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Experimental Design and Analysis of MWCNT, Nanoclay and Zinc Oxide Nanofillers on Bi-directional-Chopped Stranded Glass Fibre Reinforced Epoxy matrix on Mechanical Properties using Multi Response Performance Index Approach

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Abstract: The composite manufactured using nanofillers have found to posses better properties in certain application. In the present work, MWCNTs, Nanoclay and ZnO have been used in GFRP. The developed material can be a promising replacement of composites being used for structural applications in the aerospace sector and space technology apart from the automotives to impart light weight, superior bending and tensile strength. The methodology governing the design of experiments plays a vital role in optimization. Experimental design with three Nanofillers as parameters at three levels for optimization of output characteristics with superior properties for structural applications was done using Taguchi's L9 and L18 orthogonal arrays. Multi Response Performance Index-MRPI technique has been used for determination of maximum optimal level in the present study.Testing for the manufactured composite was conducted to obtain the ultimate tensile strength and flexural bending strength. ANOVA Analysis was performed both for L9 and L18 arrays and respective MRPI's. The effects of three nanofillers infused GFRP was investigated and their impact on tensile and flexural strength were evaluated.MRPI indicated single maximum optimal level for both the output characteristics. As GFRP play very important role in engineering application for Stealth, mechanical, thermal properties, resistance to fire by limiting oxygen and retarding flame, several human lifes travelling and working in civil, commercial as well as defence air transport can be saved and could even develop drone and aircraft meant to escape enemy countries radar tracing and monitoring range.
Keywords: GFRP, Nanofillers, Multi Response Performance Index, Orthogonal Arrays, ANOVA.

I. INTRODUCTION

GFRP infused Nanofillers can effectively outset several hybrid composites for structural applications in aerospace sector and space technology by imparting light weight, stealth, high ductility, compressiblity, bending, impact and thermal characteristics apart from resistance to fire by limiting oxygen and retarding flame that would lead to save human lifes who are travelling and working in civil,commercial and defence air transport. Apart from other automotive applications as alternative materials replacing and reducing dependency on traditional materials would lead to sustainable development and an era of design from cradle to grave.Nanocomposites are also among the innovative materialsused in composites and are distinguished from conventional composite materials by their superior mechanical qualities.

Shanti Kiran Zhade, Syam Kumar Chokka, V. Suresh Babu and K.V. Sai Srinadh reported the effects of the addition of nano clay into GFRP on its mechanical properties. Addition of nano clays enhanced the interfacial bond between reinforced fibers and the matrix which resulted in enhancement in the mechanical properties of the composite. The enhanced fiber matrix interface strength is due to good adhesion between clay platelets and epoxy allowing better stress transfer to all the fibers [1].

D Vinay Kumar and B M Rajaprakash, in the research work focused on experimental design to ascertain *optimal levels through L9, L18 - Orthogonal Arrays and MRPI - Multi Response Performance Index, ANOVA –Analysis of Variance*,and investigated effect of three nanofillers on the output characteristics of hybrid fibre reinforced polymer composite.The results and investigation forecasted future R & D work on hybrid FRP composite and recommends the use of Sonication and magnetic stirring for superior blending of MWCNTs, Nanoclay and ZnO with matrix material to prevent any agglomeration. The GFRP infused MWCNTs, Nanoclay and Zinc Oxide Nanofillers could effectively outset several hybrid composites for structural applications in aerospace sector and space technology by imparting light weight, stealth, high ductility, compressiblity, bending, impact and thermal characteristics apart from resistance to fire by limiting oxygen and retarding flame that would lead to save human lifes who are travelling and working in civil,commercial and defence air transport.[2]

D Vinay Kumar, B M Rajaprakash, Bupesh Kumar K, in their research work,used MWCNTs, Nanoclay and ZnO Nanofillers in GFRP.The developed material was found to be a promising replacement of composites being used for structural applications in the aerospace sector and space technology apart from the automotives to impart light weight, superior bending and tensile strength.Testing of GFRP infused nanofillers was conducted to obtain the ultimate tensile strength and flexural bending strength of the composite.Experimental design with three Nanofillers as parameters at three levels for optimization of output characteristics with superior properties for structural applications was done using Taguchi’s L9 and L18 orthogonal arrays. ANOVA Analysis was also performed.Their impact on mechanical properties were investigated and evaluated[3].

Abdullah Sayam’s review provides a meticulous landscape and recent progress of polymer matrixbased different carbonaceous fillers reinforced composites mechanical properties. The mechanical performance of neat CFRP was exhaustively analyzed.The strategic advantages of fiber hybrid composites over conventional CFRP were elucidated.Mechanical performance of hierarchical composites based on carbon nanotube (1D), graphene (2D) and nanodiamond (0D) was expounded and evaluated against neat CFRP.Also,different fabrication methods sorting out three-dimensional printing (3DP) as the most futuristic fabrication method.[4].

Tanjheel Mahdi in his research reported different dispersion techniques utilized to ensure uniform dispersion of nanoclays, MWCNTs and binary nanoparticles in resin. For MWCNTs ultrasonication and three roll shear mixture techniques were used.

For nanoclays magnetic stirring was employed along with ultrasonication. For binary nanoparticles,combination of all three was used. Nanoparticles reinforcement enhances almost all the properties of nanocomposites evaluated from flexure,tensile, all properties revealed from the tests conducted.Nanoclays exhibits highest life cycle in fatigue testing[5].

Ku zarina ku ahmad, Sahrim Ahmad & Mouad Ahmad Tarawneh in their paper reported the improvement of the mechanical properties of epoxy/nanoclay/multi-walled carbon nanotube (MWNT) nanocomposites prepared by the solution casting method for a range of pre-cure temperatures (room temperature, 50, and 70 ºC), cure temperature (120, 130, and 140 ºC), nanoclay content (0.5, 1.0, 1.5wt%) and content of MWNT (0.2, 0.6, 1.0 wt%) for three levels. The influence of these parameters on the mechanical properties was investigated using Taguchi’s experimental design.The output measured responses were the tensile properties,impact strength and fracture toughness. From the Analysis of Mean (ANOM) and Analysis of Variance (ANOVA), MWNT content, pre-cure temperature and cure temperature had the most significant effects for the impact strength with contribution percentages of 38%, 28% and 23% respectively.Tensile strength was influenced by nanoclay and MWNT content[6].

Ali A. Rajhi in the study of the mechanical behavior of modified GFRP with nanoparticles with different weight percentages found maximum tensile strength in the 0.5 wt% nano-silica modified GFRP. For all the types of specimens, the ultimate tensile strength decreased with the increasing addition of the nanoparticles because of agglomeration.With the inclusion of nanoparticles, the impact strength was also enhanced [7].

Mohammad Imanparast and Hamed Khosravi performed experimental investigation using graphene nanoplatelets (GnPs) to enhance the bending performance of E-glass fiber/epoxy composites.Each specimen was prepared with two layers of E-glass chopped strand mat via the hand lay-up technique and using various contents of GnPs in the matrix (0.1, 0.2, 0.3, 0.4 and 0.5 wt%).The obtained results demonstrated increase in the flexural strength for composite containing 0.4 wt% GnPs. The evaluation of the fractured surfaces clearly demonstrated that the interface between the glass fiber and polymeric matrix was improved when GnPs were added into the matrix. In this work, the effects of different GnPs wt% on the three-point bending properties of E-glass fiber/epoxy composites were explored experimentally [8].

Susilendra Mutalikdesai worked on characterization of the mechanical behaviour of GFRP composites with three types of fillers-Nanoclay, ZnO,fly ash at different weight percentages and combinations were dispersed in epoxy matrix by ultra-sonication method. Epoxy glass composites with various fillers were fabricated by hand lay-up technique. Mechanical characterization of GFRP Hybrid Composites using filler were carried out for tests for tensile, flexural and impact strength properties.It was reported that Nanoclay/ fly ash epoxy composites enhanced tensile and impact strength. ZnO/ fly ash composite enhanced flexural strength [9].

S. Vamshi Krishna studied composites materials used in both industrial and commercial fields in aerospace, marine and automotives.He investigated the mechanical properties of GFRP Composites,Glass fiber-longitudinal (Unidirectional)cross (Bidirectional) and chopped as reinforcement and epoxy resin as matrix material.Tensile test and flexural test for this composute resulted in enhanced tensile and flexural strength for optimal levels than other composites. The variation of mechanical properties like tensile strength, flexural strength, of epoxy based Glass fiber composites has been studied as function of orientation. These composites would applications as structural materials with higher strength with low cost[10].

Kamal Singh Bisht investigated performance of the composites by adding particulate filler.The "filler" play an important role for the improvement in performance of polymer and their composites. Composites samples were prepared by using simple hand-lay-up technique with varying weight fraction of bi-directional glass fiber (40wt%, 60wt%, and 80wt %). Mustard cake powder (10wt %) was used as filler in composites.The effects of fiber loading and filler on the tribological and mechanical behaviour of glass fiber reinforced epoxy composites are studied.The mechanical and wear behaviour of filled composites is more superior then unfilled composites [11].

Lokesh Vaddar investigated and analyzed, the impact of carbon nanopowder filler on the wear and thermal performance of the chopped strand mat E-glass fiber-reinforced epoxy composite (GFREC). Multiwall carbon nanotube (MWCNT) fillers were used; they react with the resin system to contribute a significant improvement of properties in the polymer cross-linking web. The experiments were carried out employing the central composite method of design of experiment (DOE). The study's findings indicate that the addition of carbon nanopowder has a substantial impact on the wear behavior of composites owing to the homogeneity created by the carbon nanofillers in uniformly dispersing the reinforcements in the matrix phase.[12]

Tuan Anh Nguyen studied flame retardants are organic compounds containing halogen or phosphorus groups and are not always well dispersed in polymers. Thus, by using a small amount of nanoclay and multiwalled carbon nanotubes (MWCNTs), they can significantly reduce the number of conventional flame retardant additives, making the material with optimal flame retardant properties.Conventional flame retardants always have some negative effects on the mechanical properties of the polymer substrate, so by using nanoclay and MWCNTs, those adverse effects can be minimized and overcome [13].

Rohit Pratyush Behera studied the use of MWCNTs as nano-compatibilizers.For fabricating samples, MWCNTs were homogeneously dispersed in FRP composite with 0,0.5, 1 and 1.5 wt. % loading using the hand layup technique.Testing reported that the tensile, compressive and inter-laminar shear strength (ILSS) increase by 103.81%, 139.78% and 36.06%, respectively corresponding to 1 wt. % loading of MWCNTs as compared to neat GFRP specimen. However, a rapid decrease in strength beyond 1 wt. % loading of MWCNTs has been noted. It was observed that after a certain loading, the mechanical properties of such laminates can only reach the best value with an optimum loading of MWCNTs[14].

Margarita Volkova devoted to the development of epoxy-encapsulated ZnO–MWCNT hybrid nanostructured composites.The ZnO–MWCNT hybrid nanostructured networks were encapsulated in commercially available epoxy adhesive. It was found that encapsulation of ZnO–MWCNT hybrid networks in epoxy adhesive resulted in a simultaneous decrease in their electrical resistance by a factor of 20–60 and an increase in the Seebeck coefficient by a factor of 3–15, depending on the MWCNT content. As a result, the thermoelectric power factor of the epoxy-encapsulated ZnO–MWCNTs hybrid networks exceeded that of non-encapsulated networks by more than 3–4 orders of magnitude [15].

K. Devendra's,investigated on the the mechanical properties of E-glass fiber reinforced epoxy com- posites filled by varying concentrations of fly ash, aluminum oxide(Al_2O_3), magnesium hydroxide($Mg(OH)_2$) and hematite powder which were fabricated by standard method and the mechanical properties such as ultimate tensile strength, impact strength and hardness of the fabricated composites were studied. The test results show that composites filled by 10% volume $Mg(OH)_2$ exhibited maximum ultimate tensile strength and hardness.Fly ash filled composites exhibited maximum impact strength [16].

Maduthuri Venkatesh investigated,epoxy polymer nanocomposites reinforced with E-glass fiber, multi-walled carbonnanotubes(MCNT), and nano bagasse prepared by hand layup technique. Nanocomposites with 3, 5, and 7 layers of E-glass were prepared. The weight percentages of MCNT were varied as1%, 3%, and 5%, while the weight percentage of nano bagasse was fixed at 0.5. A maximum ultimate tensile strength of 352 MPa was observed with 3 layered nanocomposites with 3 wt% CNT. Maximum impact strength of 132 J was in nanocomposites with seven layers and 1 wt% CNT[17].

Masoumeh Nazem study aimed to imbed secondary nanoscale reinforcement into the matrix of glass/carbon/epoxy composite where amino multi-walled carbon nanotubes and hybridization of amino multi-walled carbon nanotube and Nanoclay (Cloisite 30B) were utilized. The tensile, flexural and impact properties of hybrid composites were evaluated and a comparative study between hybrid composite reinforced with amino- MWCNTs and simultaneous amino-MWCNTs and Nanoclay was conducted.

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The results of the tensile test revealed that incorporation of amino-MWCNTs reduced the ultimate strength of hybrid composite, while the elastic modulus of composite with combination of amino-MWCNTs and Nanoclay increased.[18]

Abhishek studied, impact of cross breed E-glass built up fiber with epoxy Nano composite by hand layup procedures by shifting layers of Titanium Dioxide (TiO2) nanoparticles. Flexural properties of the glass fiber built up plastic improved with expansion of nanoTiO2 filler particles.At 0.6 wt% of TiO2,having 12 layers, the force at yield was 327.99N and in 9 layers force at yield was 149.06N.True interfacial bonding b/w the fiber and epoxy turned into the primary motive for reaching higher flexural properties.[19].

Krishna G studied the feasibility of utilizing the agro-residue as an alternative reinforcement in thermoplastics. Based upon the analyzed samples and their results, he concluded that, all samples subjected to tensile test shows that the composite sample with 30% fiber obtains high tensile strength and by addition of E-Glass reinforcement its ultimate tensile strength increases further. All samples subjected to flexural test shows that the composite material with 20%. fiber has more flexural strength when compared with other composite samples.Hence, it was concluded that the sample with the fiber reinforcement effectively improves the tensile and flexural strength when compared to the pure polymer and the composite with the 30% fiber shows promising results in the flexural tests when compared with the other sample.[20]

Rahul K, experimentally investigated tensile and flexural behavior of kenaf and glass fiber reinforced epoxy composite of different fiber lengths have been carried out. It has been observed from the work that type of fiber length strongly influence the properties of the composite.The alkalization treatment of kenaf fibers has improved the properties of the developed hybrid composite [21].

Elayaraja.R in experimental investigation, prepared hybrid composite with Bisphenol unsaturated polyester resin polymer matrix using untreated Kenaf fiber and E-glass fiber reinforcement. Kenaf/fiber glass hybrid composites were manufactured using a mixture of hand-laying techniques. Prepared composites were evaluated for compression, flexural and impact strength (Izod test) as per ASTM D3410, ASTM D790 and ASTM D256, respectively. Harness (Brinell) and water absorption tests were also carried out. Water absorption tests were conducted in two environmental conditions including sea water and distilled water. Results stated that the mechanical characteristics of kenaf fiber were reduced after the moisture had penetrated the composite [22].

Christian Narváez Improved Glass-Fiber Epoxy Composites via Interlayer Toughening with Polyacrylonitrile / Multiwalled Carbon Nanotubes Electrospun Fibers. The fabrication of cost-efficient engineered epoxy composites materials is by far one of the major challenging topics at research and industrial scale.He demonstrated for the first time that is possible to manufacture glassfiber epoxy reinforced nanocomposites (GFECs) via interlayer toughening, by employing electrospun fibers as reinforcing phase produced from a mixture of polyacrylonitrile (PAN) and multi-walled carbon nanotubes (MWCNT) solutions.Results suggest that similar GFECs nanocomposites would have potential applications in different sectors such as the aeronautics and automotive industries [23].

II.METHODS AND MATERIAL

A. Design Of Experiment

1) Taguchi's L18 (3^3) and L9 (3^3) Orthogonal Arrays

Experimental design through L18 and L9 Orthogonal Arrays with three parameters, three levels, and two output characteristics. Table 1 shows three parameters at three levels. For example, consider the P = 3, L = 3 case on table 1. When parameter a is at level 1 parameter b is tested at levels 1, 2, and 3 (all levels). Similarly, parameters c is tested at levels 1, 2, and 3 (all L levels). The same thing holds when parameter a is at level 2 or level 3. The same thing holds for all of the para- meters. Again when parameter a is at level 1, parameter b is tested at levels 1, 2, and 3 (all levels). Similarly, parameters c is tested at levels 1, 2, and 3 (all Llevels). The same thing holds when parameter a is at level 2 or level 3. The same thing holds for all of the parameters

Table 1 : Taguchi $L_{18}(3^3)$ Orthogonal Array

Trial	Parameter = 3, Levels = 3			Output Characteristics	
	A	B	C	x	y
1.	1	1	1	x_1	y_1
2.	1	2	2	x_2	y_2
3.	1	3	3	x_3	y_3
4.	2	1	2	x_4	y_4
5.	2	2	3	x_5	y_5
6.	2	3	1	x_6	y_6
7.	3	1	3	x_7	y_7
8.	3	2	1	x_8	y_8
9.	3	3	2	x_9	y_9

TABLE 2 : Taguchi $L_9(3^3)$ Orthogonal Array

Trials	Parameter = 3, Levels = 3			Output Characteristics	
	A	B	C	x	y
1.	1	1	1	x_1	y_1
2.	1	2	2	x_2	y_2
3.	1	3	3	x_3	y_3
4.	2	1	1	x_4	y_4
5.	2	2	2	x_5	y_5
6.	2	3	3	x_6	y_6
7.	3	1	2	x_7	y_7
8.	3	2	3	x_8	y_8
9.	3	3	1	x_9	y_9
10.	1	1	3	x_{10}	y_{10}
11.	1	2	1	x_{11}	y_{11}
12.	1	3	2	x_{12}	y_{12}
13.	2	1	2	x_{13}	y_{13}
14.	2	2	3	x_{14}	y_{14}
15.	2	3	1	x_{15}	y_{15}
16.	3	1	3	x_{15}	y_{15}
17.	3	2	1	x_{17}	y_{17}
18.	3	3	2	x_{18}	y_{18}

Similarly, for L9 Orthogonal Array with three levels and three parameters each level is tested 3 times that is 9 runs are required.This can also be understood from above Table 2 with three parameters at three levels. From the above it can be seen that, Taguchi's $L_9(3^3)$ Orthogonal array is a subset of Taguchi's $L_{18}(3^3)$ Orthogonal array, therefore experimentation for $L_{18}(3^3)$ Orthogonal array shall serve for both the orthogonal arrays. Hence for analyzing, two arrays are taken from $L_{18}(3^3)$, which are $L_9\,(3^3)$ and $L_{18}\,(3^3)$ itself.

2) S/N Ratio for L18(3^3) and L9(3^3) Orthogonal Array

To determine the effect each variable has on the output, the signal-to-noise ratio, or the SN number, needs to be calculated for each experiment conducted. For both the output characteristics,maximizing the performance characteristic,following definition of the S/N ratio should be calculated:

$$SN_i = -10 \log[\, 1/N_i \sum_{u=1}^{N_i} 1/y_u^2]$$

In the equation above,i is the experimental number, u is the trial number and N_i is the number of trials for experiment i

3) Anova for - L18 (3^3) AND L9 (3^3) Orthogonal Array

For output characteristics 'X' of L18 Orthogonal Array

$\mathbf{SS_{Total}} = \{ [(X_1)^2 + (X_2)^2 + (X_3)^2 + (X_4)^2 + (X_5)^2 + (X_6)^2 + (X_7)^2 + (X_8)^2 + (X_9)^2 + (X_{10})^2 + (X_{11})^2 + (X_{12})^2 + (X_{13})^2 + (X_{14})^2 + (X_{15})^2 + (X_{16})^2 + (X_{17})^2 + (X_{18})] – [C.F] \}$

$\mathbf{SS_A} = A_1^2 \div NA_1 + A_2^2 \div NA_2 + A_3^2 \div NA_3$ - C.F;

$\mathbf{SS_B} = B_1^2 \div NB_1 + B_2^2 \div NB_2 + B_3^2 \div NB_3$ - C.F ;

$\mathbf{SS_C} = C_1^2 \div NC_1 + C_2^2 \div NC_2 + C_3^2 \div NC_3$ - C.F;

$\mathbf{SS_{ERROR}} = SS_{Total} - (SS_A + SS_B + SS_C)$

Where $C.F = [(X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_{11} + X_{12} + X_{13} + X_{14} + X_{15} + X_{16} + X_{17} + X_{18})^2 \div 18]$
Hence, Analysis of variance -ANOVA can be calculated for both the output characteristics ‘X’ & ‘Y’.

TABLE 3 : ANOVA for Means (Output Characterisitcs ‘X’)

SOURCE	DoF	SS	MS	F	Percentage Contribution
A	2	SS_A	$SS_A/2$	MS_A/MS_{Er}	SS_A/SS_T x 100
B	2	SS_B	$SS_B/2$	MS_B/MS_{Er}	SS_B/SS_T x 100
C	2	SS_C	$SS_C/2$	MS_C/MS_{Er}	SS_C/SS_T x 100
ERROR	11	SS_{ER}	$SS_{ER}/2$	MS_{Er}/MS_{Er}	SS_{ER}/SS_T x 100
TOTAL	17	SS_T			100

The above ANOVA-Analysis of Varaiance procedure for L18 array can be transferred to L9 array also.

4) Multi Response Performance Index -Mrpi Technique

a) Determination Of Weights

Table 4 : L9 Array with Output Characteristics

Trials	**Parameter = 3, Levels = 3**			**Output Characteristics**	
	A	**B**	**C**	**x**	**y**
1.	1	1	1	X_1	Y_1
2.	1	2	2	X_2	Y_2
3.	1	3	3	X_3	Y_3
4.	2	1	2	X_4	Y_4
5.	2	2	3	X_5	Y_5
6.	2	3	1	X_6	Y_6
7.	3	1	3	X_7	Y_7
8.	3	2	1	X_8	Y_8
9.	3	3	2	X_9	Y_9

For X(larger-the better characteristics),individual response(data) is divided by total response value (ΣX).
For Y(larger-the better characteristics),individual response(data) is divided by total response value (ΣY).

From Table : 5

ΣX & ΣY are calculated
Now ; $W_{X1} = X_1 / \Sigma X$; $W_{Y1} = Y_1 / \Sigma Y$
$W = W_1R_1 + W_2R_2$; R_1 R_2 → Responses ;W →Weight
$(MRPI)_i = W_1Y_{11} + W_2 Y_{12} + \ldots\ldots\ldots + W_jY_{ij}$

$(MRPI)_i$ = MRPI of the i_{th} trial/experiment
W_j = Weight of the j_{th} response/dependent variable
Y_{ij} = observed data of i_{th} trial/experiment under j_{th} response.
$MRPI_1 = (X_i * W_x + Y_i * W_y)$
The weights & MRPI values for all the trials are given in Table-5

Table : 5 : Weights and MRPI values for Illustration

Trial	X_i	W_x	Y_i	W_Y	MRPI
1.	X_1	W_{x1}	Y_1	W_{Y1}	$MRPI_1$
2.	X_2	W_{x2}	Y_2	W_{Y2}	$MRPI_2$
3.	X_3	W_{x3}	Y_3	W_{Y3}	$MRPI_3$
4.	X_4	W_{x4}	Y_4	W_{Y4}	$MRPI_4$
5.	X_5	W_{x5}	Y_5	W_{Y5}	$MRPI_5$
6.	X_6	W_{x6}	Y_6	W_{Y6}	$MRPI_6$
7.	X_7	W_{x7}	Y_7	W_{Y7}	$MRPI_7$
8.	X_8	W_{x8}	Y_8	W_{Y8}	$MRPI_8$
9.	X_9	W_{x9}	Y_9	W_{Y9}	$MRPI_9$

b) Maximum MRPI

Now, we consider MRPI (Table - 6) as single response of original problem and obtain solution using methods. Since MRPI is a weighted score, optimal levels are identified based on maximum MRPI-Multi Response Performance Index values in Table - 7

Table 6 : MRPI as response

Trial	Factors			MRPI
	A	B	C	
1.	1	1	1	$MRPI_1$
2.	1	2	2	$MRPI_2$
3.	1	3	3	$MRPI_3$
4.	2	1	2	$MRPI_4$
5.	2	2	3	$MRPI_5$
6.	2	3	1	$MRPI_6$
7.	3	1	3	$MRPI_7$
8.	3	2	1	$MRPI_8$
9.	3	3	2	$MRPI_9$

Table 7 : The level total of MRPI

Factors	Levels		
	1	2	3
Inlet temp.(A)	$MRPI_{A1}$	$MRPI_{A2}$	$MRPI_{A3}$
Injection time(B)	$MRPI_{B1}$	$MRPI_{B2}$	$MRPI_{B3}$
Injection pressure(C)	$MRPI_{C1}$	$MRPI_{C2}$	$MRPI_{C3}$

The optimal levels are selected based on maximum MRPI are A_1B_1 & C_1(example) as mentioned above in Table 7

Multi Response Performance Index - MRPI discussed above for L9 array can be transferred to L18 array also. MRPI technique shall be used for determination of maximum optimal level for the present study.

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B. Materials Selection For Design Of Experiments

The materials are selected based on the design of experiments as detailed in Table 8 and illustrated in Fig 1 below.

Table 8 : Details of Materials for Experimentation

S.No.	Particulars of Materials	Specification	Supplier
1.	Chopped Stranded Glass Fibre Mat	283.33 GSM	Suntech Fibre Pvt Ltd. Bangalore
2.	Bi-Directional Glass Fibre Mat	193.33 GSM	Vijay Trading Corporation, Bangalore
3.	Epoxy Resin with Hardner	HSC 7560	Hindustan Speciality Chemicals
4.	Multi Walled Carbon Nanotubes-D MWCNT	ADMWCNT-25	Adnano technologies Pvt.Ltd., Shimoga
5.	Nanoclay	AD-MMTNC-10	
6.	Zinc Oxide	AD-ZnO	

Fig 1 : Glass Fibre,Epoxy resin,Hardner and MWCNTs,Nanoclay and ZnO

C. Determination Of Composition And Levels

The weights are determined as weight percentages for the matrix material, reinforcements and nanofillers. Levels for all three nanofillers as the factors (parameters) are assigned as stated in Table-9. Ratio of Weight percentage for Reinforcement to Matrix material was taken as 60 : 40.

Table 9 : Levels for each Parameters

Levels	Parameters		
	Wt. % of MWCNT[A]	Wt. % of Nanoclay[B]	Wt. % of ZnO[C]
I	0.5	0.5	0.5
II	0.75	0.75	0.75
III	1	1	1

D. Fabrication By Hand Layup Process

Figure 2 shows the Stacking sequence for 09 layers of Glass Fibres that was arranged as $\mathbf{G_{Bi}}$ $\boldsymbol{G_{CS}}$ $\mathbf{G_{Bi}}$ $\boldsymbol{G_{CS}}$ $\mathbf{G_{Bi}}$ $\boldsymbol{G_{CS}}$ $\mathbf{G_{Bi}}$ $\boldsymbol{G_{CS}}$ $\mathbf{G_{Bi}}$ for trials**.** Here $\mathbf{G_{Bi}}$ is Bi-directional Glass Fibre mat and, $\boldsymbol{G_{CS}}$ is Chopped Stranded Glass Fibre Mat.

For Trial Number 01, initially epoxy resin weighing 36.3 g or 34.5 %(weight percentage) was taken in a 150 ml beaker and weighed in the weighing machine.

Fig 2 : 09 layers Stacking sequence arrangement of Bi-directional and chopped stranded glass fibre mat

Subsequently, equal weight proportion of 0.5g or 0.5 %(weight percentage) of each Nanofiller namely (1) Multi Walled Carbon Nanotube-MWCNT[A], (2) Nanoclay[B] and (3) Zinc Oxide-ZnO[C] in chronological sequence corresponding to Trial Number 01 were added to the resin one by one and thoroughly hand stirred through Glass Rod following the addition of each Nanofiller.Finally, hardner weighing 4.2 g or 4%(weight percentage) was added to the mixture of epoxy resin and nanofillers and stirred thoroughly again. A thin layer of the mixture obtained through above process was then layed by pouring to the wax coated granite surface and evenly spreaded over an area of 300mm X 100 mm dimension on which the first layer of reinforcement GBi that is Bi-directional Glass Fibre mat, 300mm X 100 mm weighing 5.8 g (193.333 GSM) was layed and pressed for even adhesion. Before laying the second layer of Glass Fibre mat, matrix material was again poured over the first layer reinforcement and evenly spreaded. Thereafter, the second layer of reinforcement, GCS that is Chopped Stranded Glass Fibre Mat 300mm X 100 mm weighing 8.5 g (283.333 GSM) was layed over it.

Fig 3 : Layer-02- Chopped Stranded Mat layed over layer-01

Likewise, alternate layers of both the reinforcement comprising four layers of the latter and five layers of the former were layed with nanofilled matrix material as adhesion between them, such that the final top layer (9th layer) and the bottom layer(1st layer), both the outer layers comprised of Bi-directional Glass Fibre mat for all 18 (eighteen) trials or experiments which were conducted over a span of 02 (two) weeks to obtain the specimens.Total weight for the reinforcement accounted for 63 g or 60%(weight percentage).The ratio of weight percentage of reinforcement to matrix material was maintained at 60 : 40for all 18 runs.

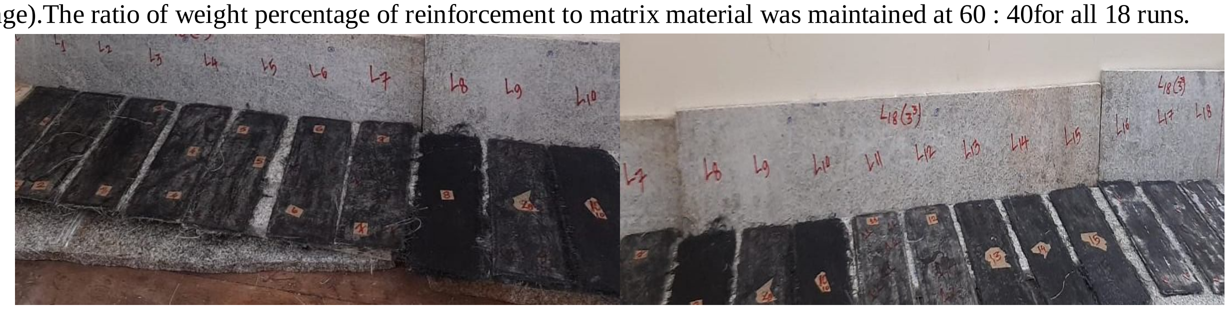

Fig 4 : All 18 Specimens layed ready for Abrasive Water jet cutting to ASTM Standards for testing

E. Abrasive Waterjet Cutting

Figure-5 below shows the 'Abrasive Waterjet Cutting' of specimens was performed to obtain samples as per ASTM standards for tensile strength (250 x 25 x 2.3mm) and flexural strength (127 x 12.7 x 2.3 mm) tests.

Fig 5 : Abrasive Waterjet Cutting of Specimens to standard dimensions for Tensile & Flexural Test

F. Testing For Mechanical Properties

Fig 6 and Fig 7 below shows the Specimens for all eighteen (18) trials tested as per ASTM Standards for Tensile Test and Flexural Bending Test in Universal Testing Machine at Material testing Laboratory.

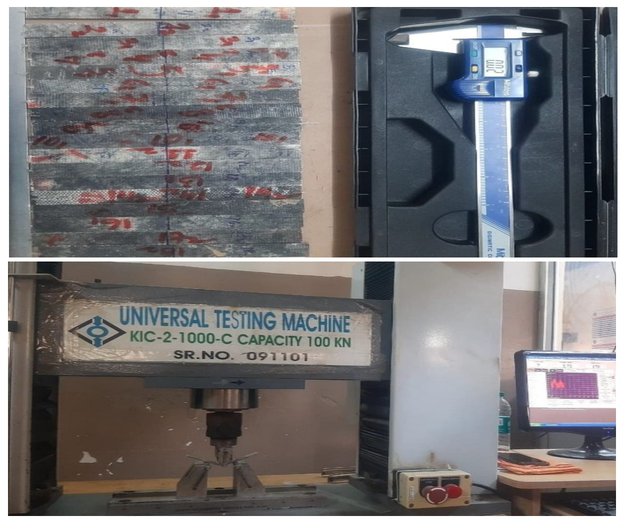

Fig 6. : Tensile test for Specimens in UTM as per ASTM Standards. Fig 7 : Flexural bending test for Specimens in UTM as per ASTM Standards.

III. RESULTS AND DISCUSSION

The Output characteristics as results for L18 and L9 Orthogonal Array are tabulated in Table 10, 14 and Table 22,26, emphasizing on calculations for S/N Ratio's. Response table for optimal levels of S/N Ratio and average mean for Tensile Strength and Flexural Strength as output characteristics were calculated theoritically and verified with results and plots obtained from Minitab Software. Multi Response Performance Index with optimal levels and ANOVA was obtained and compared for both the arrays.

A. Ultimate Tensile Strength – UTS L18

The Ultimate tensile strength obtained from testing of specimens for all the eighteen compositions were tabulated alongwith S/N Ratio calculations for *Larger is better.*

1) Calculations of S/N Ratio's – UTS(L18)

S/N Ratio : *For Larger the Better :*

$$\mathbf{S/N = -10 \log [1*1/(UTS)^2]}$$

For Trial 01,S/N = -10 log$[1*1/(63.78)^2]$ = 36.0936903, For Trail 02, S/N = -10log$[1*1/(61.76)^2]$ = 35.81414575

For Trail 03, S/N = -10 log$[1*1/(57.89)^2]$ = 35.25207099, For Trail 04, S/N = -10 log$[1*1/(55.22)^2]$ = 34.84192805

For Trail 05, S/N = -10 log$[1*1/(51.25)^2]$ = 34.19387739, For Trail 06, S/N = -10 log$[1*1/(54.73)^2]$ = 34.76450896

For Trail 07, S/N = -10 log$[1*1/(44.75)^2]$ = 33.01586079, For Trail 08, S/N = -10 log$[1*1/(59.67)^2]$ = 35.51512076

For Trail 09, S/N = -10 log[1*1/$(49.93)^2$] = 33.96723132, For Trail 10, S/N = -10 log[1*1/$(57.22)^2$]= 35.15095707
For Trail 11, S/N = -10 log[1*1/$(41.51)^2$] =32.36305467, For Trail 12, S/N = -10 log[1*1/$(53.13)^2$] = 34.50679632
For Trail 13, S/N = -10 log[1*1/$(47.19)^2$] = 33.47699955, For Trail 14, S/N = -10 log[1*1/$(70.02)^2$] = 36.90444213
For Trail 15, S/N = -10 log[1*1/$(52.89)^2$] = 34.46747134, For Trail 16, S/N = -10 log[1*1/$(50.32)^2$] = 34.03481265
For Trail 17, S/N = -10 log[1*1/$(38.38)^2$] = 31.68209941, For Trail 18, S/N = -10 log[1*1/$(44.51)^2$] = 32.96915189

Table 10 : L18(3^3) Orthogonal Array-Ultimate Tensile Strength and S/N Ratio

Trial	Parameter - Wt % of			Ultimate Tensile Strength (Mpa)	S/N Ratio for Ultimate Tensile strength
	MWCNT [A]	Nanoclay [B]	ZnO [C]		
1.	0.5	0.5	0.5	63.78	36.0936903
2.	0.5	0.75	0.75	61.76	35.81414575
3.	0.5	1	1	57.89	35.25207099
4.	0.75	0.5	0.5	55.22	34.84192805
5.	0.75	0.75	0.75	51.25	34.19387739
6.	0.75	1	1	54.73	34.76450896
7.	1	0.5	0.75	44.75	33.01586079
8.	1	0.75	1	59.67	35.51512076
9.	1	1	0.5	49.93	33.96723132
10.	0.5	0.5	1	57.22	35.15095707
11.	0.5	0.75	0.5	41.51	32.36305467
12.	0.5	1	0.75	53.13	34.50679632
13.	0.75	0.5	0.75	47.19	33.47699955
14.	0.75	0.75	1	70.02	36.90444213
15.	0.75	1	0.5	52.89	34.46747134
16.	1	0.5	1	50.32	34.03481265
17.	1	0.75	0.5	38.38	31.68209941
18.	1	1	0.75	44.51	32.96915189

2) Response Table – UTS (L18)

For S/N ratios, A1, B1 and C3 give maximum ultimate tensile strength. This has been calculated theoritically as stated below and tabulated in Table 11.1

A_1=209.1807151/6=34.86345252, A_2=208.6492274/6=34.77487123, A_3=201.1842768/6= 33.5307128
B_1 = 206.6142484/6= 34.43570807, B_2= 206.4727401/6 = 34.41212335,B_3=205.9272308/6= 34.32120513
C_1 = 203.4154751/6= 33.90257918, C_2= 203.9768317/6= 33.99613862, C_3=211.6219126/6=35.27031877

Table 11.1 – Response Table for Avg. S/N ratio of UTS –Optimal level $A_1B_1C_3$

Levels	A	B	C
1	34.86345252	34.43570807	33.90257918
2	34.77487123	34.41212335	33.99613862
3	33.5307128	34.32120513	35.27031877
Delta	1.33273972	0.11450294	1.367739587
Rank	2	3	1

The above theoritical S/N ratios were verified with the main effect plot and table for S/N ratio obtained from MINITAB Software as shown in Figure 8.1 and Table 11.2

Table 11.2 Response Table for Signal to Noise Ratios(Minitab)

Level	Wt % of MWCNT (A)	Wt% of Nanoclay (B)	Wt% of ZnO(C)
1	34.86	34.44	33.90
2	34.77	34.41	34.00
3	33.53	34.32	35.27
Delta	1.33	0.11	1.37
Rank	2	3	1

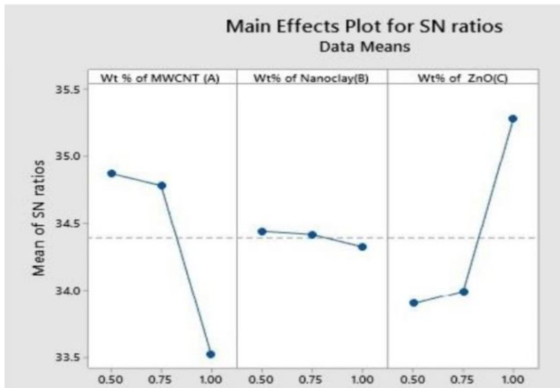

Figure 8.1 : Main Effects Plot for S/N ratios(L18-UTS)

For Mean of UTS A1, B2 and C3 gave maximum Ultimate Tensile strength. This has been calculated theoritically as stated below and tabulated in Table 12.1

A_1 = 335.29/6 = 55.88166667, A_2 =331.3/6=55.21666667, A_3=287.56/6=47.92666667

B_1 = 318.48/6=53.08, B_2= 322.59/6=53.765, B_3=313.08/6=52.18

C_1 = 301.71=50.285, C_2= 302.59=50.43166667, C_3=349.85/6=58.30833333

TABLE 12.1 : Average mean of Ultimate tensile Strength with optimal level $A_1B_2C_3$

Level	A	B	C
1	55.88166667	53.08	50.285
2	55.21666667	53.765	50.43166667
3	47.92666667	52.18	58.30833333
Delta	7.955	1.585	8.02333333
Rank	2	3	1

The above theoritical Average mean of UTS were verified with the main effect plot and table for means obtained from MINITAB Software as shown in Figure 8.2 and Table 12.2

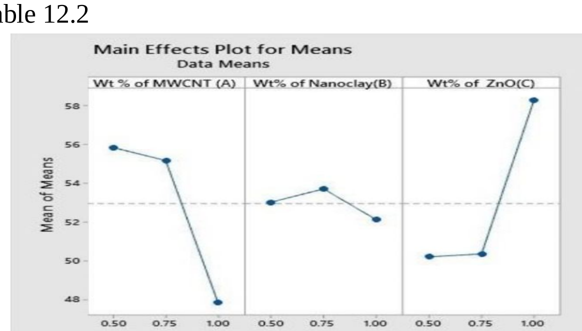

Figure 8.2 : Main Effects Plot for Means(L18-UTS)

Table 12.2 Response Table for Means(Minitab)

Level	Wt % of MWCNT (A)	Wt% of Nanoclay(B)	Wt% of ZnO(C)
1	55.88	53.08	50.28
2	55.22	53.76	50.43
3	47.93	52.18	58.31
Delta	7.95	1.58	8.02
Rank	2	3	1

3) *Anova Calculations – UTS(L18)*

SS_{Total} ={[(63.78)^2+(61.76)^2+(57.89)^2+(55.22)^2+ (51.25)^2+(54.73)^2+(44.75)^2+(59.67)^2+(49.93)^2+(57.22)^2+(41.51)^2+53.13)^2+(47.19)^2 + (70.02)^2 + (52.89)^2 + (50.32)^2 +(38.38)^2 + (44.51)^2] – [(63.78+ 61.76+57.89+55.22+51.25+54.73+44.75+59.67+49.93+57.22+ 41.51+ 53.13+47.19+70.02+52.89+50.32+38.38+ 44.51)^2/ 18] }

= 51694.0191 – (954.15)^2/18

= 51694.0191 – 910402.2225/18

= 51694.0191 – 50577.90125

SS_{Total} = 1116.11785

SS_A = $A_1^2/NA_1 + A_2^2/NA_2 + A_3^2/NA_3$ - C.F ;

= 335.29^2/6 + 331.3^2/6 +287.56^2/6 -50577.90125

= 50811.63796 – 50577.90125

SS_A = 233.73671

SS_B = $B_1^2/NB_1 + B_2^2/NB_2 + B_3^2/NB_3$ - C.F ;

= 318.48^2/6 + 322.59^2/6 +313.08^2/6-50577.90125

= 50585.48415– 50577.90125

SS_B = 7.5829

SS_C = $C_1^2/NC_1 + C_2^2/NC_2 + C_3^2/NC_3$ - C.F ;

= 301.71^2/6 + 302.59^2/6 + 349.85^2/6 - 50577.90125

= 50830.77579 – 50577.90125

SS_C = 252.87454

SS_{ERROR} = (SS_{Total} - SS_A - SS_B - SS_C)

= (1116.11785- 233.7367067- 7.5829-252.8745367)

SS_{ERROR} = 621.9237

Table 13 : ANOVA for Mean (Ultimate Tensile Strength-L18)

SS	SOURCE	DoF	MS	F	Percentage Contribution
233.73671	A	2	116.868355	0.375828594	20.94193817
7.5829	B	2	3.79145	0.012192653	0.679399581
252.87454	C	2	126.43727	0.406600584	22.65661641
621.9237	ERROR	11	310.96185	1	55.72204584
1116.11785	TOTAL	17			100.00006

4) *Theoritical – UTS(L18)*

After conducting the experiment and on determining the optimum composition, the theoritical value of Ultimate Tensile Strength for Optimal Level **A1B1C3**(Average S/N Ratio) is calculated.

σ_{UTS} = [Avg. σ_{UTS} of A_1 + Avg. σ_{UTS} of B_1 + Avg. σ_{UTS} of C_3]– [2(Avg.σ_{UTS})]

σ_{UTS} = 60.2533333 MPa

Also, the theoritical value of Ultimate Tensile Strength for Optimal Level **A1B2C3**(Average mean) is calculated:

σ_{UTS} = 60.9383333 Mpa

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B. Flexural Strength – FS - L18

Flexural strength obtained from testing of specimens for all the eighteen compositions were tabulated alongwith S/N Ratio calculations for *Larger is better.*

1) Calculations of S/N Ratio's – FS(L18)

S/N Ratio : *For Larger the Better :*

$$S/N = -10 \log [1*1/(FS)^2]$$

For Trial Number 01, $S/N= -10\log[1*1/(6.24)^2] = 15.90369179$

For Trial Number 02, $S/N = -10 \log[1*1/(6.18)^2] = 15.8197685$

For Trial Number 03, $S/N = -10 \log[1*1/(10.74^2] = 20.62008563$

For Trial Number 04, $S/N = -10 \log[1*1/(15.15)^2] = 23.60825266$

For Trial Number 05, $S/N = -10 \log[1*1/(7.45)^2] = 17.44312545$

For Trial Number 06, $S/N = -10 \log[1*1/(11.88)^2] = 21.49632881$

For Trial Number 07, $S/N = -10 \log[1*1/(10.11)^2] = 20.09502311$

For Trial Number 08, $S/N = -10 \log[1*1/(35.88)^2] = 31.09704869$

For Trial Number 09, $S/N = -10 \log[1*1/(7.99)^2] = 18.05093559$

For Trial Number 10, S/N = -10log[1*1/(23.77)2] = 27.52058363

For Trial Number 11, $S/N = -10 \log[1*1/(7.04)^2] = 16.95145318$

For Trial Number 12, $S/N = -10 \log[1*1/(20.01)^2] = 26.02494177$

For Trial Number 13, $S/N = -10 \log[1*1/(15.57)^2] = 23.84577225$

For Trial Number 14, $S/N = -10 \log[1*1/(11.47)^2] = 21.19126836$

For Trial Number 15, $S/N = -10 \log[1*1/(27.96)^2] = 28.93074334$

For Trial Number 16, $S/N = -10 \log[1*1/(19.23)^2] = 25.67958568$

For Trial Number 17, $S/N = -10 \log[1*1/(11.91)^2] = 21.51823523$

For Trial Number 18, $S/N = -10 \log[1*1/(18.66)^2] = 25.41823279$

Table 14 : L18(3^3) Orthogonal Array- Flexural Strength and S/N Ratio

Trial	Parameter Wt % of			Flexural Strength (Mpa)	S/N Ratio Flexural Strength
	MWCNT grams(A)	Nanoclay grams(B)	ZnO grams(C)		
1.	0.5	0.5	0.5	6.24	15.90369179
2.	0.5	0.75	0.75	6.18	15.8197685
3.	0.5	1	1	10.74	20.62008563
4.	0.75	0.5	0.5	15.15	23.60825266
5.	0.75	0.75	0.75	7.45	17.44312545
6.	0.75	1	1	11.88	21.49632881
7.	1	0.5	0.75	10.11	20.09502311
8.	1	0.75	1	35.88	31.09704869
9.	1	1	0.5	7.99	18.05093559
10.	0.5	0.5	1	23.77	27.52058363
11.	0.5	0.75	0.5	7.04	16.95145318
12.	0.5	1	0.75	20.01	26.02494177
13.	0.75	0.5	0.75	15.57	23.84577225
14.	0.75	0.75	1	11.47	21.19126836
15.	0.75	1	0.5	27.96	28.93074334
16.	1	0.5	1	19.23	25.67958568
17.	1	0.75	0.5	11.91	21.51823523
18.	1	1	0.75	18.66	25.41823279

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2) Response Table – FS(L18)

For S/N ratios, A3, B3 and C3 give maximum Flexural Strength. This has been calculated theoritically as stated below and tabulated in Table 15.1

$\mathbf{A_1}$= 122.8405245/6 = 20.47342075, A_2 = 136.5154909/6 = 22.75258181, A_3 =141.8590611/6 =2 3.64317685

B_1=136.6529091/6=22.77548485,B_2=124.0208994/6=20.6701499,B_3=140.541268/6=23.42354466

C_1=124.9633118/6=20.82721863,C_2=128.6468639/6=21.44114398,C_3=147.6051535/6=24.60085891

Table 15.1- Average S/N ratios of Flexural Strength – Optimal level is $A_3B_3C_3$

Level	A	B	C
1	20.47342075	22.77548485	20.82721863
2	22.75258181	20.6701499	21.44114398
3	23.64317685	23.42354466	24.60085891
Delta	3.1697561	2.75339476	3.77364028
Rank	2	3	1

The above theoritical S/N ratios were verified with the main effect plot and table for S/N ratio obtained from MINITAB Software as shown in Figure 9.1 and Table 15.2

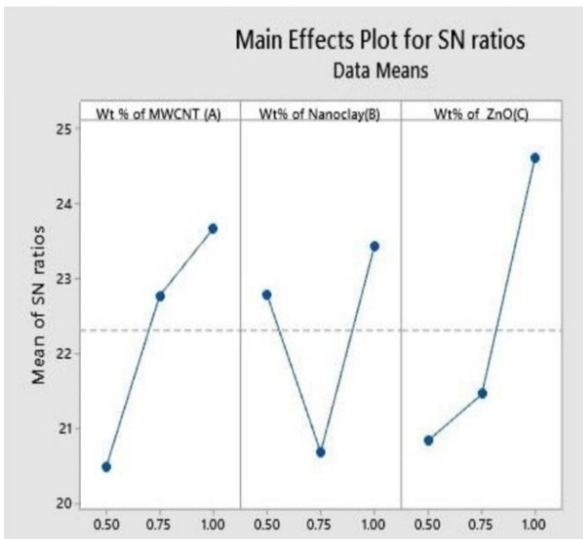

Figure 9.1 : Main Effects Plot for S/N ratios (L18-FS)

Table 15.2 Response Table for Signal to Noise Ratios(Minitab)

Level	Wt % of MWCNT (A)	Wt% of Nanoclay(B)	Wt% of ZnO(C)
1	20.47	22.78	20.83
2	22.75	20.67	21.44
3	23.64	23.42	24.60
Delta	3.17	2.75	3.77
Rank	2	3	1

For Mean of Flexural Strength A3, B3 and C3 gave maximum Flexural strength.This has been calculated theoritically as stated below and tabulated in Table 16.1

A_1=73.98/6 = 12.33 , A_2=89.47999998/6=14.91333333, A_3=103.78/6 = 17.29666667

B_1=90.07/6=15.01166667, B_2=79.93000002/6=13.32166667, B_3=97.24000002/6=16.20666667

C_1=76.29/6=12.715,C_2=77.98/6=12.99666667,C_3=112.97/6=18.82833333

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Table 16.1 - Average mean of Flexural Strength - Optimal level is $A_3B_3C_3$

Level	A	B	C
1	12.33	15.01	12.715
2	14.91333333	13.32166667	12.99666667
3	17.29666667	16.20666667	18.82833333
Delta	4.96666667	2.884999997	6.113333333
Rank	2	3	1

The above theoritical Average mean of Flexural Strength were verified with the main effect plot and table for means obtained from MINITAB Software as shown in Figure 9.2 and Table 16.2

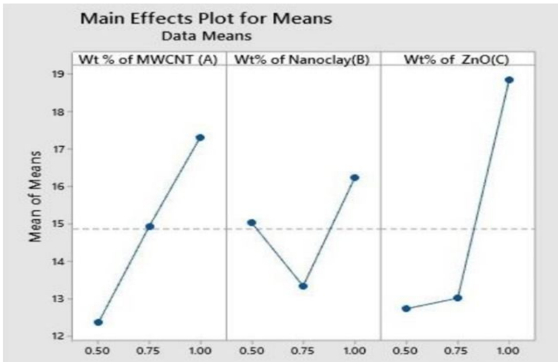

Figure 9.2 : Main Effects Plot for Means(L18-FS)

Table 16.2 Response Table for Means(Minitab)

	Wt % of MWCNT(A)	Wt% of Nanoclay(B)	Wt% of ZnO(C)
1	12.33	15.01	12.71
2	14.91	13.32	13.00
3	17.30	16.21	18.83
Delta	4.97	2.88	6.11
Rank	2	3	1

3) Anova Calculations – FS(L18)

SS_{Total} = $\{[(6.24)^2+(6.18)^2+(10.74)^2+(15.15)^2+(7.45)^2+(11.88)^2+(10.11)^2+(35.88)^2+(7.99)^2+(23.77)^2+(7.04)^2+(20.01)^2+(15.57)^2+(11.47)^2+(27.96)^2+(19.23)^2+(11.91)^2+(18.66)^2]–$

$[(6.24+6.18+10.74+15.15+7.45+11.88+10.1+35.88+7.99+23.77+7.04+20.01+15.57+11.47+27.96+19.23+11.91+18.66)^2/18]\}$

$= [5100.5533] – (267.23)^2/18$

$= 5100.5533 – 3967.326272$

SS_{Total} = 1133.227028

$SS_A = A_1^2/NA_1 + A_2^2/NA_2 + A_3^2/NA_3 - C.F$;

$= 912.1734+1334.445067+1794.70215 - 3967.326272$

$= 4041.320617- 3967.326272$

SS_A = 73.994345

$SS_B = B_1^2/NB_1 + B_2^2/NB_2 + B_3^2/NB_3 - C.F$;

$= 1351.8006 + 1064.800817 + 1575.936267 - 3967.326272$

$= 3992.537684 – 3967.326272$

SS_B = 25.21141167

$SS_C = C_1^2/NC_1 + C_2^2/NC_2 + C_3^2/NC_3 - C.F$;
$= 970.02735 + 1013.22015 + 2127.036817 - 3967.326272$
$= 4110.284317 - 3967.326272$
$SS_C = 142.9580447$

$SS_{ERROR} = (SS_{Total} - SS_A - SS_B - SS_C)$
$= (1133.227028 - 73.994345 - 25.21141167 - 142.9580447)$
$SS_{ERROR} = 891.0632266$

TABLE 17 : ANOVA for Mean (Flexural Strength-L18)

SOURCE	DoF	SS	MS	F	Percentage Contribution
A	2	73.994345	36.9971725	0.08304051	6.529525256
B	2	25.21141167	12.60570584	0.028293628	2.224745002
C	2	142.9580447	71.47902235	0.160435354	12.6151284
ERROR	11	891.0632266	445.5316133	1	78.63060133
TOTAL	17	1133.227028			99.99999999

4) Theoritical – FS(L18)

After conducting the experiment and on determining the optimum composition, the theoritical value of Flexural Strength for Optimal Level **A3B3C3**(Average S/N Ratio and Mean) is calculated.

$\sigma_{FS} = [\text{Avg.}\sigma_{FS} \text{ of } A_3 + \text{Avg. } \sigma_{FS} \text{ of } B_3 + \text{Avg. } \sigma_{FS} \text{ of } C_3] - [2(\text{Avg.}\sigma_{FS})]$

$\sigma_{FS} = 22.63833334$ Mpa

C. Multi Response Performance Index – Mrpi Values

TABLE 18 : WEIGHTS AND MULTI RESPONSE PERFORMANCE INDEX VALUES

Trial	Ultimate Tensile Strength	W_{UTS}	Flexural Strength	W_{FS}	MRPI
1.	63.78	0.066844835	6.24	0.023349797	4.40906631
2.	61.76	0.064727768	6.18	0.02312528	4.140501182
3.	57.89	0.060671802	10.74	0.040188594	3.943916117
4.	55.22	0.057873499	15.15	0.056690615	4.054637432
5.	51.25	0.053712728	7.45	0.027877563	2.960465154
6.	54.73	0.057359953	11.88	0.044454422	3.667428761
7.	44.75	0.046900382	10.11	0.037831163	2.481265152
8.	59.67	0.062537336	35.88	0.134261338	8.548899647
9.	49.93	0.052329298	7.99	0.029898218	2.851688611
10.	57.22	0.059969606	23.77	0.088946265	5.545713574
11.	41.51	0.04350469	7.04	0.026343361	1.991336943
12.	53.13	0.055683068	20.01	0.074876515	4.456720468
13.	47.19	0.049457632	15.57	0.058262236	3.241048669
14.	70.02	0.073384687	11.47	0.042920221	5.630690719
15.	52.89	0.055431535	27.96	0.104625056	5.857090452
16.	50.32	0.052738039	19.23	0.07195779	4.037526424
17.	38.38	0.040224283	11.91	0.044566681	2.074597152
18.	44.51	0.046648849	18.66	0.069824876	3.379272455

1) *Calculations for Weights and Multi Response Performance Index Values*

From table 18 ; ΣUTS = 954.15 and ΣFS = 267.24

W_{UTS1} = UTS_1/Summation of UTS
= 63.78/954.15
= 0.066844835

W_{FS1} = FS_1/Summation of SH
=6.24/267.24
= 0.023349797

$W = W_1R_1 + W_2R_2$

$MRPI_1 = W_{UTS1} * TS_1 + W_{FS1} * FS1$
= 0.066844835* 63.78 + 0.023349797 * 6.24 =4.40906631

Table 19 : Multi Rsponse Performance Index as Response

Trials	Factors/Parameters			MRPI
	Wt% of MWCNT [A]	Wt% of Nanoclay[B]	Wt% of ZnO[C]	
1)	0.5	0.5	0.5	4.40906631
2)	0.5	0.75	0.75	4.140501182
3)	0.5	1	1	3.943916117
4)	0.75	0.5	0.5	4.054637432
5)	0.75	0.75	0.75	2.960465154
6)	0.75	1	1	3.667428761
7)	1	0.5	0.75	2.481265152
8)	1	0.75	1	8.548899647
9)	1	1	0.5	2.851688611
10)	0.5	0.5	1	5.545713574
11)	0.5	0.75	0.5	1.991336943
12)	0.5	1	0.75	4.456720468
13)	0.75	0.5	0.75	3.241048669
14)	0.75	0.75	1	5.630690719
15)	0.75	1	0.5	5.857090452
16)	1	0.5	1	4.037526424
17)	1	0.75	0.5	2.074597152
18)	1	1	0.75	3.379272455

Table 20 : Levels totals of MRPI Multi Response Performance Index

FACTORS	LEVELS		
	1	2	3
Wt % of MWCNT (grams) A	24.48725459	25.41136119	23.37324944
Wt% of Nanoclay(grams) B	23.76925756	25.3464908	24.15611686
Wt% of ZnO (grams) C	21.2384169	20.65927308	31.37417524

The optimal level are selected based on maximum MRPI are **A2B2C3**

2) ANOVA Calculations for MRPI

SS_{Total} = { [$(4.40906631)^2 + (4.140501182)^2 + (3.943916117)^2 + (4.054637432)^2 + (2.960465154)^2 + (3.667428761)^2 + (2.481265152)^2 + (8.548899647)^2 + (2.851688611)^2 + (5.545713574)^2 + (1.991336943)^2 + (4.456720468)^2 + (3.241048669)^2 + (5.630690719)^2 + (5.857090452)^2 + (4.037526424)^2 + (2.074597152)^2 + (3.379272455)^2$] – [(4.40906631 +4.140501182+3.943916117+4.054637432+2.960465154+3.667428761+2.481265152 +8.548899647+2.851688611+5.545713574+1.991336943+4.456720468+3.241048669 +5.630690719+5.857090452+4.037526424+2.074597152+3.379272455$)^2$/18]}

= 341.2874098 – $(73.27186522)^2/18$

= 341.2874098 – 298.2647907

SS_{Total} = 43.0226191

$SS_A = A_1^2/NA_1 + A_2^2/NA_2 + A_3^2/NA_3$ - C.F ;

= $24.48725459^2/6 + 25.41136119^2/6 + 23.37324944^2/6$ - 298.2647907

= 99.93760623 + 107.6228796 + 91.0514649 - 298.2647907

SS_A = 298.6119507 – 298.2647907

SS_A = 0.347160027

$SS_B = B_1^2/NB_1 + B_2^2/NB_2 + B_3^2/NB_3$ - C.F ;

= $23.76925756^2/6 + 25.3464908^2/6 + 24.15611686^2/6$ - 298.2647907

= 94.16293416 + 107.0740993 + 97.25299696 - 298.2647907

SS_B = 298.4900304 – 298.2647907

SS_B = 0.225239719

$SS_C = C_1^2/NC_1 + C_2^2/NC_2 + C_3^2/NC_3$ - C.F ;

= $21.2384169^2/6 + 20.65927308^2/6 + 31.37417524^2/6$ - 298.2647907

= 75.17839207 + 71.1342607 + 164.0564787 - 298.2647907

SS_C = 310.3691314 – 298.2647907

SS_C = 12.10434074

$SS_{ERROR} = (SS_{Total} - SS_A - SS_B - SS_C)$;

= (43.0226191- 0.347160027- 0.225239719-12.10434074)

SS_{ERROR} = 30.34587861

Table 21 : ANOVA for MRPI

SOURCE	DoF	SS	MS	F	Percentage Contribution
A	2	0.347160027	0.173580013	0.011440104	0.806924438
B	2	0.225239719	0.112619859	0.00742241544	0.523537905
C	2	12.10434074	6.05217037	0.398879231	28.13482998
ERROR	11	30.34587861	15.17293931	1	70.53470767
TOTAL	17	43.0226191			99.99999999

3) Theoritical UTS and FS for maximum MRPI

The theoritical value of Ultimate Tensile Strength for optimal level selected based on maximum MRPI **A2B2C3** is calculated.

σ_{UTS} = [Avg. σ_{UTS} of A_2 + Avg. σ_{UTS} of B_2 + Avg. σ_{UTS} of C_3]– [2(Avg.σ_{UTS})]

= [{(55.22+51.25+54.73+47.19+70.02+52.89)/6} + {(61.76+51.25+59.67+41.51 70.02+38.38)/6}+{(57.89+54.73+59.67+57.22+70.02+50.32)/6}] - [2 x (954.15/18)]

= [(331.3/6+322.59/6+349.85/6) – (2 x (954.15/18)]

= [(55.21666667+53.765+58.30833333) - 2 x(954.15/18)]

= [(167.29) – (2 x 53.00833333)]

= 167.29- 106.0166667

= 61.27333334 MPa

The theoritical value of Flexural Strength for optimal level selected based on maximum MRPI **A2B2C3** is calculated.

σ_{FS} = [Avg. σ_{FS} of A_2 + Avg. σ_{FS} of B_2 + Avg. σ_{FS} of C_3]– [2(Avg.σ_{FS})]

= [(89.48/6 + 79.93/6 + 112.97/6)] – [(2 x 267.24) ÷ 18]

= [(14.91333333+13.32166667+18.82833333) – (29.69333333)]

= 47.06333333 – 29.69333333

= 17.37 Mpa

D. Ultimate Tensile Strength – UTS(L9)

The Ultimate tensile strength obtained from testing of specimens for nine compositions corresponding to L9 Orthogonal array was taken from L18 array and tabulated alongwith S/N Ratio calculations for *Larger is better.*

1) Calculations of S/N Ratio's – UTS(L9)

S/N Ratio for Larger the Better is tabulated in Table-14.

Table 22 : L9(3^3) Orthogonal Array- Tensile Strength and S/N Ratio

Trial	Parameters -Wt% of			Tensile Strength (Mpa)	S/N Ratio Tensile Strength
	MWCNT (A)	Nanoclay (B)	ZnO (C)		
1.	0.5	0.5	0.5	63.78	36.0936903
2.	0.5	0.75	0.75	61.76	35.81414575
3.	0.5	1	1	57.89	35.25207099
4.	0.75	0.5	0.75	47.19	33.47699955
5.	0.75	0.75	1	70.02	36.90444213
6.	0.75	1	0.5	52.89	34.46747134
7.	1	0.5	1	50.32	34.03481265
8.	1	0.75	0.5	38.38	31.68209941
9.	1	1	0.75	44.51	32.96915189

2) Response Table – UTS(L9)

For S/N ratios, A1, B2 and C3 give maximum Ultimate tensile strength.This has been calculated and tabulated in Table 23.1

Table 23.1 : Average S/N ratios of Ultimate Tensile Strength - Optimal level $A_1B_2C_3$

Level	A	B	C
1	35.71996901	34.5351675	34.08108702
2	34.94863767	34.8002291	34.08676573
3	32.89535465	34.22956474	35.39710859
Delta	2.82461436	0.57066436	1.31602157
Rank	1	3	2

The above theoritical S/N ratios were verified with the main effect plot and table for S/N ratio obtained from MINITAB Software as shown in Figure 10.1 and Table 23.2

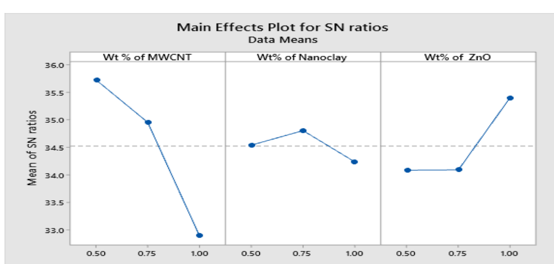

Figure 10.1 : Main Effects Plot for S/N ratios(L9-UTS)

Table 23.2 Response Table for Signal to Noise Ratios(Minitab)

Level	Wt % of MWCNT (A)	Wt% of Nanoclay(B)	Wt% of ZnO(C)
1	35.72	34.54	34.08
2	34.95	34.80	34.09
3	32.90	34.23	35.40
Delta	2.82	0.57	1.32
Rank	1	3	2

For Mean of Ultimate Tensile Strength A1, B2 and C3 give maximum Ultimate tensile strength.This has been calculated theoritically and tabulated in Table 24.1.

Table 24.1 - Average mean of Ultimate Tensile Strength – Optimallevel is $A_1B_2C_3$

Level	A	B	C
1	61.14333333	53.76333333	51.68333333
2	56.7	56.72	51.15333333
3	44.40333333	51.76333333	59.41
Delta	16.74	4.95666667	8.25666667
Rank	1	3	2

The above theoritical Average Mean of UTS were verified with the main effect plot and table for means obtained from MINITAB Software as shown in Figure 10.2 and Table 24.2.

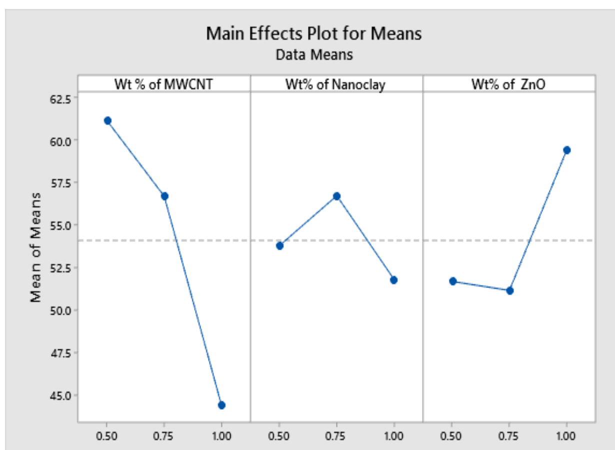

Figure 10.2 : Main Effects Plot for Means(L9-UTS)

Table 24.2 Response Table for Means(Minitab)

Level	Wt % of MWCNT(A)	Wt% of Nanoclay(B)	Wt% of ZnO(C)
1	61.14	53.76	51.68
2	56.70	56.72	51.15
3	44.40	51.76	59.41
Delta	16.74	4.96	8.26
Rank	1	3	2

3) Anova Calculations for UTS(L9)

SS_{Total} $=\{[(63.78)^2+(61.76)^2+(57.89)^2+(47.19)^2+(70.02)^2+ (52.89)^2 +(50.32)^2+(38.38)^2+(44.51)^2]–[(63.78+61.76+57.89+47.19 + 70.02 + 52.89 + 50.32+ 38.38+ 44.51)^2/9]\}$

$= 27146.7536 – (486.74)^2/9$

$= 27146.7536 – 236915.8276/9$

$= 27146.7536 – 26323.98084$

$SS_{Total} = 822.77276$

$SS_A = A_1^2/NA_1 + A_2^2/NA_2 + A_3^2/NA_3 - C.F;$

$= 183.43^2/3 + 170.1^2/3 + 133.21^2/3 - 26323.98084$

$= 26775.15966 – 26323.98084$

$= 451.1788233$

$SS_B = B_1^2/NB_1 + B_2^2/NB_2 + B_3^2/NB_3 - C.F;$

$= 161.29^2/3 + 170.16^2/3 + 155.29^2/3 - 26323.98084$

$= 26361.29127 – 26323.98084$

$SS_B = 37.31042633$

$SS_C = C_1^2/NC_1 + C_2^2/NC_2 + C_3^2/NC_3 - C.F;$

$= 155.05^2/3 + 153.46^2/3 + 178.23^2/3 - 26323.98084$

$= 26452.13567 – 26323.98084$

$SS_C = 128.154826$

$SS_{ERROR} = (SS_{Total} - SS_A - SS_B - SS_C);$

$SS_{ERROR} = 206.1286844$

Table 25 : ANOVA for Mean Ultimate Tensile Strength(L9)

SOURCE	DoF	SS	MS	F	Percentage Contribution
A	2	451.1788233	225.5894117	2.188821147	54.83638318
B	2	37.31042633	1 8.65521317	0.181005503	4.534718229
C	2	128.154826	64.077413	0.621722427	15.57596851
ERROR	11	206.1286844	1 03.0643422	1	25.05293006
TOTAL	17	822.77276			99.99999998

4) Theoritical–UTS(L9)

After conducting the experiment and on determining the optimum composition, the theoritical value of Ultimate Tensile Strength for Optimal Level **A1B2C3**(Average S/N Ratio) is calculated.

$\sigma_{UTS} = [(\text{Avg. } \sigma_{UTS} \text{ of } A_1+\text{Avg. } \sigma_{UTS} \text{ of } B_2+\text{Avg. } \sigma_{UTS} \text{ of } C_3) – 2 (\text{Avg. } \sigma_{UTS})]$

$= 69.10888893$ Mpa

E. Flexural Strength – FS(L9)

The Flexural strength obtained from testing of specimens for nine compositions corresponding to L9 Orthogonal array was taken from L18 Orthogonal array and tabulated alongwith S/N Ratio calculations for *Larger is better.*

1) Calculations of S/N Ratio's – FS(L9)

S/N Ratio for Larger the Better is tabulated in Table 26.

Table 26. : L9(3^3) Orthogonal Array- Flexural Strength and S/N Ratio

Trial	Parameter Wt % of MWCNT grams(A)	Nanoclay grams(B)	ZnO grams(C)	Flexural Strength (Mpa)	S/N Ratio Flexural Strength
1.	0.5	0.5	0.5	6.24	15.90369179
2.	0.5	0.75	0.75	6.18	15.8197685
3.	0.5	1	1	10.74	20.62008563
4.	0.75	0.5	0.75	15.57	23.84577225
5.	0.75	0.75	1	11.47	21.19126836
6.	0.75	1	0.5	27.96	28.93074334
7.	1	0.5	1	19.23	25.67958568
8.	1	0.75	0.5	11.91	21.51823523
9.	1	1	0.75	18.66	25.41823279

2) Response Table – FS(L9)

For S/N ratios, A2,B3 and C3 gave maximum Flexural strength. This has been calculated theoritically and tabulated in Table 27.1.

Table 27.1- Average S/N ratios of Flexural Strength – Optimal levels $A_2B_3C_3$

Level	A	B	C
1	17.44784864	21.80968324	22.11755679
2	24.65592798	19.50975736	21.69459118
3	24.20535123	24.98968725	22.49697989
Delta	7.20807934	5.47992989	0.80238871
Rank	1	2	3

The above theoritical S/N ratios were verified with the main effect plot and table for S/N ratio obatined from MINITAB Software as shown in Figure 11.1 and Table 27.2

Table 27.2 Response Table for Signal to Noise Ratios(Minitab)

Level	Wt % of MWCNT (A)	Wt% of Nanoclay(B)	Wt% of ZnO(C)
1	17.45	21.81	22.12
2	24.66	19.51	21.69
3	24.21	24.99	22.50
Delta	7.21	5.48	0.80
Rank	1	2	3

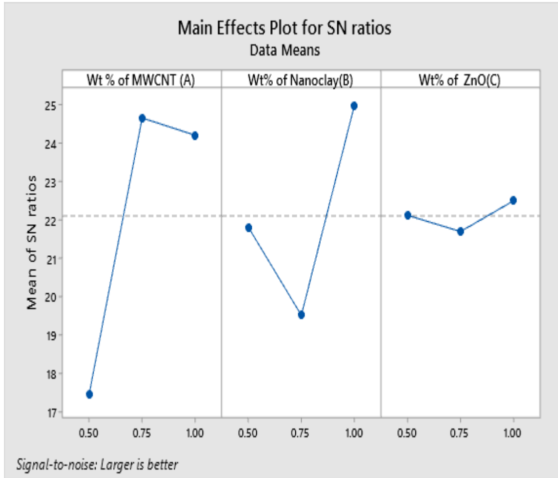

Figure 11.1 : Main Effects plot for S/N ratios(L9-FS)

For Mean of Flexural Strength, A2, B3 and C1 give maximum Flexural strength.This has been calculated theoritically and tabulated in Table 28.1

Table 28.1 - Average mean of Flexural Strength- Optimal levels $A_2B_3C_1$

Level	A	B	C
1	7.72	13.68	15.37
2	18.33	9.85	13.47
3	16.6	19.12	13.81
Delta	10.61	9.27	1.9
Rank	1	2	3

The above theoritical Average mean of Flexural strength were verified with the main effect plot and table for Means from MINITAB Software as shown in Figure 11.2 and Table 28.2

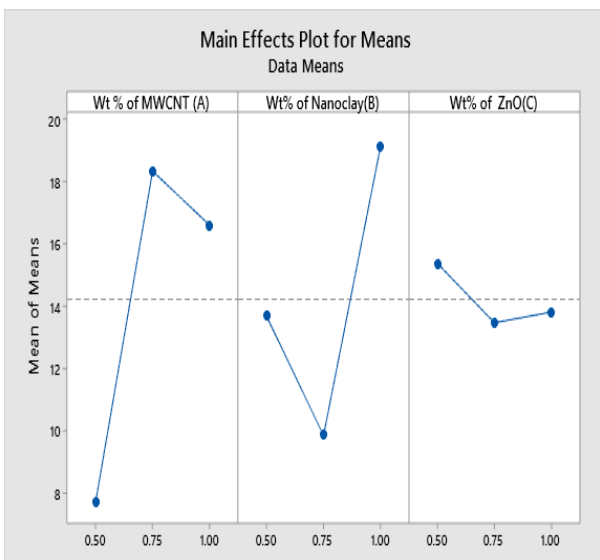

Figure 11.2 : Main Effects plot for Means(L9-FS)

Table : 28.2 Response Table for Means(Minitab)

Level	Wt % of MWCNT(A)	Wt% of Nanoclay(B)	Wt% of ZnO(C)
1	7.720	13.680	15.370
2	18.333	9.853	13.470
3	16.600	19.120	13.813
Delta	10.613	9.267	1.900
Rank	1	2	3

3) Anova Calculations for FS(L9)

SS_{Total} =[$(6.24)^2+(6.18)^2+(10.74)^2+(15.57)^2+(11.47)^2+(27.96)^2+(19.23)^2+(11.91)^2+(18.66)^2$] –[(6.24 + 6.18 +10.74 + 15.57 + 11.47 + 27.96 +
19.23 + 11.91 + 18.66)^2/ 9] }
= [2208.0616] – $(127.96)^2$/9

SS_{Total} = 388.754756

SS_A = $A_1^2/NA_1 + A_2^2/NA_2 + A_3^2/NA_3$ - C.F ;
= $(23.16)^2/3 + (55)^2/3 + (49.8)^2/3$ - 1819.306844
= 2013.808533- 1819.306844

SS_A = 194.501689

SS_B = $B_1^2/NB_1 + B_2^2/NB_2 + B_3^2/NB_3$ - C.F ;
= $(41.04)^2/3 + (29.56)^2/3 + (57.36)^2/3$ - 1819.306844
= 1949.4149 – 1819.306844

SS_B = 130.108056

SS_C = $C_1^2/NC_1 + C_2^2/NC_2 + C_3^2/NC_3$ - C.F ;
= $(46.11)^2/3 + (40.41)^2/3 + (41.44)^2/3$ - 1819.306844
= 1825.457933 – 1819.306844

SS_C = 6.151089333

SS_{ERROR} = ($SS_{Total} - SS_A - SS_B - SS_C$);

SS_{ERROR} = 57.99392167

Table 29 : Analysis of Variance(ANOVA) for Mean(FlexuralStrength)

SOURCE	DoF	SS	MS	F	Percentage Contribution
A	2	194.501689	97.2508445	3.353828873	50.03197671
B	2	130.108056	65.054028	2.243477458	33.4790078
C	2	6.151089333	3.075544667	0.106064379	1.582254426
ERROR	2	57.99392167	28.99696084	1	14.91786808
TOTAL	10	388.754756			100.011107

4) Theoritical–FS(L9)

After conducting the experiment and on determining the optimum composition, the theoritical value of Flexural Strength for Optimal Level **A2B3C1**(Average Mean) is calculated.

σ_{FS}=[Avg.σ_{FS} of A_2+Avg.σ_{FS} of B_3+Avg.σ_{FS} of C_1]–[2 x Avg. σ_{FS}]

$\sigma_{Flexural\ Strength}$ = 24.38777777 Mpa

Also, the theoritical value of Flexural strength for Optimal Level of A2B3C3(S/N Ratio) **:**

σ_{FS}=[Avg.σ_{FS} of A_2+Avg.σ_{FS} of B_3+Avg.σ_{FS} of C_3]–[2 x Avg. σ_{FS}]

$\sigma_{Flexural\ Strength}$ = 22.8311111 Mpa

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F. Multi Response Performance Index – Mrpi Values

Table 30 : Weights and Multi Response Performance Index Values

Trial	Ultimate Tensile Strength	W_{TS}	Flexural Strength	W_{SH}	MRPI
1.	63.78	0.131035049	6.24	0.048765239	8.661710517
2.	61.76	0.126884989	6.18	0.048296342	8.134888314
3.	57.89	0.118934133	10.74	0.083932478	7.786531773
4.	47.19	0.096951144	15.57	0.121678649	6.46966105
5.	70.02	0.143855035	11.47	0.089637386	11.10087037
6.	52.89	0.108661708	27.96	0.218505783	11.85653943
7.	50.32	0.103381682	19.23	0.150281337	8.092076349
8.	38.38	0.078851132	11.91	0.093075961	4.134841142
9.	44.51	0.091445124	18.66	0.14582682	6.79135093

1) Calculations for Weights and Multi Response Performance Index Values

From table 30 ; ΣUTS = 486.74 and ΣFS = 127.96

W_{UTS1} = UTS_1/Summation of TS
= 63.78/486.74
= 0.131035049

Table 31: Multi Response Performance Index as response

Trials	Factors/Parameters			MRPI
	Wt % of MWCNT A	Wt% of Nanoclay B	Wt% of ZnO C	
1)	0.5	0.5	0.5	8.661710517
2)	0.5	0.75	0.75	8.134888314
3)	0.5	1	1	7.786531773
4)	0.75	0.5	0.75	6.46966105
5)	0.75	0.75	1	11.10087037
6)	0.75	1	0.5	11.85653943
7)	1	0.5	1	8.092076349
8)	1	0.75	0.5	4.134841142
9)	1	1	0.75	6.79135093

W_{FS1} = FS_1/Summation of SH
= 6.24/127.96
= 0.023350671

$W = W_1R_1 + W_2R_2$

$MRPI_1 = W_{UTS1} * TS_1 + W_{FS1} * FS1$
= 0.131035049 * 63.78 + 0.048765239* 6.24 = 8.661710517

Table 32 : Levels totals of MRPI Multi Response Performance Index

FACTORS	LEVELS		
	1	2	3
Wt % of MWCNT (grams) A	24.5831306	29.42707085	19.01826842
Wt% of Nanoclay(grams) B	23.22344792	23.37059983	26.43442213
Wt% of ZnO (grams) C	24.65309109	21.39590029	26.97947849

The optimal level selected based on maximum MRPI are **A2B3C3**

2) Anova Calculations for MRPI

SS_{Total} = { [$(8.661710517)^2 + (8.134888314)^2 + (7.786531773)^2 + (6.46966105)^2 + (11.10087037)^2 + (11.85653943)^2 + (8.092076349)^2 + (4.134841142)^2 + (6.79135093)^2$] – [$(8.661710517+8.134888314+7.786531773+6.46966105+11.10087037+11.85653943+8.092076349+4.134841142+6.79135093)^2/9$]}

$= 636.1961367 – (73.02846988)^2/9$

$= 636.1961367 – 592.5730458$

$SS_{Total} = 43.6230909$

$SS_A = A_1^2/NA_1 + A_2^2/NA_2 + A_3^2/NA_3$ - C.F;

$= 24.5831306^2/3 + 29.42707085^2/3 + 19.01826842^2/3 - 592.5730458$

$= 201.4434367 + 288.6508329 + 120.5648446 - 592.5730458$

$= 610.6591142 – 592.5730458$

$SS_A = 18.0860684$

$SS_B = B_1^2/NB_1 + B_2^2/NB_2 + B_3^2/NB_3$ - C.F ;

$= 23.22344792^2/3 + 23.37059983^2/3 + 26.43442213^2/3 - 592.5730458$

$= 179.7761778 + 182.0616455 + 232.9262244 - 592.5730458$

$= 594.7640477 – 592.5730458$

$SS_B = 2.191001949$

$SS_C = C_1^2/NC_1 + C_2^2/NC_2 + C_3^2/NC_3$ - C.F ;

$= 24.65309109^2/3 + 21.39590029^2/3 + 26.97947849^2/3 - 592.5730458$

$= 202.5916334 + 152.5948497 + 242.6307532 - 592.5730458$

$= 597.8172363 – 592.5730458$

$SS_C = 5.244190497$

$SS_{ERROR} = (SS_{Total} - SS_A - SS_B - SS_C)$;

$= (43.6230909- 18.0860684- 2.191001949-5.244190497)$

$SS_{ERROR} = 18.10183005$

Table 33 : ANOVA for Multi Response Performance Index

SOURCE	DoF	SS	MS	F	Percentage Contribution
A	2	18.0860684	9.0430342	0.999129278	41.4598508
B	2	2.191001949	1.095500975	0.121037593	5.022573834
C	2	5.244190497	2.622095249	0.28970499	12.02159313
ERROR	2	18.10183005	9.050915025	1	41.49598224
TOTAL	8	43.6230909			

3) Theoritical UTS and FS for maximum MRPI

The theoritical value of Ultimate Tensile Strength for optimal level selected based on maximum MRPI **A2B3C3** is calculated.

σ_{UTS} = [Avg. σ_{UTS} of A_2 + Avg. σ_{UTS} of B_3 + Avg. σ_{UTS} of C_3]– [2(Avg.σ_{UTS})]

= [{(47.19+70.02+52.89)/3}+{(57.89+52.89+44.51/3)}+{(57.89+70.02+50.32/3)}-[2(486.74/9)

= [(56.7+51.76333333+59.41) - 2 x(54.08222222)]

= 167.8733333 - 108.1644444

= 59.70888893 MPa

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The theoritical value of Flexural Strength for optimal level selected based on maximum MRPI **A2B3C3** is calculated.

σ_{FS} = [Avg. σ_{FS} of A_2 + Avg. σ_{FS} of B_3 + Avg. σ_{FS} of C_3]– [2(Avg.σ_{FS})]

= 55/3 + 57.36/3 + 41.44/3 – 2 x (127.96 ÷ 9)

= (18.33333333+19.12+ 13.81333333) – 2 x (14.21777778)

= 51.26666666 – 28.43555556

$\sigma_{Flexural\ Strength}$ = 22.8311111 Mpa

The theoritical and experimental Ultimate tensile strength and Flexural Strength for optimal level selected based on maximum MRPI is tabulated in Table 34..

G. *Result Comparision And Optimization*

From Section 3.1 to 3.6 the results have been discussed for both L18 and L9 Orthogonal Arrays.Multi Response Performance Index was also obtained with Optimal levels for both the arrays.

1) *L18(3^3) Orthogonal Array vs L9(3^3) Orthogonal Array*

A detailed comparison of result is incorporated below in Table 34.

Table 34 : Result Comparision for Optimal Levels

Sl. No.	Orthogonal Array	Response Table	Optimal Level	Ultimate tensile strength		Flexural Strength	
				Theoritical	Experimental	Theoritical	Experimental
1.	L9	S/N Ratio & Means	A1B2C3	69.11 Mpa	-	NA	NA
		Means	A2B3C1	51.98 Mpa	52.89 MPa	24.39 Mpa	27.96 Mpa
		S/N Ratio	A2B3C3	59.71 MPa	54.73 MPa	22.83 MPa	11.88 MPa
2.	L18	Means	A1B2C3	60.93 Mpa	-	NA	NA
		S/N Ratio	A1B1C3	60.25 Mpa	57.22 MPa	16.48 MPa	23.77 MPa
		S/N Ratio & Means	A3B3C3	NA	NA	22.64 MPa	-
3.	MRPI- L9	Max.MRPI	A2B3C3	59.71 Mpa	54.73 Mpa	22.83 Mpa	11.88 Mpa
4.	MRPI-L18	Max.MRPI	A2B2C3	61.27 Mpa	70.02 Mpa	17.37 Mpa	11.47pa

From the above comparision it can be ascertained that the Optimum Levels for Ultimate Tensile Strength is A2B2C3 with 70.02 Mpa and for Flexural Strength is A2B3C1 27.96 Mpa. Further the above results are within the experimental limits which are evident on testing.

IV. CONCLUSION

Addition of nanofillers with different composition of weight percentage to the Epoxy Resin enhanced the Mechanical properties of the GFRP, as the inherent properties and chemical compositions of the Multi walled carbon nanotubes, Nanoclay and Zinc oxide nanofillers were imparted to the GFRP on infusing with the epoxy resin.

Based on the results of present research and investigation, conclusion has been arrived which are discussed below.

1) The Maximum Multi Response Performance Index – MRPI, for L9 array at optimal levels A2B3C3 collectively enhanced Tensile strength to 54.73 Mpa and Flexural strength to 11.88 Mpa for weight percentage of MWCNTs[A], Nanoclay[B] and ZnO[C] at 0.75%, 1 %, 1% respectively. MRPI for L18 array at optimal levels A2B2C3 enhanced tensile strength to 70.02 Mpa and the Flexural strength was reported equivalent at 11.47 Mpa for weight percentage of MWCNTs[A], Nanoclay[B] and ZnO[C] at 0.75%, 0.75 %, 1% respectively
2) Tensile Strength : It was concluded that an increase in composition of both MWCNTs and Nanoclay upto a weight percentage from 0.5 % to 0.75% keeping the weight percentage of ZnO as constant at 1%, enhanced the tensile strength of GFRP from *57.22 Mpa at A1B1C3* to *70.02 MPa at A2B2C3.*

3) Flexural Strength: It was further concluded that an increase in the weight percentage of, MWCNTs from 0.75 % to 1%, ZnO from minimum 0.5% to maximum 1% and decreasing the weight percentage of Nanoclay from 1% to 0.75% enhanced flexural Strength *from 27.56 Mpa at A2B3C1* to *35.88 Mpa at A3B2C3.*
4) Infusing three Nanofillers - MWCNTs, Nanoclay and ZnO to GFRP Composite enhanced both tensile and flexural properties.
5) It was also investigated from ANOVA analysis that Taguchi's L_9 (3^3) Orthogonal array gives less ***error*** in comparison to the L_{18}(3^3) Orthogonal Array both individually and collectively for MRPI.
6) ANOVA Analysis indicated Multi walled Carbon Nanotube-MWCNT has a signifcance of 54.84 % on enhancing Ultimate Tensile Strength followed by ZnOwith 15.58%. Similarly, MWCNTs had a significance of 50.03% on enhancing Flexural Strength followed by Nanoclay with 33.48 %.
7) ANOVA Analysis for MRPI-L9 indicated MWCNT has a signifcance of 41.46 % on enhancing both Ultimate Tensile Strength and Flexural Strength followed by ZnO and Nanoclay with 12.1% and 5% respectively. Similarly, ANOVA for MRPI-L18 indicated ZnO has a significance of 28.13% on enhancing both Ultimate Tensile Strength and Flexural Strength followed by MWCNTs and Nanoclay very little significance.
8) Results obtianed can be fetched to machine learning and artificial intelligence and just by performing experiments through L_9 Orthogonal Array,the predictions and results can be obtained for L_{18} Orthogonal Array and vice versa.
9) Single Maximum optimal levels and ANOVA analysis for multiple output characteristics were significantly calculated through MRPI.
10) Experimental results and investigation forecasted future R & D work on this hybrid GFRP composite and recommends the use of Sonication and magnetic stirring for superior infusing of MWCNTs, Nanoclay and ZnO with matrix material to prevent any agglomeration.
11) Fire testings: Limit oxygen test, flame retardent test and Mechanical tests: compression test, wear test and impact test are recommended due to the infusing of MWCNT and Nanoclay with matrix.
12) The authors intends for extensive research in the domain to address fire accidents of aircraft and spacecrafts round the globe as people's losses life. Hence, the GFRP infused MWCNTs,Nanoclay and Zinc Oxide Nanofillers could effectively outset several hybrid composites for structural applications in aerospace sector and space technology by imparting light weight,stealth,high ductility, compressiblity, bending, impact and thermal characteristics apart from resistance to fire by limiting oxygen and retarding flame that would lead to save human lifes who are travelling and working in civil, commercial and defence air transport.
13) Future investigation for fabrication of FRP through injection molding, resin transfer molding, compression molding, laying prepreg, and pultrusion to suit it for industrial application is viable.
14) Apart from the above, its intended for applications in various mechanical and automotive applications viz light weight cars structures and frames, door panel, dash board etc.
15) After thorough research work in future it is also intended for applications alongwith hybrid layer with other synthetic and natural fibres for developing stealth Drones and aircrafts for defence so as to escape enemy countries radar tracing and monitoring range.

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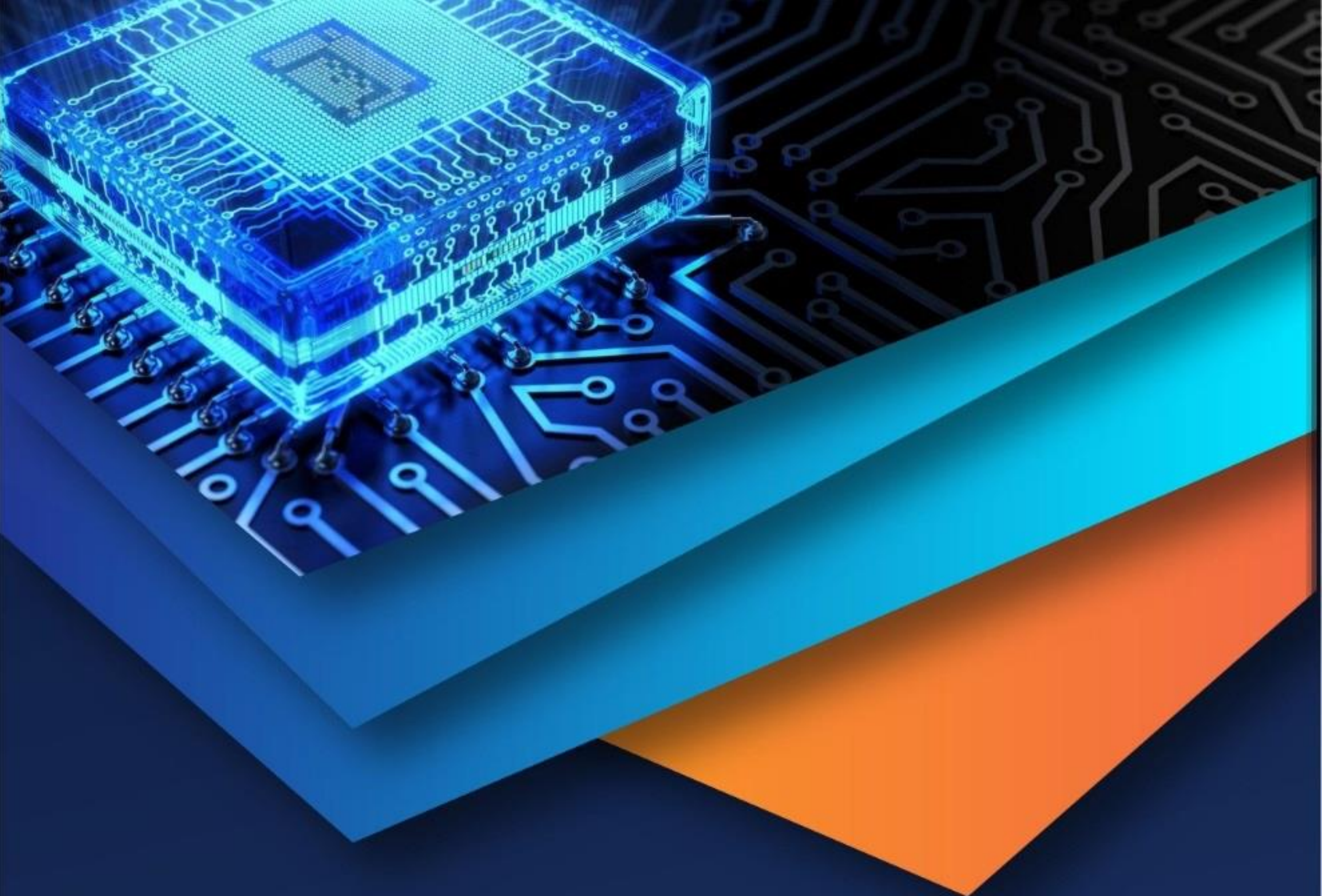

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