0.88 | 9.72 | 2.07 | 8.74 |
| Lack-of-Fit | 0.02 | 0.92 | 2.39 | 0.88 | 9.72 | 2.07 | 8.47 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

**Table 7**. Coefficient of determination for different materials.

| | CFPC | CFPC5G | CFPC5S | CFPC5F |
|---|---|---|---|---|
| $R^2$ | 99.98% | 99.08% | 97.61% | 99.12% |
| $R^2$ Adj. | 99.95% | 97.85% | 95.83% | 98.24% |
| $R^2$ Predicted | 99.90% | 90.29% | 83.58% | 93.81% |
| | CFPC3G | CFPC3S | CFPC3F | |
| $R^2$ | 90.28% | 97.93% | 91.53% | |
| $R^2$ Adj. | 82.99% | 96.38% | 83.07% | |
| $R^2$ Predicted | 61.12% | 93.07% | 62.40% | |

With one replica for seven different composites, a total of 210 coefficient of friction values was collected.

2. Train the network: A total of 190 input data (90%) was used for training the network, and the left 20 input points (10%) were used for testing. The schematic diagram of the created ANN for training is shown in Fig. 11. The network was trained with a feed-forward backpropogation algorithm with a train scaled conjugate gradient training function with 10 neurons in a hidden layer. The trained network shows the coefficient of determination $R$ = 0.87729 shown in the Fig. 12.

3. Test the network: The network was tested/ simulated for the remaining 20 data points. Fig. 13 shows the percentage difference between the experimental and predicted friction. A negative and positive sign shows the underfitting and overfitting of the network.

To check the validity of the obtained network and regression equations, validation experiments were conducted for a new set of input parameters. The validation test results were listed in Table 8.

The test results were evaluated in terms of the mean fitting error and mean average percentage deviation. From the mean average percentage deviation, it is seen that the ANN has a good predictive ability.

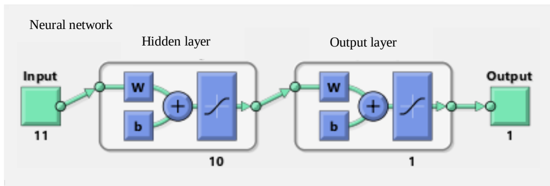



**Fig. 11.** Schematic diagram of ANN.

**Table 8.** Conformation test results for COF (P): Predicted COF from model, (E): Experimental value of COF, ANN: Predicted COF from network.

| Parameters | | | CFPC | | CFPC5G | | CFPC5S | | CFPC5F | | CFPC3G | | CFPC3S | | CFPC3F | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L | S | SD | P / ANN | E | P / ANN | E | P / ANN | E | P / ANN | E | P / ANN | E | P / ANN | E | P / ANN | E |
| 3 | 1.25 | 750 | 0.12 / 0.11 | 0.14 | | - | | - | 0.04/ 0.06 | 0.05 | | - | | | | - |
| 4 | 0.66 | 1000 | 0.12/ 0.17 | 0.15 | 0.28/ 0.30 | 0.3 | 0.48/ 0.41 | 0.42 | 0.08/ 0.07 | 0.07 | 0.33/ 0.60 | 0.40 | 0.17/ 0.25 | 0.20 | | - |
| 5 | 0.75 | 1050 | | - | 0.16/ 0.25 | 0.2 | 0.59/ 0.59 | 0.60 | | - | | - | | - | 0.23/ 0.30 | 0.28 |
| 3.5 | 0.58 | 800 | | - | | - | | - | | - | 0.28/ 0.40 | 0.35 | 0.190/ 0.235 | 0.22 | 0.29/ 0.32 | 0.30 |
| 5 | 0.66 | 850 | | - | | - | | - | | - | | - | | - | | - |

| | ANN | Regression |
|---|---|---|
| Mean fitting error | -0.17 (under fitting model) | 0.022857 (over fitting Model) |
| Mean average percentage deviation | 9.13 | 10.09818 |

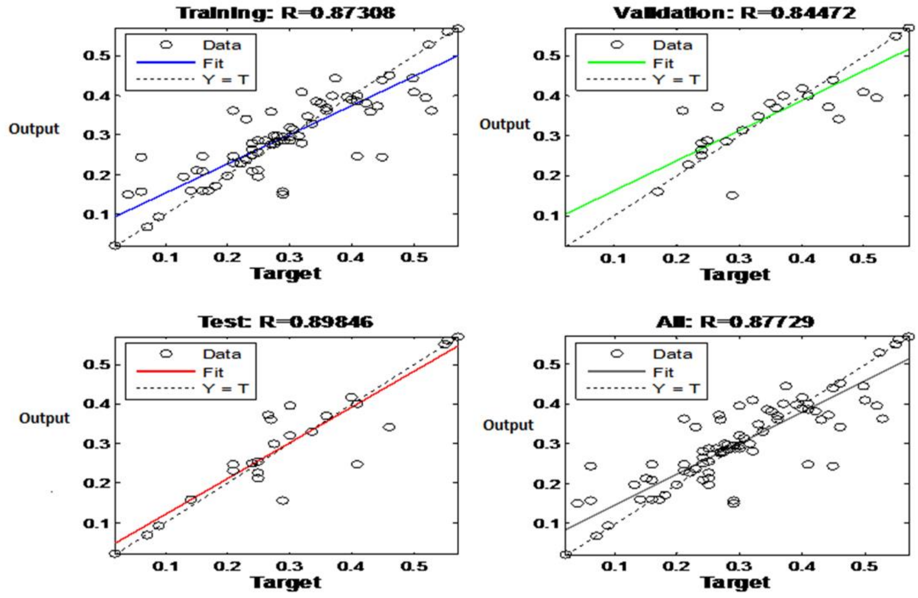



**Fig. 12.** Results of training network.

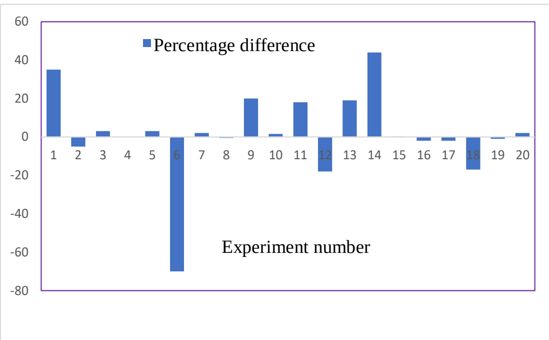



**Fig. 13.** Percentage difference between experimental and predicted friction.

## 6. Conclusions

This study evaluated and estimated the frictional behavior of polymer matrix composites, and led to the following conclusions:

- Cotton fiber reinforced polyester matrix composites filled with various weight concentration of fillers were made successfully with a quite uniform dispersion of fillers.
- Incorporation of different weight concentration of fillers has a significant effect on the coefficient of friction of the CFPCs.
- The experimental results revealed that, different weight concentrations of fillers have significant effects on COF of the material.
- The materials, which show low COF, may be used for the bearings and structural applications like opening and closing of door channels provided, and they give a low wear rate. The materials with high COF, may be used as medium strength, breaking pads, and clutch pads provided, and they give a low wear rate.
- The validation test results revealed the ANN as an effective method to estimate the frictional behavior of materials.

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