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Wear Characteristics of Hybrid Polymer Composite Manufactured by Hand Layup Technique using Fuzzy Logic Systems

Abdul Raheem[1], K.M. Subbaya[2], Vikram C.K[3] and Syed Imran Ali[4]

[1]Assistant Professor, Department of Mechanical Engineering, PESCE, Mandya 571401.
E-mail: abdulraheem3030@gmail.com
[2]Professor, Department of Industrial and Production Engineering, The National Institute of Engineering, Mysore 570008
[3]Assistant Professor, Department of Mechanical Engineering, PESCE,Mandya 571401
[4]Assistant Professor, Department of Mechanical Engineering, PESCE,Mandya 571401

Abstract

Synthetic fiber reinforced composites have already been proved to be stronger and more durable. The composites are being globally used in all the possible fields like automobiles, aircraft and marine industry. The present work is an investigation on the wear behaviour of the hybrid polymer composites. In this experimental work, the carbon fibres are reinforced with vinyl ester, g-C_3N_4 and Si_3N_4 were used to obtain hybrid composite by hand layup technique. The experiments were designed according to Taguchi (L27) orthogonal array. Experiments are carried out using slurry abrasive wear testing machine to inspect the wear rate. Further, a fuzzy logic model is adopted for the estimation of sliding wear in hybrid composites by the experimental data. Results showed that estimated fuzzy logic outputs are compared to experimental results, which is very much satisfied with a mean error estimation of 0.27%, so that the fuzzy logic model can be efficiently used to compute the wear performance.

1.0 Introduction

Hybrid composites exhibit superior mechanical and tribological properties than FRP. Influence of several fillers like silicon carbide, MoS_2, and Gr were reinforced in epoxy composite coating for industrial applications. It was found that several fillers in epoxy coating considerably decrease its wear [1]. Three-body abrasive wear characteristic of carbon-epoxy composite with and without silicon carbide filler was studied by Subbaya et al.[2]. They have used Taguchi L27 orthogonal array, by using grey relational analysis, carried out the experiments and optimized the process parameters. Following results were obtained; Grain size and filler content are the influencing factor in the abrasive wear of composites. Azmi[3] conducted dry end milling experiment and Mamdani fuzzy inference system to perform fuzzy logic correlation between the machining conditions and tool life. D. Rajamani et al.[4] developed a fuzzy logic model to calculate the wear rate of selective inhibition sintered high density polyethylene and observed good agreement of experimental value with predicted value. Rajesh Prabha and Edwin Raja [5] developed a model called fuzzy logic in order to calculate the wear rate in Al composite. Results showed that good agreement with real results. Ambigai and Prabhu [6] have carried out the study on tribological behaviour of Aluminium-Graphite-Si_3N_4 hybrid composite. Aluminium-Graphite-Si_3N_4 hybrid composite was fabricated under dry sliding conditions by the stir casting method for frictional and wear characteristic. Aluminium-Graphite-Silicon nitride hybrid composite wear rate is optimum with fuzzy logic investigation compared to experimental results. Low prediction errors of Aluminium-Graphite-Silicon nitride hybrid composite is 4.27%.

Stalin examined the use of tamarind seed filler as reinforcement with vinyl ester composites. Outcome showed that there is an enhancement in physical and mechanical properties [7]. Agnivesh Kumar et al [8] built a fuzzy model for prediction of sliding wear in hybrid abaca-epoxy composites. Experimental result showed that in sliding wear, accuracy of hybrid composite is 87%. Dipen Kumar Rajak et al.[9] conducted a study on overview of composite materials, their characterization, classification, advantages, physical and mechanical properties. The new advanced manufacturing technology was used to fabricat the composites laminates when compared to conventional methods and reported that percentage of reinforcement, resin to hardener ratio, and micro/nano fillers to improve the mechanical, and tribological properties.

In this work, the objective is to predict the wear rate from fuzzy logic rule expert system for hybrid C-V composites. Using Fuzzy logic model, the experiments were conducted. The fuzzy model includes the process parameters as sliding velocity, abrading distance, applied load and percentage of fillers and response is wear rate.

2.0 Details of Experimental Work

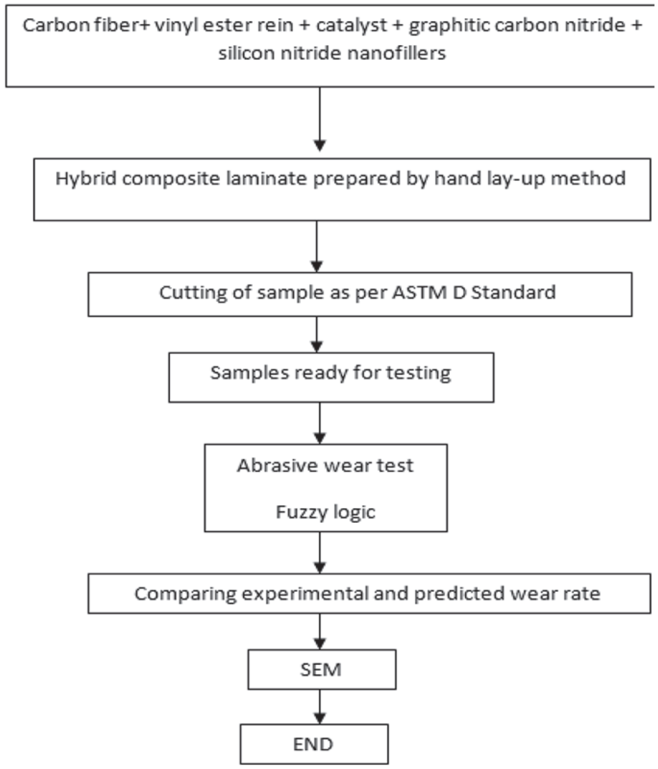
2.1. Fabrication of composite materials

In the present work, the matrix material is Vinyl ester, Methyl ethyl ketone peroxide is curing catalyst and cobalt naphthenate as accelerator are supplied by Sathyam Fibertex Tamilnadu, India. High strength carbon fiber was used as reinforcement are supplied by RPI, Bangalore. The Si_3N_4 and g-C_3N_4 supplied by Nanowings Enterprises Tamilnadu, India. The average size of g-C_3N_4 and Si_3N_4 are 10-30 nm which is used as nanofiller materials. The process begins with the addition of vinyl ester with methyl ethyl ketone peroxide at a ratio of 10:1. The fabrication was done by hand layup technique. First the silica gel is provided in order to avoid the sticking of resin with mould. Fibers were cut for a required size of 300mm x300 mm. For each layer of the carbon fiber mats, resin mixture was applied with the brush and a roller.

Table 1: Composite selected for the present work

Composite	Vinyl Ester (wt.%)	Carbon Fiber (wt.%)	g-C_3N_4 (wt %)	Si_3N_4 (wt.%)
C-V	40	60	-	-
1C-V	38	60	1	1
2 C-V	36	60	2	2

Table 2: Shows the flow chart of hybrid polymer composite



Rollers were used to eliminate any air bubbles from the mould and maintain the uniform thickness throughout. This process is repeated until the required thickness is achieved. The weight percentage of reinforcement was kept constant at 60%. Table 1 shows the details of composite selected in the present work. From the laminate using a tipped cutter, slurry abrasion wear test sample size of 75x25x6 mm^3 was prepared. Table 2 shows the flow chart of hybrid polymer composite.

2.2 Abrasive wear test

The Abrasive wear experiment was carried out using slurry abrasion test rigas per ASTM G105 standard and supplied by DUCOM Instruments

Private Limited. Test rig schematic diagram as shown in the Figure 1. The rubber wheel diameter is 178 mm and width of 12.7 mm. A combination of silica sand (212μm) with a 0.94 kg and water of 1.5 kg is fed between the sample and rotating wheel. The test specimen is pressed against a rotating wheel at a specified force by means of a lever arm while the slurry abrades the test surface. Specimen's mass loss is measured with the help of electronic balance machine before and after each test. Specific wear rate (Ks) of the specimen is calculated from equation.(1).

$$Ks = \Delta V/(LxD)\ m^3/Nm \quad \ldots (1)$$

ΔV = volume loss in m^3

L = load in N

D = abrading distance in mts.

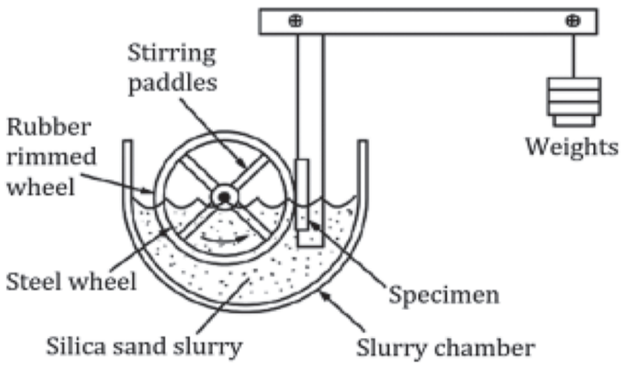


Figure 1: Schematic diagram of abrasive wear test rig.

2.3 Design of Experiments

Taguchi technique is used for conducting the experimental work and correlating the model between the input and output variable for estimation of specific wear rate. The input parameters are load, sliding distance, filler and sliding velocity. Wear rate is the output response. The set of Twenty seven experiments were carried out under cutting environment by DOE. Table 3 shows the specific wear rate parameters and levels.

Table 3: Parameters and Levels

Parameters	L1	L2	L3
Load (N)	130	170	210
Sliding distance (m)	200	400	600
Filler (wt%)	0	1	2
Sliding velocity (m/s)	0.93	1.21	1.49

3.0 Fuzzy Logic Based Modelling

Fuzzy logic is a soft computing tool which is used to solve the complex problems. Fig.2 shows the parts of fuzzy logic system. The input parameters are load, sliding distance, filler and sliding velocity. Conversion of input data into fuzzy quantities through the Fuzzifier. Based on rules to build the fuzzy logic modelling and each rule leans on the fuzzy input and then fuzzy output is achieved. Fuzzy output is transferred into the defuzzifier unit and converts the fuzzy output into crisp data. In this study, input parameters are load, sliding distance, filler and sliding velocity and output variable is wear rate which is found from experiment. Define membership functions, used in between inputs, and output response is determined. In the current work the triangular membership function is selected because of its mathematical effectiveness and its extensive use in the actual time work [10]. The experimental and predicted wear rate is shown in the Table 4.

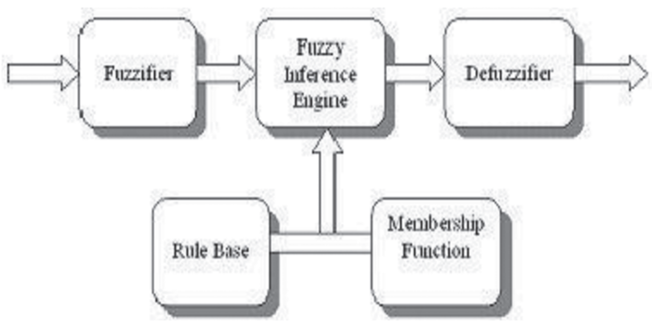


Figure 2: Components of fuzzy logic system

Fuzzy equations for I/P parameters and O/P variables are divided into 3 sets which ranges from low to high by using triangular membership function. The triangular shaped membership function for a given I/P parameter is calculated using the following expression [11].

$$Triangle\ (x; a, b, c) = \begin{cases} 0, & x \le a \\ \frac{x-a}{b-a}, & a \le x \le b \\ \frac{c-x}{c-b}, & b \le x \le c \\ 0, & c \le x \end{cases} \quad \ldots (2)$$

Where x is a variable, a, b, c represent triangular fuzzy triplet. 3 fuzzy sets are assigned for each of the input parameters as low, medium, and high. Membership function considered for sliding velocity, load, distance travelled and filler are presented in Figs.3 and 4 displays the partitions of output

Table 4

Exp. No	Sliding velocity (m/s)	Load (N)	Distance (m)	Filler (wt%)	Experimental wear rate (x10mm3/ N-m)	Fuzzy wear rate (mm3/Nm)	Error %
1	0.93	130	200	1	2.94	3.03	-3.0612
2	0.93	130	400	2	72.87	74.9	-2.7858
3	0.93	130	600	0	57.12	55.2	3.3613
4	0.93	170	200	0	35.85	34.65	3.3473
5	0.93	170	400	1	33.43	35.52	6.2519
6	0.93	170	600	2	26.98	28.85	6.9311
7	0.93	210	200	2	27.14	29.26	7.8113
8	0.93	210	400	0	25.07	26.14	4.2680
9	0.93	210	600	1	17.49	16.8	3.9451
10	1.21	130	200	1	18.79	17.8	5.2688
11	1.21	130	400	2	38.21	37.32	2.3292
12	1.21	130	600	0	14.47	13.6	6.0124
13	1.21	170	200	2	40.81	39.78	2.5239
14	1.21	170	400	0	25.58	24.48	4.3002
15	1.21	170	600	1	20.97	19.99	4.6733
16	1.21	210	200	0	56.01	50	10.71
17	1.21	210	400	1	22.12	21.25	3.9331
18	1.21	210	600	2	22.05	21.15	4.0816
19	1.49	130	200	2	34.22	33.32	2.6300
20	1.49	130	400	0	8.83	8.93	-1.1325
21	1.49	130	600	1	18.5	19	2.63
22	1.49	170	200	0	75.48	74.5	1.2984
23	1.49	170	400	1	44.81	43.90	2.0308
24	1.49	170	600	2	35.23	34.32	2.5830
25	1.49	210	200	1	57.39	56.47	1.6031
26	1.49	210	400	2	28.74	27.86	3.0619
27	1.49	210	600	0	42.63	41.73	2.1112

membership function for wear rate under chosen three fuzzy linguistic variables. Fig.5 shows rules for wear rate.

For attaining required wear rate nine conditional rules are formulated using MATLAB R 2018 fuzzy logic toolbox. The centroid defuzzification method is employed to determine the fuzzy crisp output using the following relationship [12].

$$y_o = \frac{\sum y * \left[\mu_{C_i}(y_j)\right]}{\sum \left[\mu_{C_i}(y_j)\right]} \quad \text{... (3)}$$

Where yo is defuzzified output of response variable, yj is centre value of region

4.0 Results and Discussion

The rule viewer is utilized for finding out each predicted output. For instance, by selecting the 16th experiment number, wear rate prediction through the rule viewer is presented in Fig.6. As a result, the wear rate 50 mm^3/Nm is achieved for the inputs of sliding velocity 1.21 m/s, sliding distance 200 m, filler of neat and loads of 210 N as illustrated in Fig.6.

Comparative evaluation was conducted between experimental work and predicted value which is as shown in Fig.7. It was found that average error in wear rate is 0.27% which is quite less. Hence, good

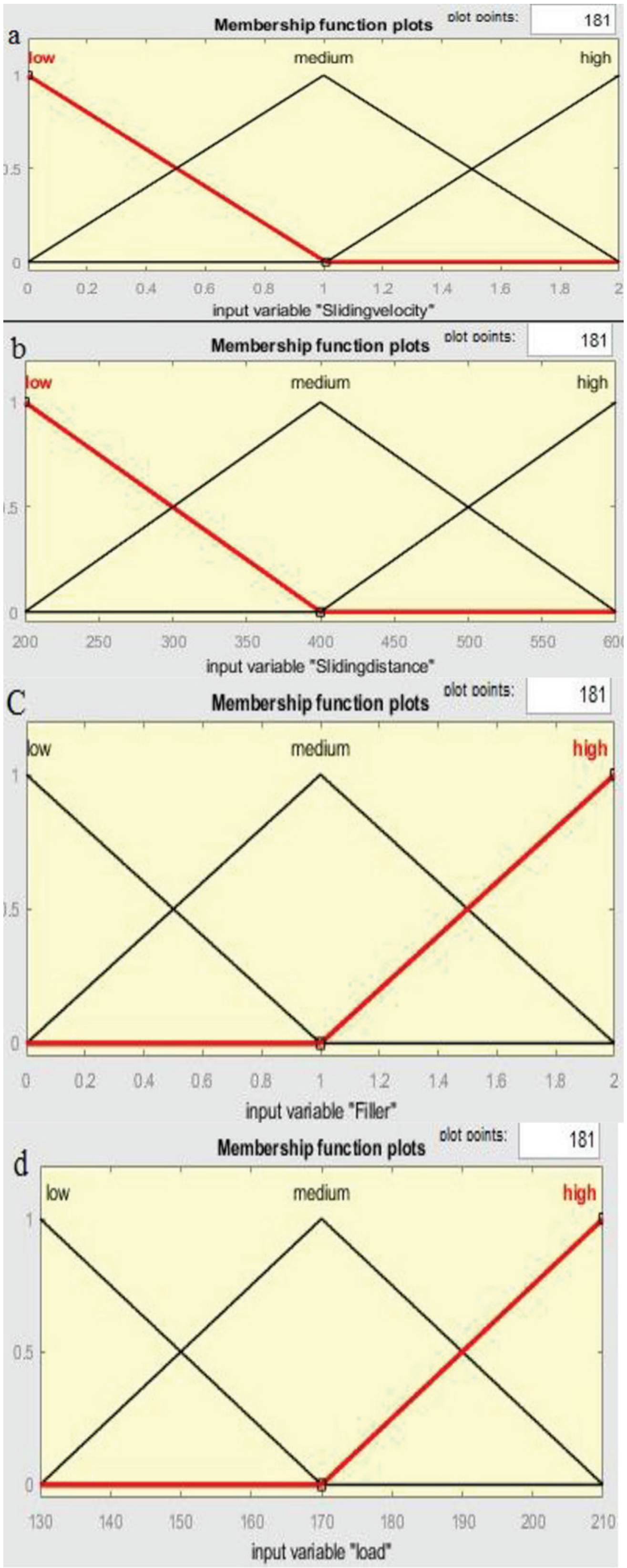


Figure 3: Membership function for input variables

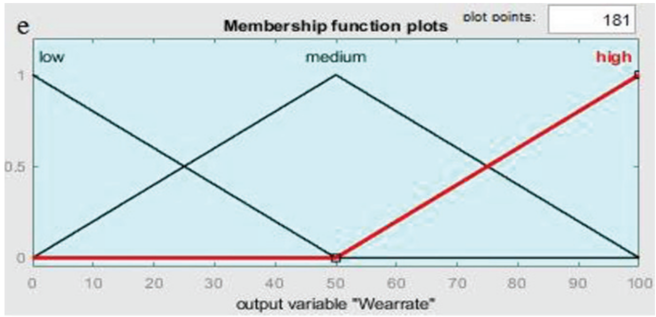


Figure 4: Membership function for wear rate

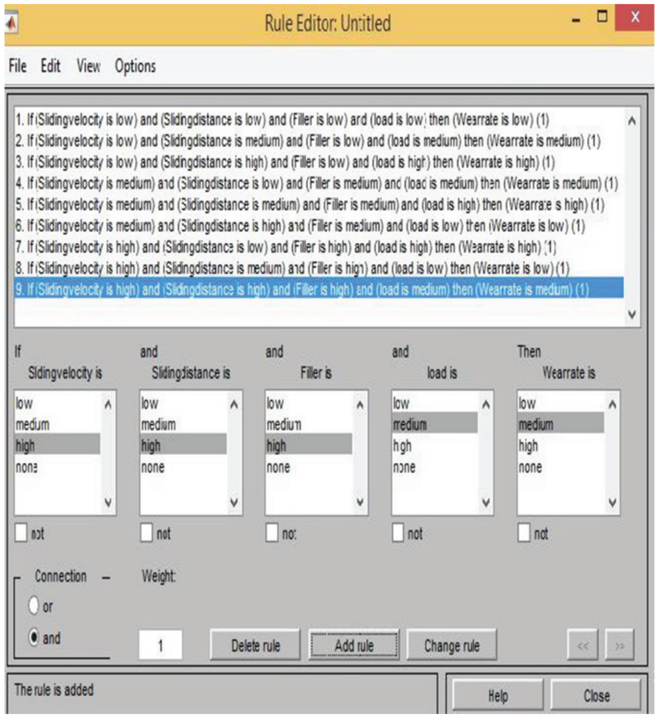


Figure 5: Rules for wear rate

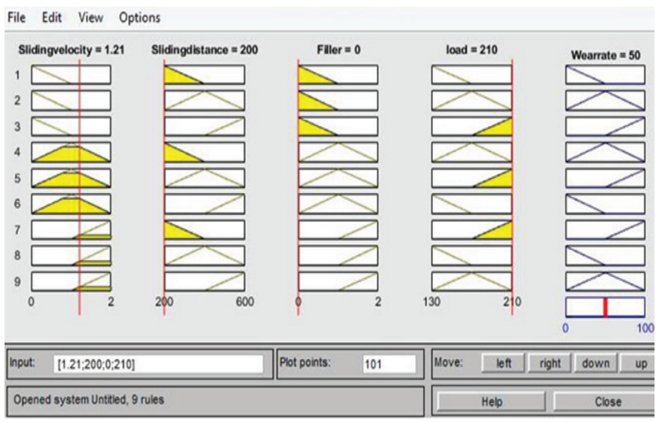


Figure 6: Wear rate prediction by rule viewer

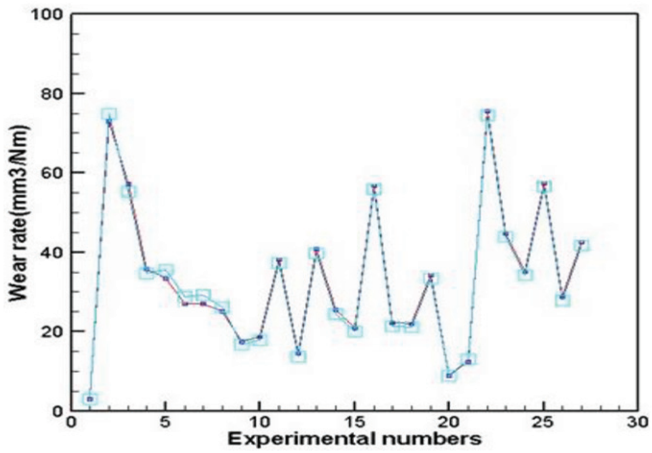


Figure 7: Relationship between experimental and fuzzy predicted values for wear rate

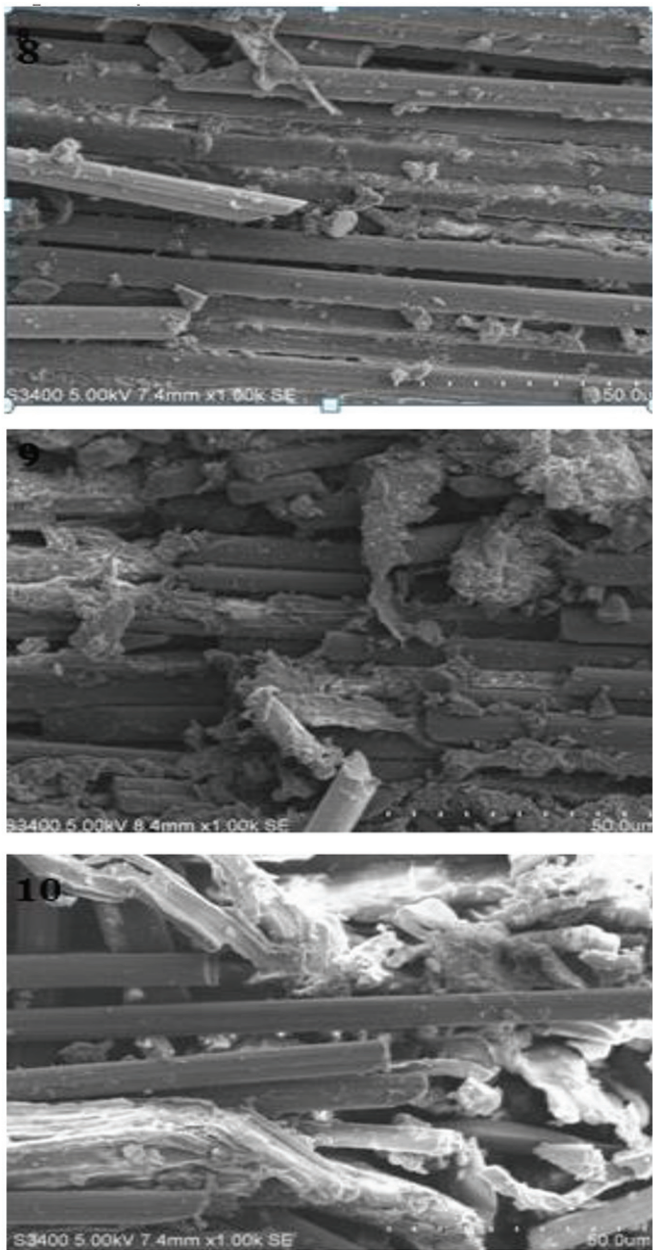
agreement exists between experimental work and predicted value of wear rate.

5.0 SEM

Composite wear specimens is analysed with the help of SEM imagesof different sliding velocity, load and filler percentage. Figs.8, 9 and 10 represent the SEM images of the abraded surface of the 1C-V, 2C-V and C-V composite at lower velocity (0.93m/s) and higher velocity (1.49m/s) respectively.

The abraded surface of the material 1 wt% filler filled CV composite at 130 N load, 200 m abrading distance by 212 μm grain size abrasive respectively is shown in Figure 8. Uniform dispersion of Si_3N_4 and g-C_3N_4 fibres apparently are well bonded to the matrix material keeping the load constant, the sample abraded against slurry led to appearance of small sized fiber with matrix debris adhered to the broken end of the fibres.

From the Figure 9 shows the photomicrograph of worn abraded surface of the material 2 wt% filler filled CV composite at 130 N load, 400 m abrading distance by 212 μm grain size abrasive respectively. With the increase in velocity, the wear escalates due to high material removal, severe detachment by the action of slurry abrasion on the surface. With lower velocity shows some evidence of matrix removal, micro cracks and exposed fiber surfaces. The abraded surface of the CV composite at 130 N load, 400 m abrading distance by 212μm grain size abrasive respectively. The carbon fibers are poorly bonded with the adhesive and carbon fibers are completely separated from the adhesive. This is due to cutting action of sharp abrasive particles on the counter face at higher load and at higher sliding distance. The matrix removal leading to few exposed fibers. The exposed fibers show good adhesion with the matrix. Matrix material is removed by ploughing mechanism as shown in Figure.10.



Figures 8, 9 and 10: Photomicrograph of worn surface of 1C-V,2C-V composite at 0.93 m/s,and C-V composite at 1.49 m/s.

6. Conclusions

Based on the experimental observation, the following conclusions can be drawn.

- Composite wear performance of carbon-vinyl ester andg-C_3N_4 and Si_3N_4 filled carbon-vinyl ester composites at different loads show that specific wear rate of slurry abrasion wear.
- From taguchi method using L27 orthogonal array procedure the behaviour of sliding characteristic of hybrid composites was optimized. Estimated fuzzy modelling outputs are compared to experimental results, which is very much satisfied with average error estimation of 0.27% which represents that the fuzzy logic model is efficiently used to compute the wear rate.
- The abrasive wear behaviour on composites in slurry environment shows that specific wear rate increases with increase in sliding distances and sliding velocity, while decreases slowly with increase in load. 1 wt.% of g-C_3N_4 and Si_3N_4 filled carbon-vinyl ester showed better wear resistance under different loads, different sliding velocity and different sliding distances. This is because the filler-filler interaction and uniform dispersion of filler in carbon-vinyl ester composite.
- Micro structural observation of abraded composite surface indicates the presence of debris, matrix removal and breakage of fibers.

Acknowledgements

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