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WEAR ANALYSIS OF FIBER AND PARTICULATE REINFORCED POLYMER COMPOSITES

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ABSTRACT

This research work carried out on wear analysis of roselle fiber and coconut shell particulate (CSP) reinforced vinylester composites. The inorganic fillers are used in fiber-reinforced composites for producing the desired mould shape and to reduce the fabrication cost of the composites. The newly developed composites are characterized with respect to their erosion wear characteristics. As the mechanical properties of roselle-vinyl ester composites mainly depend upon the fiber content and filler content, Experiments are carried out to study the effect of fiber content, impact velocity, impingement angle, stand-off distance and erodent size on the solid particle erosion behavior of this roselle fiber –vinyl ester based hybrid composites. The Taguchi method used for the significant control factors and their interactions predominantly influencing the wear rate. The study reveals that the fiber content in the composites, impact velocity, impingement angle and erodent size have substantial influence in determining the rate of material loss from the composite surface due to erosion. The erosion rate calculate by Also, artificial neural network (ANN) technique has been use to predict the erosion rate.

***Keywords:* Coconut Shell Particle (CSP), Roselle-vinyl ester composites, Taguchi, Artificial neural network.**

1. INTRODUCTION

The improved performance of polymer composites in engineering applications by the addition of filler materials has shown a great promise and so has become a subject of considerable interest. Ceramic filled polymer composites have been the subject of extensive research in last two decades. Various kinds of polymers and polymer matrix composites reinforced with ceramic particles have a wide range of industrial applications such as heaters, electrodes [1], The organic fillers are used in fiber-reinforced composites for producing the desired mould shape and to reduce the fabrication cost of the composites [2],Hard particulate fillers consisting of ceramic or metal particles and fiber fillers made of glass are being used these days to dramatically improve the wear resistance even up to three orders of magnitude [3].It is reported by Bonner [4] that with the inclusion of micro-sized particulates into polymers, a high filler content (typically greater than 20 vol. %) is generally required to bring the above stated positive effects into play. But at the same time, this may also have detrimental effects on some important properties of the matrix polymers 11such as processability, appearance, density and aging performance. It has also been reported that the fracture surface energies of epoxy and polyester resin and their resistance to crack propagation are relatively low [5]. Most of the researches have been carried out on the characterization of natural fiber composites but the prediction of mechanical properties is found to be limited in literature. Some of the manufacturing studies on glass fiber reinforced polymer composites have been carried out using fuzzy logic techniques and neuro fuzzy techniques[6],[7].Showed that the fracture toughness of epoxy resin could be improved by addition of fly ash particles as filler. The fillers also affect the tensile properties according to their packing characteristics, size and interfacial bonding. The maximum volumetric packing fraction of filler reflects the size distribution and shapes of the particles [8].Erosion as well as abrasion experiments on metallic materials, ceramics and polymers have clearly indicated that the hardness of the eroding or abrading material by itself cannot adequately explain the observed behavior [9]. As a result, combined parameters involving both hardness and fracture toughness have been utilized to correlate the erosion data of metals [9], ceramics and polymers [10]. In this study, identify the significant control factors and their interactions predominantly influencing the erosive wear rate of the composites by using Taguchi experimental design and the erosion rate based on the experimentally measured database of composites using artificial neural network (ANN) technique [11]-[13].

2. MATERIALS AND METHODS

The resin system consists of unsaturated vinyl ester resin; methyl ethyl ketone peroxide (MEKP) catalyst and cobalt octoate accelerator supplied by Sri GVR Enterprises, Chennai, and Tamilnadu, India were used. The resin, catalyst and accelerator were mixed in the ratio of 1:0.02:0.02 for preparing composite plates. The simple hand lay-up process was followed for fabricating inorganic fillers impregnated roselle-vinyl ester composites. Poly vinyl acetate (PVA) release agent was applied to the surfaces of mold before the fabrication. The inorganic fillers were purchased from Vinayaga Puram Main Road, Mugalivakkam, and Chennai.

The roselle fibers supplied from Vibrant Nature**,** Kasthurbai Nagar, Adyar, Next To Nalli, Chennai, Tamil Nadu, India were used. The randomly oriented fibres were distributed over the resin system in 24 % by weight and pressed heavily with load value of 500 N for one hour. After one hour, the composite was removed from the mold and cured at room temperature (29°C) for 24 h. The same procedure was followed to prepare different types of CSP-roselle-vinyl ester composites as per full factorial design matrix.

The fiber parameters and their levels are given in Table 1. As per full factorial design (3 parameters and 3 levels in each parameter), 27 particles-impregnated roselle-vinyl ester composites were fabricated.

Composites	Compositions
C1	Vinyl ester (60wt%)+Roselle Fiber (30wt%)+ CSP (10wt%)
C2	Vinyl ester (50wt%)+Roselle Fiber (40wt%)+CSP (10wt%)
C3	Vinyl ester (40wt%)+Roselle Fiber (50wt%)+CSP (10wt%)

Table 1 Designation of Composites

Figure 1 shows the schematic diagram of erosion test rig confirming to ASTM G 76. The set up is capable of creating reproducible erosive situations for assessing erosion wear resistance of the prepared composite samples. It consists of an air compressor, an air particle mixing chamber and an accelerating chamber. Dry compressed air is mixed with the particles which are fed at constant rate from a sand flow control knob through the nozzle tube and then accelerated by passing the mixture through a convergent brass nozzle of 3 mm internal diameter. These particles impact the specimen which can be held at various angles with respect to the direction of erodent flow using a swivel and an adjustable sample clip. The velocity of the eroding particles is measured using double disc method. In the present study, dry silica sand (angular) of different particle sizes (400, 500 and 600 μm) is used as erodent. Each sample is cleaned in acetone, dried and weighed to an accuracy of ±0.1 mg using a precision electronic balance. It is then eroded in the test rig for 30 minutes and weighed again to determine the weight loss. The process is repeated till the erosion rate attains a constant value called steady-state erosion rate. The ratio of this weight loss to the weight of the eroding particles causing the loss is then computed as a dimensionless incremental erosion rate. The erosion rate is defined as the weight loss of the specimen due to erosion divided by the weight of the erodent causing the loss.

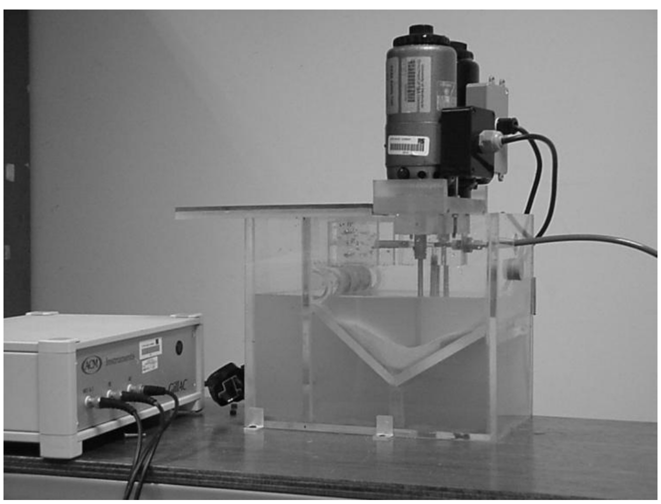

Figure: 1. Picture of the erosion test rig

3. TAGUCHI EXPERIMENTAL ANALYSIS

Design of experiment is a powerful analysis tool for modeling and analyzing the influence of Control factors on performance output. The most important stage in the design of experiment lies in the selection of the control factors. Therefore, a number of factors are included so that non-significant variables can be identified at earliest opportunity. The wear tests are carried out under operating conditions given in Table 2.

Control factor	Level			
	I	II	III	Units
A: Velocity of impact	45	65	85	m/sec
B: Fiber loading	30	40	50	Wt %
C: Standoff distance	120	180	240	mm
D: Impingement angle	30	60	90	degree
E: Erodent size	400	500	600	μm

Table: 2. Levels of the variables used in the experiment

The tests are conducted at room temperature as per experimental design given in Table 3. Five parameters viz., velocity of impact, fiber loading, standoff distance, impingement angle and erodent size each at three levels, are considered in this study in accordance with L_{27} (313) orthogonal array design. In Table 3, each column represents a test parameter and a row gives a test condition which is nothing but a combination of parameter levels. The experimental observations are transformed into signal-to-noise (S/N) ratios. There are several S/N ratios available depending on the type of characteristics. The S/N ratio for minimum wear rate coming under smaller is better characteristic, which can be calculated as logarithmic transformation of the loss function as shown below

Smaller is the better characteristic: $\frac{S}{N} = -10 \log \frac{1}{n}(\sum y^2)$ (1)

Where n is the number of observations, and y is the observed data. "Lower is better" (LB) characteristic, with the above S/N ratio transformation, is suitable for minimization of wear rate.

$L_{27}(3^{13})$	1 A	2 B	3 (AxB) 1	4 (AxB)2	5 C	6 (BxC)1	7 (BxC) 2	8 (AxC) 1	9 D	10 E	11 (AxC) 2	12	13
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2	2	2	2	2	2
3	1	1	1	1	3	3	3	3	3	3	3	3	3
4	1	2	2	2	1	1	1	2	2	2	3	3	3
5	1	2	2	2	2	2	2	3	3	3	1	1	1
6	1	2	2	2	3	3	3	1	1	1	2	2	2
7	1	3	3	3	1	1	1	3	3	3	2	2	2
8	1	3	3	3	2	2	2	1	1	1	3	3	3
9	1	3	3	3	3	3	3	2	2	2	1	1	1
10	2	1	2	3	1	2	3	1	2	3	1	2	3
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13	2	2	3	1	1	2	3	2	3	1	3	1	2
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15	2	2	3	1	3	1	2	1	2	3	2	3	1
16	2	3	1	2	1	2	3	3	1	2	2	3	1
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24	3	2	1	3	3	2	1	1	3	2	2	1	3
25	3	3	2	1	1	3	2	3	2	1	2	1	3
26	3	3	2	1	2	1	3	1	3	2	3	2	1
27	3	3	2	1	3	2	1	2	1	3	1	3	2

Table: 3. Orthogonal array for L_{27} (3^3) Taguchi's Experimental Design

The standard linear graph, as shown in Figure: 2, is used to assign the factors and interactions to various columns of the orthogonal array.

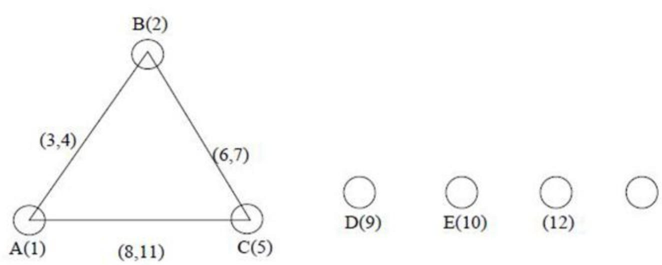

Figure: 2. Linear graphs for L_{27} array

The plan of the experiments is as follows: the first column is assigned to impact velocity (A), the second column to fiber loading (B), the fifth column to stand-off distance (C), ninth column to impingement angle (D) and twelfth column to erodent size (E), the third and fourth column are assigned to (A X B)1 and (A X B)2, respectively to estimate interaction between impact velocity (A) and fiber loading (B), the sixth and seventh column are assigned to (B X C)1 and (B XC)2 respectively, to estimate interaction between the fiber loading (B) and stand-off distance (C), the eighth and eleventh column are assigned to (A X C)1 and (A X C)2 respectively, to estimate interaction between the impact velocity (A) and stand-off distance (C). The remaining columns are assigned to error columns respectively

Input Parameters for Training	Values
Error tolerance	0.01
Learning rate (ß)	0.01
Momentum parameter(a)	0.03
Noise factor (NF)	0.01
Number of epochs	20,0000
Slope parameter (£)	0.6
Number of hidden layer	12
Number of input layer neuron (I)	5
Number of output layer neuron (O)	1

Table: 4. A typical case of Input parameters selected for training

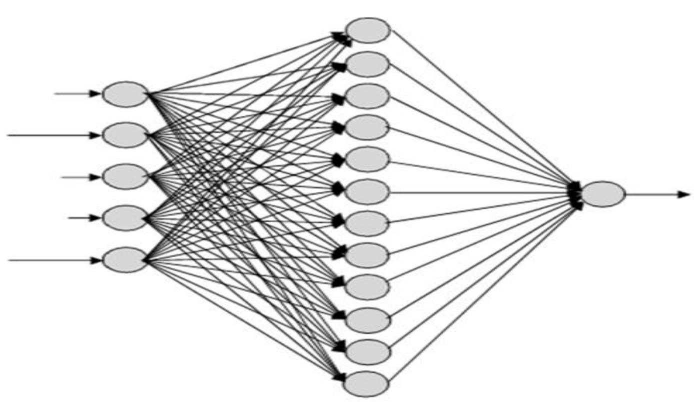

Figure: 3. Neural network architecture

4. EXPERIMENTAL ANALYSIS

From Table 5, the overall mean for the S/N ratio of the erosion rate is found to be -49.02 db. Figure 4 shows graphically the effect of the five control factors on erosion rate. The analysis is made using the popular software specifically used for design of experiment applications known as MINITAB 14. Before any attempt is made to use this simple model as a predictor for the measures of performance, the possible interactions between the control factors must be considered. Thus factorial design incorporates a simple means of testing for the presence of the interaction effects. Analysis of the result leads to the conclusion that factor combination of A1, B2, C3, D2 and E2 gives minimum erosion rate. As for as minimization of erosion rate is concerned, factors A, B, D and E have significant effect whereas factor C has least effect as shown in Figure 4. It is also observed from figure: 4 that the significant level of each factor for minimization of erosion rate. Similarly Figures 5, 6 and 7 shows the interaction graphs for A x B, A x C and B x C for erosion rate respectively.

Expt. No.	Impact velocity (A)m/sec	Fiber content (B) %	Stand-off Distance (C) mm	Impingement angle (D)Degree	Erodent size (E) µm	Erosion rate (Er)mg/kg	S/N ratio (db)
1	45	30	120	30	400	290.43	-49.26
2	45	30	180	60	500	245.45	-47.8
3	45	30	240	90	600	226.34	-47.1
4	45	40	120	60	500	195.71	-45.83
5	45	40	180	90	600	282.84	-49.03
6	45	40	240	30	400	264.94	-48.46
7	45	50	120	90	600	394.12	-51.91
8	45	50	180	30	400	281.42	-48.99
9	45	50	240	60	500	178.58	-45.04
10	65	30	120	60	600	325.61	-50.25
11	65	30	180	90	400	356.88	-51.05
12	65	30	240	30	500	245.43	-47.8
13	65	40	120	90	400	249.45	-47.94
14	65	40	180	30	500	258.83	-48.26
15	65	40	240	60	600	242.16	-47.68
16	65	50	120	30	500	234.75	-47.41
17	65	50	180	60	600	339.37	-50.61
18	65	50	240	90	400	378.19	-51.55
19	85	30	120	90	500	407.20	-52.2
20	85	30	180	30	600	228.26	-47.17
21	85	30	240	60	400	246.19	-47.83
22	85	40	120	30	600	268.49	-48.58
23	85	40	180	60	400	332.80	-50.44
24	85	40	240	90	500	208.56	-46.38
25	85	50	120	60	400	352.17	-50.94
26	85	50	180	90	500	420.58	-52.48
27	85	50	240	30	600	369.54	-51.35

Table: 5. Experimental design using L_{27} orthogonal array

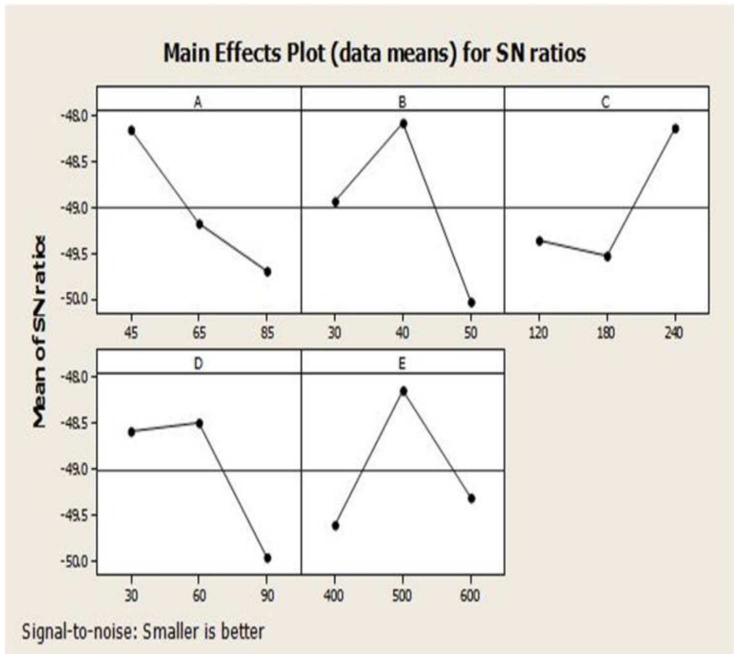

Figure: 4 Effect of control factors on erosion rate

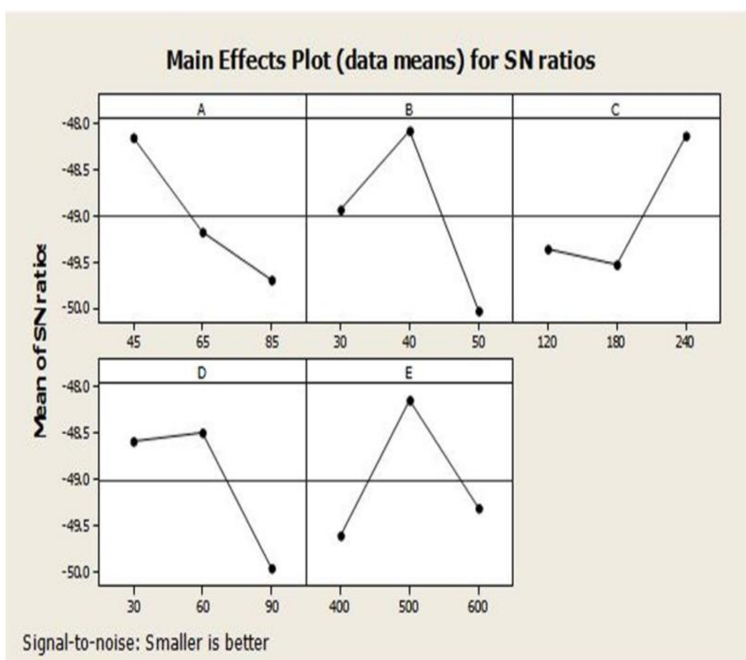

Figure: 5. Interaction graph between A × B for erosion rate

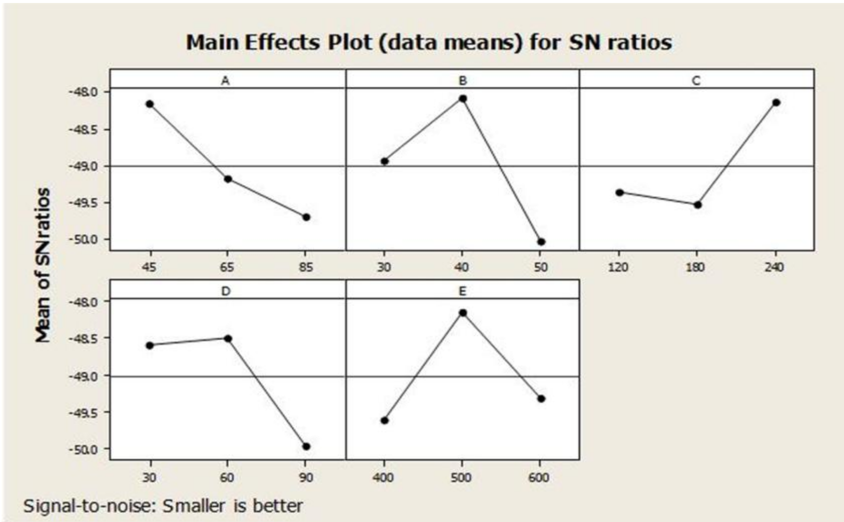

Figure: 6 Interaction graph between A × C for erosion rate

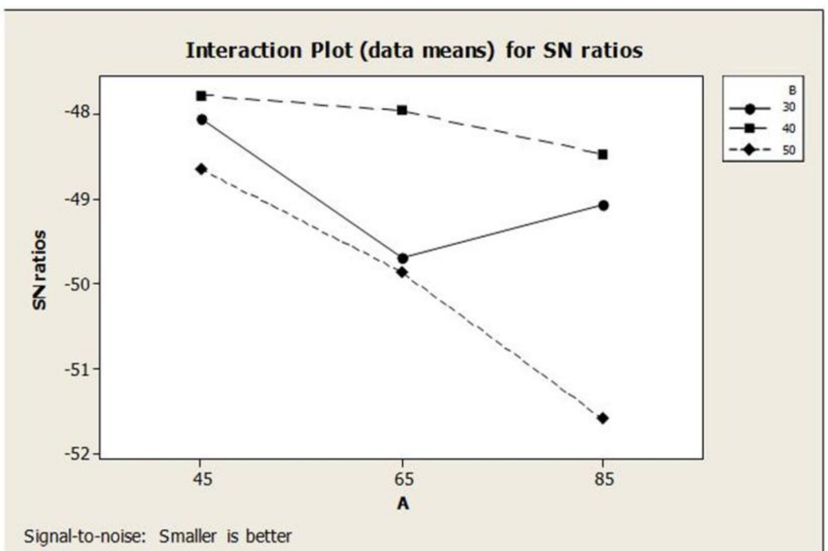

Figure: 7. Interaction graph between B × C for erosion rate

The experimental erosion wear rate (E_{expt}) of the CSP filled roselle fiber reinforced vinyl ester composites are calculated as given in Table 5. Seventy five percent of data collected from erosion test is used for training where as twenty five percent data is used for testing. The parameters of three layer architecture of ANN model are set as input nodes = 5, output node = 1, hidden nodes = 12, learning rate = 0.01, momentum parameter = 0.03, number of epochs = 20, 0000 and a set of predicted output (ErANN) is obtained. Table 6 presents a comparison between the experimental and the ANN predicted results. The errors calculated with respect to the theoretical results are also given.

Expt. No.	Erex pt. (mg/	ErA NN (mg/	Error (%)
1	290.43	245.33	6.85191
2	245.45	203.95	9.57425
3	226.34	176.93	6.88787
4	195.71	111.31	9.91262
5	282.84	230.34	4.41946
6	264.94	204.54	1.73624
7	394.12	286.33	10.8571
8	281.42	193.51	8.14085
9	178.58	127.07	7.55404
10	325.61	224.53	11.0807
11	356.88	302.1	2.86371
12	245.43	173.76	2.71767
13	249.45	168.65	6.33393
14	258.83	186.49	2.83583
15	242.16	156.04	8.72150
16	234.75	178.27	3.62939
17	339.37	262.33	3.54775
18	378.19	286.06	7.17364
19	407.20	307.29	8.57318
20	228.26	183.82	9.00727
21	246.19	171.43	3.96441
22	268.49	233.62	11.2224
23	332.80	232.37	10.6461
24	208.56	164.48	10.0307
25	352.17	264.4	6.46562
26	420.58	326.23	6.97845
27	369.54	298.25	1.70211

Table 6.Comparison of experimental result and ANN results

It is observed that maximum error between ANN prediction and experimental wear rate is 0- 12%. The error in case of ANN model can further be reduced if number of test patterns is increased. However, present study demonstrates application of ANN for prediction of wear rate in a complex process of solid particle erosion of polymer composites.

5. STEADY STATE EROSION

Erosion behavior of the composites is generally ascertained by correlating erosion rate with impingement angle, erodent velocity and erodent particle size. Erosion behavior strongly depends on impingement angle. Ductile behavior is characterized by maximum erosion rate and generally occurs at 15–300. Brittle behavior is characterized by maximum erosion rate at 900. Semi-ductile behavior is characterized by the maximum erosion rate at 45-600. Thus the erosion wear behavior of polymer composites can be grouped into ductile and brittle categories although this grouping is not definitive because the erosion characteristics equally depend on the experimental conditions as on composition of the target material. The results are presented in Figure 8. Which shows the peak erosion taking place at an impingement angle of 600 for the filled composites? This clearly indicates that these composites respond to solid particle impact neither in a purely shows semi-ductile behavior as per literature. This behavior can be termed as semi-ductile in nature which may be attributed to the incorporation of roselle fibers and CSP particles within the vinyl ester body.

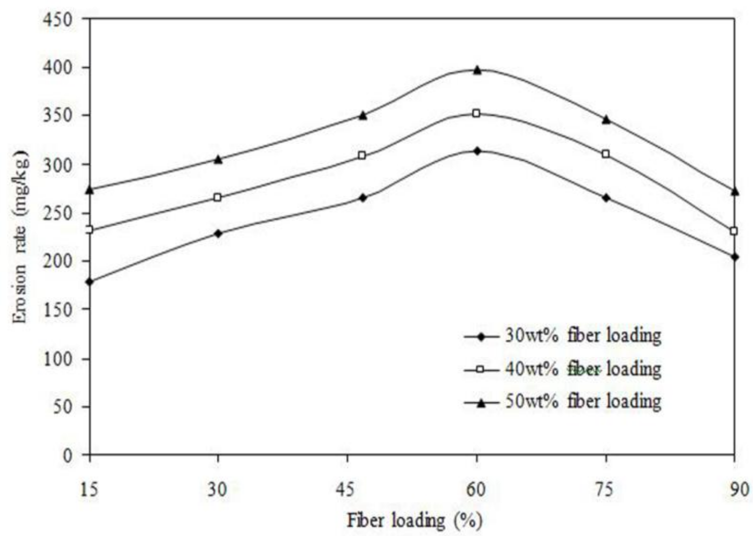

Figure: 8. Variation of erosion rate with impingement angle

6. CONCLUSIONS

This work shows that successful fabrication of a roselle fiber reinforced vinyl ester composites filled with micro-sized CSP is possible by simple hand lay-up technique. Solid particle erosion characteristics of these composites can be successfully analyzed using Taguchi experimental design scheme. Taguchi method provides a simple, systematic and efficient methodology for the optimization of the control factors. Study of influence of impingement angle on erosion rate of the composites with different percentage of fiber loading reveals their semi-ductile nature with respect to erosion wear. The peak erosion rate is found to be occurring at 600 impingement angle under the various experimental conditions. Artificial neural network technique has been applied to predict the erosion rate of composites. The results show that the predicted data are well acceptable when comparing them to measured values. The predicted property profiles as a function of fiber content and testing conditions proved a remarkable capability of well-trained neural networks for modeling concern.

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