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Optimization Studies of Kevlar/Epoxy Composites Strengthened with Hybrid SiC-ZnO Nanofillers using Taguchi L16 Technique

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Abstract: ***Fibre Reinforced Polymer Composites (FRPCs) have been found to exhibit enhanced mechanical properties on addition of nanofillers. Recent research has also delved into the use of hybrid nanofillers to synergistically enhance their mechanical properties. In this present research, an attempt has been made to study the effect of hybrid Silicon Carbide (SiC) – Zinc Oxide (ZnO) nanofillers on the mechanical properties of Kevlar/Epoxy composite. Taguchi L16 technique has been employed in this current research for design and optimisation. The mechanical properties such as tensile strength, flexural strength, inter laminar shear strength and energy absorbed have been evaluated as output characteristics for optimising the input variables like weight percentage of SiC, weight percentage of ZnO, curing temperature and curing time. Confirmatory tests have also been performed for repeatability and validity.***

Keywords: Fibre Reinforced Polymer Composites, Hybrid Nanofillers, Vacuum Bag Moulding, Mechanical Characterization, Optimization Studies.

I. INTRODUCTION

Fibre Reinforced Polymer Composites (FRPCs) are engineered materials consisting of strong reinforcing fibres embedded within a polymer matrix. FRPCs are lightweight and exhibit high strength, stiffness, and are also corrosion resistant, making them superior to many conventional metals in structural applications. FRPCs are widely used in aerospace, automotive, marine, and civil engineering industries due to their excellent mechanical performance and design flexibility [1]. Researchers have found that the addition of nanofillers have been shown to significantly enhance the performance of fibre reinforced polymer composites by improving fibre–matrix adhesion, increasing tensile strength, stiffness, and fatigue resistance while also enhancing thermal stability and reducing moisture uptake. These innovations are expanding the application of FRPCs in aerospace, automotive, biomedical, and eco-friendly engineering sectors.

Thiagarajan, Melvin, et. al., investigated the tensile strength of silicon carbide epoxy polymer nanocomposite. The materials used were epoxy resin, glass fibre of Woven Roving Mat (WRM) and Chopped Strand Mat (CSM) and silicon carbide nanoparticle. The Nanocomposite laminates were prepared by hand layup method by varying the Silicon carbide nanoparticles at 0, 1, 2 and 3 Wt. %. The fabricated nanocomposites were then subject to tensile test. It was observed that by increasing the weight percentage of silicon carbide nanoparticles, the tensile strength also increased [2].

Sujesh and Ganesan studied the effect of inclusion of nano silica particle in the Glass Fibre Reinforced Plastic (GFRP) manufactured by vacuum bagging technique. They also studied the behaviour of Nano filled bidirectional fibre reinforced polymer under uniaxial loading at different strain rates. The results show that nanofilled GFRP have better tensile strength compared to plane GFRP. Result shows that addition of nanoparticle increased the mechanical properties such as tensile strength, tensile modulus and Ultimate tensile load without considerable weight increment [3].

Chang, Xin, et. al., investigated the enhancement of mechanical behaviour of FRPCs modified by silica nanoparticles. Three types of composites were fabricated: Epoxy-Basalt, Epoxy-Carbon and Vinyl Ester- Basalt. Multiple specimens with various weight percentages of silica nanopowder were prepared. Various mechanical tests were carried out on all the specimens. Scanning electron microscopy was employed to study the structure of the specimens after testing. Results concluded that the addition of silica nanoparticles had significantly improved the properties of the composites and it was most significant for the epoxy based composites. Scanning electron microscopy revealed a rough surface which implied an increase in fracture toughness [4].

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Vipin Kumar Tripathi and Shailesh Ambekar investigated the wear behaviour of Carbon Fibre Reinforced Polymer (CFRP) hybrid nano composite with nanoclay and nano ZnO as fillers. The CFRP nanocomposite laminates were manufactured by a hand layup method followed by vacuum bagging. The clay and Zinc Oxide nanoparticles were used as filler. The wt.% of nanoparticle used was in the range of 1 to 5 % with the epoxy resin and hardener mixture. The wear properties of CFRP hybrid nanocomposites were tested by using a pin-on-disc machine under various loads. ANOVA results shows that the nanoclay and nano ZnO had an improved effect on wear properties with the 2–3% of the each nanoclay and nano ZnO particles [5].

Setayesh Zaer-Miri and Hamed Khosravi, assessed the wear behaviour and inter laminar shear properties of modified nano-TiO_2/jute fibre/epoxy multiscale composites. The authors functionalized TiO_2 nanoparticles by using a amin-terminated silane-coupling agent. The multiscale composites were fabricated using hand layup technique by dispersing various amounts of the functionalized TiO_2 nanoparticles (0.5, 1, 3, and 5 wt.%) in the matrix and by using jute fibre as reinforcement. The wear behaviour and inter laminar shear properties of the fabricated multiscale nano-TiO_2/jute fibre/epoxy composites were investigated. It was observed that the addition of 3 wt.% TiO_2 increased the inter laminar shear strength of the composite and decreased the wear rate and coefficient of friction of the jute fibre/epoxy composite [6].

Çağrı Uzay and Safa Kamer, investigated the effect of Silane-Coated SiO_2 Nanoparticles on the Hardness Values of Glass FRP Composites. The SiO_2 Nanoparticles were coated with two different types of silane coating (KH550 and KH570). The nanoparticles were dispersed within the polymer epoxy at 1.5 and 3 wt.% ratios. The vacuum bag method was applied to produce silane-coated nano SiO_2 filled glass FRP composites. The fabricated nanocomposites were subjected to various mechanical testing. It was found that the addition of silane-coated SiO_2 nanoparticles into the polymer matrix considerably improved the hardness of the developed composite structures [7]. In recent years, researchers have also found that by hybridisation, which combine two or more nanofillers, have shown synergistic effects in enhancing the properties of FRPCs. Studies demonstrate that hybrid systems improve fibre–matrix interfacial bonding more effectively than single nanofillers, resulting in superior mechanical strength, toughness, and fatigue resistance, making hybrid nanofillers a promising route for next-generation aerospace, automotive, and structural composites.

Esranur, Osman, et. al., mixed hybrid multiwalled carbon nanotubes and graphene nanoparticles to epoxy matrices for carbon fibre laminates for various weight percentages. They evaluated the specimens for various mechanical properties and observed that the use of hybrid nanofillers led to synergistic gains in stiffness and fracture resistance. They concluded that the hybrid nanofillers produce best results at specific nanofiller ratios [8].

Megahed, Tobbala, et. al., combined silica and cobalt ferrite nanoparticles. Glass/epoxy hybrid composite laminates with hybrid nanofillers were fabricated using hand lay-up technique. The resultant hybrid nanocomposites showed good mechanical properties as compared to hybrid nanocomposites fabricated by individually loading nanoparticles [9].

Azhagarsamy and Pannirselvam developed Basalt Fibre Reinforced Polymer (BFRP) composites using Isophthalic Polyester (IP) resin modified with Graphene Oxide (GO) and Nano Silica (NS) hybrid nanofillers. BFRP laminates were produced via hand lay-up and compression moulding. They observed that the addition of hybrid nanofillers exhibited further enhancements with tensile strength, flexural strength, impact strength and hardness. They concluded that GO–NS hybrid nanofillers were an efficient reinforcement strategy for IP resin–based BFRP composites [10].

Sathish, Boobalan, et. al., evaluated tensile performance of basalt/glass fibre-reinforced polymer composites enhanced with hybrid nanofillers, comprising equal proportions of multi-walled carbon nanotubes and silicon dioxide. They found that the hybrid nanofillers synergistically enhance the tensile properties, load transfer efficiency and interfacial bonding [11].

In this study, an attempt has been made to evaluate and optimise the mechanical properties of Kevlar/Epoxy composites strengthened with hybrid SiC-ZnO nanofillers. SiC nanoparticles are considered because of their high hardness and wear resistance, strong resistance to corrosion and radiation and high mechanical strength at nanoscale. ZnO nanoparticle were considered because of their high hardness, high elastic modulus, high strength and high fracture toughness. Taguchi L16 design of experiments has been employed to determine weight percentage of SiC, weight percentage of ZnO, curing temperature and curing time for higher tensile strength, flexural strength, inter laminar shear stress and energy absorption.

II. MATERIALS AND EXPERIMENTATION

A. Materials

The materials used in this research were: Kevlar Fibre Fabric Mat as the reinforcement material, Epoxy resin with hardener as the matrix material and Silicon Carbide (SiC) nanoparticles and Zinc Oxide (ZnO) nanoparticles as the hybrid nanofillers. The Kevlar Fibre Fabric Mat was sourced by GoGreen Products, Chennai, Tamil Nadu, India. The specifications of the Kevlar Fibre Fabric Mat used for the current research is shown in Table I.

TABLE I
SPECIFICATIONS OF KEVLAR FIBRE MAT

Area Weight (g/m^2)	220
Dry Fabric Thickness (mm)	0.32
Density (g/cm^3)	1.44
Filament Diameter (µm)	12
Elongation (%)	2.8

The epoxy resin LY556 with hardening agent HY951 was sourced by Zenith Industrial Supplies, Bangalore, Karnataka, India. The specifications of the epoxy resin and hardener are shown in Table II and Table III respectively.

TABLE II
SPECIFICATIONS OF EPOXY RESIN LY556

Chemical Name	Phenol 4,4-(-1-Methyleneethylienedene) bipolymer with (Chloromethyl) oxirane
State	Liquid
Colour	Light yellow
Density	1.2 g/cm^2
Viscosity	1800-2200 MPa/sec

TABLE III
SPECIFICATIONS OF HARDENER HY951

Chemical Name	Triethyleneteramine (TETA)
State	Liquid
Colour	Clear pale yellow
Density	0.937 g/cm^2
Viscosity	10-20 MPa/sec

The SiC nanopowder was supplied by Ultrananotech Private Limited, Bangalore, Karnataka, India. The ZnO nanopowder was supplied by Adnano Technologies, Shimoga, Karnataka, India. Table IV details the specifications of the nanofillers.

TABLE IV
SPECIFICATIONS OF THE NANOFILLERS

Nanofiller	Form	Purity	Colour	Size	CAS No.
Silicon Carbide (SiC)	Powder	99.9%	Greenish Grey	30 - 50 nm	409-21-2
Zinc Oxide (ZnO)	Powder	99%	White	30 - 50 nm	1314-13-2

B. Selection of Process, Process Parameters and their Levels

The fabrication of the FRPC specimens was to be done by vacuum bag moulding process. The process parameters which were selected for optimisation were: Weight percentage of SiC nanofiller, Weight % of ZnO nanofiller, Curing temperature and Curing time. The parameters and their levels which were selected are shown in Table V. The number of Kevlar layers was kept constant at eight layers. The values of levels of process parameters are derived based on the trial experiments for feasibility study.

TABLE V
PROCESS PARAMETERS AND THEIR LEVELS

Parameter	Level 1	Level 2	Level 3	Level 4
Wt. % of SiC	0.5	0.75	1	1.25
Wt. % of ZnO	1	1.25	1.5	1.75
Curing Temperature (^oC)	95	100	105	110
Curing Time (mins)	55	60	65	70

C. Design of Experiments

Since there are four parameters and four levels, Taguchi L16 array was employed and as a result of which 16 specimens are fabricated. Table VI shows the list of specimens to be fabricated as per Taguchi L16 array.

TABLE VI
EXPERIMENTAL DESIGN USING TAGUCHI L16 ARRAY

Experiment No.	Wt. % of SiC	Wt. % of ZnO	Temperature (^oC)	Time (mins)
1.	0.5	1	95	55
2.	0.5	1.25	100	60
3.	0.5	1.5	105	65
4.	0.5	1.75	110	70
5.	0.75	1	100	65
6.	0.75	1.25	95	70
7.	0.75	1.5	110	55
8.	0.75	1.75	105	60
9.	1	1	105	70
10.	1	1.25	110	65
11.	1	1.5	95	60
12.	1	1.75	100	55
13.	1.25	1	110	60
14.	1.25	1.25	105	55
15.	1.25	1.5	100	70
16.	1.25	1.75	95	65

D. Fabrication of specimens by Vacuum Bag Moulding

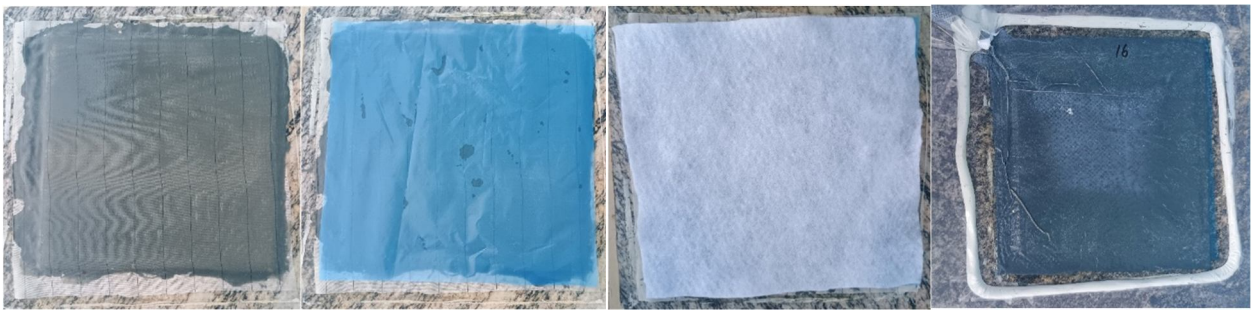
The Kevlar/Epoxy composite specimens were fabricated by using hand layup method followed by vacuum bag moulding. The Kevlar Fibre Mat was cut into 30 x 30 centimetre squares. The resin mixture comprising of epoxy resin and hardener were prepared in the ratio of 10:1. The ZnO and SiC nanoparticles with weight percentages as per the experimental plan were then stirred into the epoxy-hardener mixture for 10 minutes. The mixture was then spread on the mould and a kevlar fibre mat was placed on this layer. The epoxy-hardener-nanoparticle resin mixture was then poured onto the kevlar fibre mat and evenly spread using a roller. This process was repeated until eight layers of mat were obtained. Fig. 1 shows the specimen after hand layup.



Fig. 1 The specimen after hand layup process

The specimen was then covered with a layer of peel ply sheet (Fig. 2 (a)) followed by a layer of vacuum bag film (Fig. 2 (b)) and breather fabric (Fig. 2 (c)). The whole mould was then sealed with a plastic bag and a pipe connected to a vacuum pump was introduced inside the mould, subjecting it to vacuum conditions (Fig. 2 (d)). The mould was under vacuum for three hours after which the vacuum pump was turned off. The specimens were then left to cure in the mould for 24 hours following which they were removed. Fig 2. shows the various stages of the vacuum moulding process.

Vacuum bag moulding process was selected because it enhances both quality and performance of FRPCs. The uniform pressure from the vacuum pump ensures better fibre consolidation, minimizes voids, and improves resin distribution, which directly translates to higher mechanical strength and durability of the composite. Additionally, vacuum bagging reduces porosity and enhances surface finish, making the final FRPCs more reliable for structural applications.



(a) (b) (c) (d)

Fig. 2 Various stages of the vacuum bag moulding process

The specimens were then cured as per the predetermined curing temperature and curing time in a hot air oven at the Micropaleontology Lab, Department of Geology, Bangalore University, Bangalore. Fig. 3 shows the specimens fabricated as per experimental plan.



Fig 3. Specimens fabricated as per experimental plan

E. Cutting of specimens by Abrasive Waterjet Cutting

The fabricated fibre reinforced polymer composite specimens were then cut according to dimensions mentioned in ASTM standards for mechanical characterization. The specimens were cut by an abrasive waterjet cutting machine at BMS College of Engineering, Bangalore, Karnataka, India. Fig. 4 shows the specimen cut for various mechanical tests.

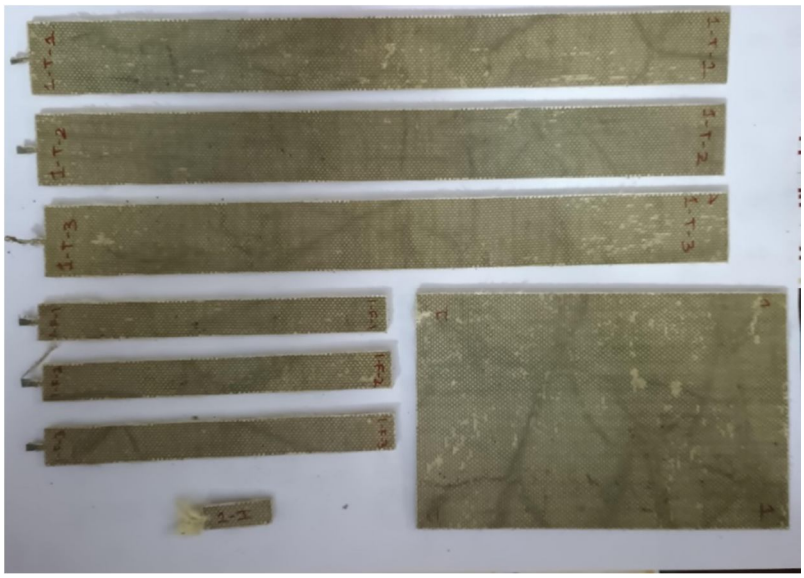


Fig. 4 A fabricated specimen cut for various tests

F. Mechanical Characterization

The characterization of the fabricated specimens involved conducting four tests, namely, Tensile Test (ASTM D3039), Flexural Test (ASTM D790), Inter Laminar Shear Strength Test (ASTM D2344) and Energy Absorption Test. The tensile test, flexural test and inter laminar shear strength tests were conducted using a Universal Testing Machine at SLN Testing Laboratory Private Limited, Bangalore, Karnataka, India. The energy absorption test was conducted using the drop weight test facility at Vemana Institute of Technology, Bangalore, Karnataka, India. Fig. 5 shows the drop weight impact test facility.



Fig 5. Drop weight impact test facility

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III.RESULTS AND DISCUSSIONS

A. Mechanical Characterization

The results of mechanical characterization tests conducted: tensile test, flexural test, inter laminar shear strength (ILSS) test and energy absorption test are shown in Table VII.

TABLE VII
RESULTS OF MECHANICAL CHARACTERIZATION OF SPECIMENS

Specimen	Wt.% of SiC	Wt.% of ZnO	Temperature (^{0}C)	Time (Minutes)	Tensile Strength (MPa)	Flexural Strength (MPa)	ILSS (MPa)	Energy Absorbed (J)
1	0.5	1	95	55	461.23	160.8	431.32	44
2	0.5	1.25	100	60	338.57	197.07	387.54	60
3	0.5	1.5	105	65	215.84	114.84	212.65	60
4	0.5	1.75	110	70	261.16	139.36	260.25	43
5	0.75	1	100	65	276.98	131.17	290.65	45
6	0.75	1.25	95	70	392.42	174.55	290.65	44
7	0.75	1.5	110	55	279.16	139.87	330.57	55
8	0.75	1.75	105	60	440.41	167.52	417.32	60
9	1	1	105	70	335.73	145.7	301.58	60
10	1	1.25	110	65	349.63	155.51	360.58	58
11	1	1.5	95	60	385.03	168.14	426.32	54
12	1	1.75	100	55	251.83	114.03	287.32	53
13	1.25	1	110	60	289.6	145.12	287.32	31
14	1.25	1.25	105	55	310.7	143.21	312.35	38
15	1.25	1.5	100	70	356.16	122.94	403.32	36
16	1.25	1.75	95	65	354.77	142.65	360.58	51

B. ANOVA

ANOVA was employed to determine the which parameter was the most influential on the tensile strength, flexural strength, inter laminar shear strength and energy absorption respectively.

1) *ANOVA for Tensile Strength:* The ANOVA results for tensile strength is shown in Table VIII. It can be observed that weight percentage of SiC nanofiller (p value = 0.98) is the parameter which has the most influence on the tensile strength of the fabricated specimens.

TABLE VIII
ANOVA TABLE FOR TENSILE STRENGTH

Source	DoF	SS	MS	F	P
Wt. % of SiC	3	1653	551.0	0.06	**0.980**
Wt. % of ZnO	3	3513	1171.2	0.12	0.944
Temperature (^{0}C)	3	26003	8667.8	0.87	0.543
Time (Minutes)	3	8444	2814.6	0.28	0.836
Error	3	29772	9923.8		
Total	15	69385			

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2) *ANOVA for Flexural Strength*: The ANOVA results for flexural strength is shown in Table IX. It can be observed that weight percentage of SiC nanofiller (p value = 0.605) is the parameter which has the most influence on the flexural strength of the fabricated specimens.

TABLE IX
ANOVA TABLE FOR FLEXURAL STRENGTH

Source	DoF	SS	MS	F	P
Wt. % of SiC	3	591.3	197.1	0.71	**0.605**
Wt. % of ZnO	3	2289.6	763.2	2.77	0.213
Temperature (^{0}C)	3	1054.6	351.5	1.27	0.423
Time (Minutes)	3	2725.4	908.5	3.29	0.177
Error	3	827.5	275.8		
Total	15	7488.4			

3) *ANOVA for Inter Laminar Shear Strength Strength:* The ANOVA results for inter laminar shear strength is shown in Table X. It can be observed that weight percentage of ZnO nanofiller (p value = 0.997) is the parameter which has the most influence on the inter laminar shear strength of the fabricated specimens.

TABLE X
ANOVA TABLE FOR INTER LAMINAR SHEAR STRENGTH

Source	DoF	SS	MS	F	P
Wt. % of SiC	3	1070.3	356.8	0.03	0.992
Wt. % of ZnO	3	565.8	188.6	0.02	**0.997**
Temperature (^{0}C)	3	12210.3	4070.1	0.33	0.805
Time (Minutes)	3	13191.5	4397.2	0.36	0.789
Error	3	36779.6	12259.9		
Total	15	63817.4			

4) *ANOVA for Energy Absorbed:* The ANOVA results for energy absorbed is shown in Table XI. It can be observed that weight percentage of ZnO nanofiller (p value = 0.777) is the parameter which has the most influence on the energy absorption of the fabricated specimens.

TABLE XI
ANOVA TABLE FOR ENERGY ABSORBED

Source	DoF	SS	MS	F	P
Wt. % of SiC	3	652.5	217.50	2.16	0.272
Wt. % of ZnO	3	114.5	38.17	0.38	**0.777**
Temperature (^{0}C)	3	140.5	46.83	0.47	0.727
Time (Minutes)	3	148.5	49.50	0.49	0.713
Error	3	302.0	100.67		
Total	15	1358.0			

Based on the ANOVA tests conducted, it can be concluded that SiC and ZnO nanofillers have significant contribution in enhancing the mechanical properties.

C. Determination of Optimum Parameters using S/N Ratios

S/N Ratio studies were computed to determine optimized parametric levels for each of the characterizing tests, i.e., tensile strength, flexural strength, inter laminar shear strength and energy absorption respectively. The S/N values calculated was for "larger the better" conditions to predict maximized output values.

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1) *Optimization of Tensile Strength using S/N Ratio:* The effect of process parameters on tensile strength is shown in Figure 6. The S/N ratio response table for tensile strength is shown in Table XII. It can be observed from the table that the optimum process parameters for tensile strength are A2B2C1D2.

TABLE XII
RESPONSE TABLE FOR S/N RATIO OF TENSILE STRENGTH

Level	Wt. % of SiC	Wt. % of ZnO	Temperature (^{0}C)	Time (Minutes)
1	49.72	50.47	51.97	50.02
2	50.63	50.80	49.62	51.10
3	50.28	49.59	49.98	49.35
4	50.28	50.06	49.34	50.44
Delta	0.91	1.21	2.62	1.75
Rank	4	3	1	2

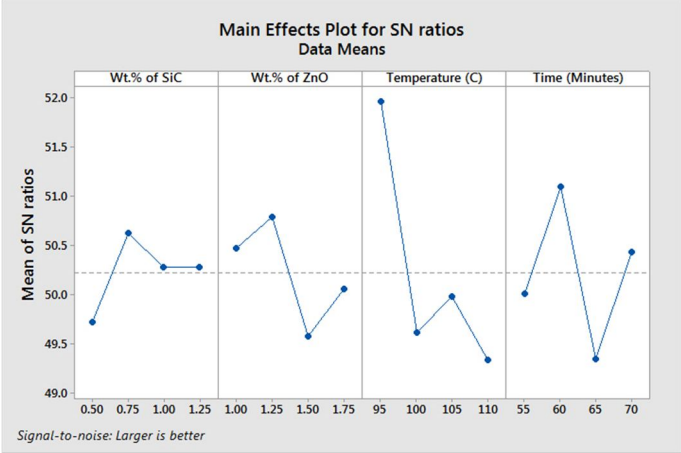


Fig 6. Main effect plots for S/N ratio of tensile strength

2) *Optimization of Flexural Strength using S/N Ratio:* The effect of process parameters on flexural strength is shown in Figure 7. The S/N ratio response table for flexural strength is shown in Table XIII. It can be observed from the table that the optimum process parameters for flexural strength are A2B2C1D2.

TABLE XIII
RESPONSE TABLE FOR S/N RATIO OF FLEXURAL STRENGTH

Level	Wt. % of SiC	Wt. % of ZnO	Temperature (^{0}C)	Time (Minutes)
1	43.53	43.25	44.14	42.83
2	43.65	44.42	42.80	44.53
3	43.19	42.61	43.02	42.62
4	42.81	42.90	43.22	43.20
Delta	0.84	1.82	1.34	1.91
Rank	4	2	3	1

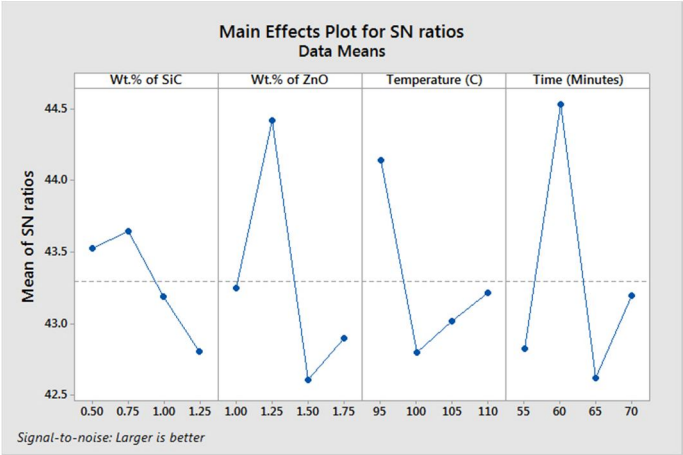


Fig. 7 Main effect plots for S/N ratio of flexural strength

3) *Optimization of Inter Laminar Shear Strength using S/N Ratio:* The effect of process parameters on inter laminar shear strength is shown in Figure 8. The S/N ratio response table for inter laminar shear strength is shown in Table XIV. It can be observed from the table that the optimum process parameters for inter laminar shear strength are A2B2C1D2.

TABLE XIV
RESPONSE TABLE FOR S/N RATIO OF INTER LAMINAR SHEAR STRENGTH

Level	Wt. % of SiC	Wt. % of ZnO	Temperature (^{0}C)	Time (Minutes)
1	49.83	50.18	51.42	50.54
2	50.33	50.52	50.58	51.48
3	50.62	50.41	49.61	49.53
4	50.58	50.26	49.75	49.82
Delta	0.79	0.34	1.81	1.96
Rank	3	4	2	1

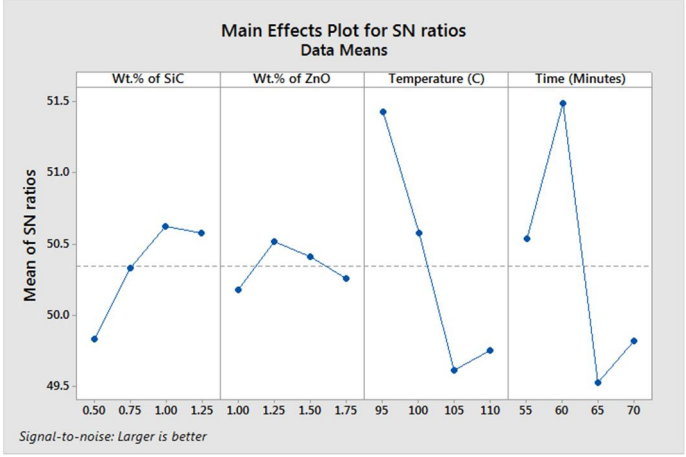


Fig. 8 Main effect plots for S/N ratios of inter laminar shear strength

4) *Optimization of Energy Absorption using S/N Ratio:* The effect of process parameters on energy absorption is shown in Figure 9. The S/N ratio response table for energy absorption is shown in Table XV. It can be observed from the table that the optimum process parameters for energy absorption are A2B2C1D2.

TABLE XV
RESPONSE TABLE FOR S/N RATIO OF ENERGY ABSORPTION

Level	Wt. % of SiC	Wt. % of ZnO	Temperature (^{0}C)	Time (Minutes)
1	34.17	32.83	33.63	33.44
2	34.08	33.82	33.56	33.90
3	34.99	34.04	34.57	34.51
4	31.68	34.22	33.14	33.06
Delta	3.32	1.39	1.43	1.45
Rank	1	4	3	2

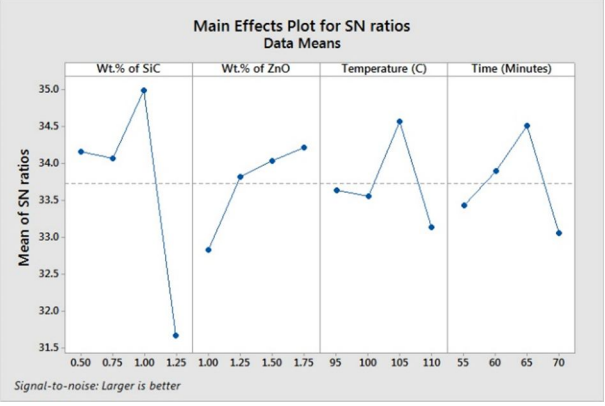


Fig. 9 Main effect plots for S/N ratios of energy absorbed.

The combinations for optimized mechanical properties along with their predicted value is given in Table XVI.

TABLE XVI
PREDICTED OPTIMIZED PARAMETERS TABLE

Output Parameter	Optimized Input Process Parameter	Predicted Value
Maximum Tensile Strength	A2B2C1D2	512.1 MPa
Maximum Flexural Strength	A2B2C1D2	232.45 MPa
Maximum ILSS	A3B2C1D2	433.5 MPa
Maximum Energy Absorption	A3B4C3D3	67 J

D. Confirmatory Tests

Specimens were fabricated as per the parametric levels derived from the optimization studies. The specimens for the confirmatory tests were fabricated by vacuum bag moulding process.

The first specimen fabricated was for maximum tensile strength and flexural strength with the process parameter A2B2C1D2. The second specimen fabricated was for maximum inter laminar shear strength with the process parameter A3B2C1D2. The third specimen fabricated was for maximum energy absorption with the process parameter A3B4C3D3.

TABLE XVII
CONFIRMATORY TESTS TABLE

Output Parameter	Optimized Input Process Parameter	Predicted Value	Experimental Value	Error %
Maximum Tensile Strength	A2B2C1D2	512.1 MPa	468.31 MPa	8.5
Maximum Flexural Strength	A2B2C1D2	232.45 MPa	211.62 MPa	8.9
Maximum ILSS	A3B2C1D2	433.5 MPa	395.97 MPa	8.6
Maximum Energy Absorption	A3B4C3D3	67 J	60 J	10.4

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Table XVII shows the results of the confirmatory tests conducted. The predicted value, experimental value and the error percentage indicating variation can also be observed from the Table XVII.

IV. CONCLUSIONS AND SCOPE

The specimens were fabricated as per the Taguchi L16 experimental plan and were evaluated for mechanical properties such as tensile strength, flexural strength, inter laminar shear strength and energy absorption. ANOVA was employed to find the parameters influencing each mechanical property. Optimization studies were conducted to predict the optimal maximized specimens for each test. Finally, confirmatory tests were carried out for repeatability and validity of the experimental design.

ANOVA revealed that weight percentage of SiC nanofiller was the parameter most influencing the tensile strength and flexural strength of the specimens, whereas weight percentage of ZnO nanofiller was the parameter most influencing the inter laminar shear strength and energy absorption. It can be concluded from the ANOVA studies that the use of hybrid nanofillers has led to synergistic enhancement of mechanical properties of the fabricated specimens.

Optimization studies predicted that for maximum tensile strength and maximum flexural strength, the parametric condition was A2B2C1D2 (0.75 weight percent of SiC, 1.25 weight percent of ZnO, curing temperature of 95^0C and curing time of 60 minutes).

Optimization studies predicted that for maximum inter laminar shear strength, the parametric condition was A3B2C1D2 (1 weight percent of SiC, 1.25 weight percent of ZnO, curing temperature of 95^0C and curing time of 60 minutes).

Optimization studies predicted that for maximum energy absorption, the parametric condition was A3B4C3D3 (1 weight percent of SiC, 1.75 weight percent of ZnO, curing temperature of 105^0C and curing time of 65 minutes).

Confirmatory tests were conducted for repeatability and validation of the experimental model and it was observed that the predicted value and experimental values were in good agreement with each other.

It can be concluded that the addition of SiC and ZnO nanofillers play an important role in enhancing mechanical properties of hybrid nanofilled FRPC.

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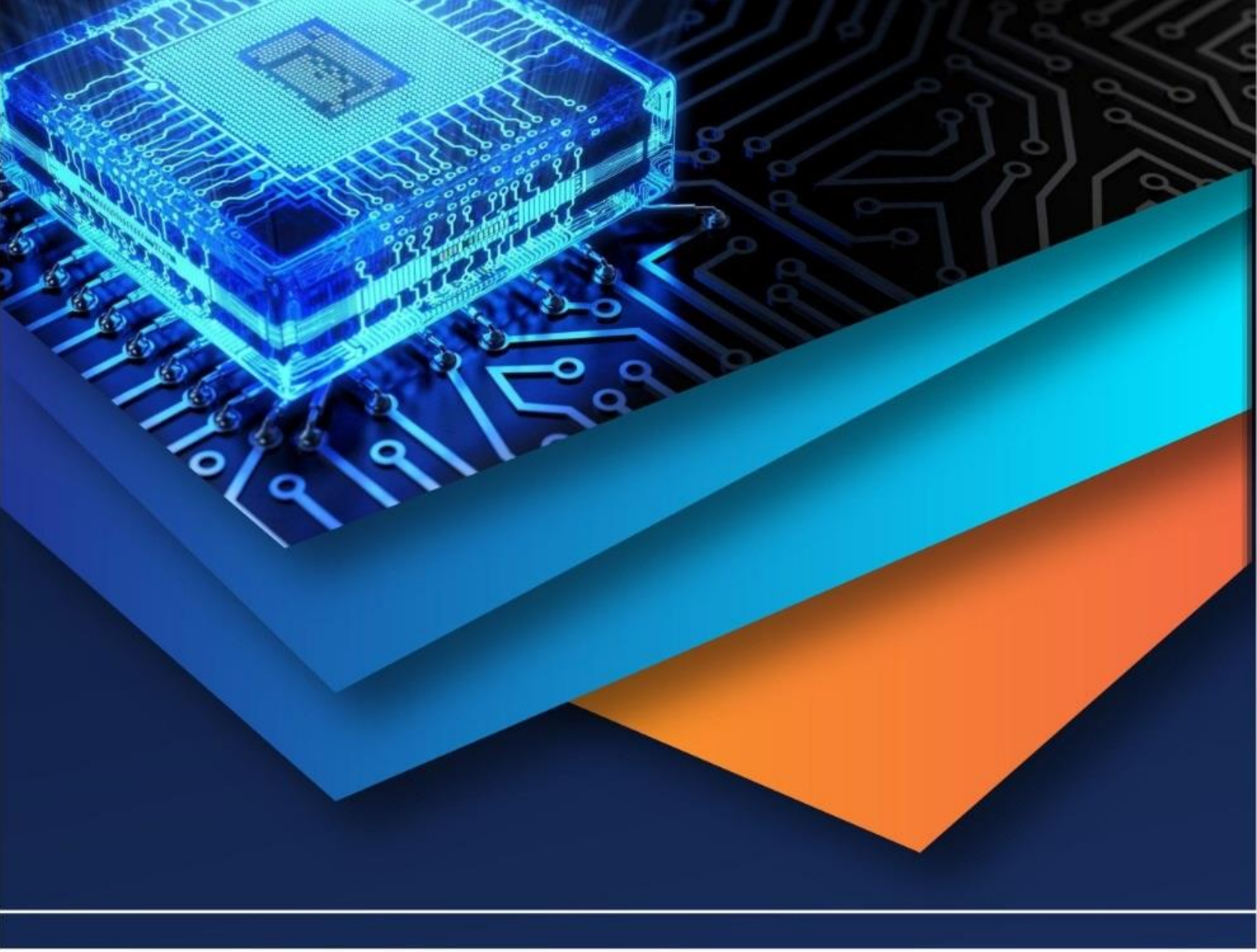
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