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Optimization of Sisal Fiber, Glass Fiber and Alumina- Based Hybrid Composite for Flexural Strength Using Taguchi Technique

Veenapani R[1], B M Rajaprakash[2], Shreyas S[3]
[1]PG Scholar, Mechanical Engg. UVCE, Bangalore University, Bengaluru, Karnataka, India
[2]Professor, Mechanical Engg. UVCE, Bangalore University, Bengaluru, Karnataka, India
[3]PG Scholar, Mechanical Engg. UVCE, Bangalore University, Bengaluru, Karnataka, India

Abstract: In the current study, flexural strength of combination of natural and synthetic fiber with particle filled hybrid composites have been studied. The flexural strength of the hybrid composite mainly depends on the proportion of the sisal fiber weight, glass fiber weight and alumina weight. Taguchi technique has been applied to find the optimized parameters of the developed hybrid composites. Results were obtained for the L9 orthogonal combination from experimentation. The results were analysed with the help of Signal/Noise (S/N) Ratio, Main effect plot and Analysis of variance (ANOVA) using Mini Tab 19. Regression equation are developed for all three reinforcements separately. From the current study it was observed that the flexural strength of the hybrid composite mainly depends on the sisal fiber precent that the other two reinforcements. Based on the experimental observations the maximum ultimate flexural strength was found to be 145.97 MPa for optimised input parameters as 20% of sisal fiber, 20% of glass fiber and 2% of alumina.
Keywords: Taguchi technique, ANOVA, Flexural strength, Sisal fiber, Glass Fiber, Alumina

I. INTRODUCTION

The present-day society is dealing with some of demanding situations associated with health, sustainability, and environmental protection. Inevitably, the need of designing and growing new useful substances that would enhance the nice of lifestyles and cause the improvement of superior technology is of paramount importance. During the beyond decades, polymer technology has strongly been getting into the sphere of organic–inorganic hybrids, aiming to mix the residences of polymers with the ones of inorganic additives. The former consists of ease of processing, light-weight, flexibility, extraordinarily excessive versatility in substances' layout in regard to the structural and architectural traits and therefore in substances' residences. Inorganic substances showcase advanced thermal and mechanical conduct in addition to precise optical, electrical, catalytic, and magnetic residences, particularly while the ones are characterized with the aid of using nanoscale dimensions. It is a truism that technological improvement relies upon on advances withinside the subject of substances. Nature is complete of examples in which the concept of composite substances is used. The coconut palm leaf, for instance, is largely a cantilever bit the usage of the idea of fiber reinforcement. Wood is a fibrous composite: cellulose fibers in a lignin matrix. The cellulose fibers have excessive tensile power however are very flexible (i.e., low stiffness), even as the lignin matrix joins the fibers and furnishes the stiffness. Weiner and Wagner (1998) deliver an excellent description of shape and residences of bone. For descriptions of the shape–feature relationships withinside the plant and animal kingdoms, the reader is noted Elices (2000) and Wainwright et al. (1982) [1]. The new composite material often displays many beneficial characteristics; in many cases, composites are stronger, of lower density, or less costly in comparison to established materials. Commonly, composites consist of two or more different components forming regions sufficiently large to be considered as continua; the basic components are usually strongly fused at the interface. A variety of both natural and synthetic materials confirm to this picture, such as mortar and concrete, reinforced rubber, alloys, polymers containing fillers, aligned and chopped fiber composites, porous and cracked media, polycrystalline (metal) aggregates, and others [2]. Composite materials are composed of individual basic materials, which are referred to as so-called constituent materials. Two main categories of constituent materials are distinguished: the matrix ("binder") and the reinforcement. At least one representative from each category is needed to create a composite. The matrix phase embeds, surrounds, and supports the reinforcements by preserving their relative locations. The reinforcements contribute their specific physical and mechanical assets, thus enhancing the properties of the matrix.

The achieved synergism between the two phases generates material properties not observed for the individual constituent materials, while the unlimited number of binders and reinforcements enables the designer to develop optimum combinations, thus creating tailor-made composites [3].

Particle reinforced composites are subclassified as Large-particle and dispersion-strengthened composites. The distinction between these is based upon reinforcement or strengthening mechanism. The term "large" is used to indicate that particle–matrix interactions cannot be treated on the atomic or molecular level; rather, continuum mechanics is used. For most of these composites, the particulate phase is harder and stiffer than the matrix. These reinforcing particles tend to restrain movement of the matrix phase in the vicinity of each particle. In essence, the matrix transfers some of the applied stress to the particles, which bear a fraction of the load. The degree of reinforcement or improvement of mechanical behavior depends on strong bonding at the matrix–particle interface. For dispersion-strengthened composites, particles are normally much smaller, with diameters between 0.01 and 0.1 m (10 and 100 nm). Particle–matrix interactions that lead to strengthening occur on the atomic or molecular level [4-5].

Glass fibers (GFs) are most widely used among all the synthetic fibers as they offer excellent strength and durability, thermal stability, resistance to impact, chemical, friction, and wear properties. However, the machining of glass fiber-reinforced polymers (GFRPs) is relatively slow, challenging, and shows reduced tool life while working on conventional machining systems. GFs also carry the disadvantage of disposal at the end of their service life. However, in some applications, more stiffness is required, so carbon fibers (CFs) are employed instead of GFs. Although some of the other types of synthetic fibers like aramid, basalt, polyacrylonitrile (PAN-F), polyethylene terephthalate (PET-F), or polypropylene fibers (PP-F) offer some advantages, they are rarely used in thermoplastic short-fiber-reinforced polymers (SFRP); they have been used for specific applications where their desired properties are applicable [6-9].

Mukherjee and Satyanarayana in this work they studied the properties of Sisal fiber, such as tensile properties (ultimate tensile strength (UTS), initial modulus (YM), average modulus (AM), and percent elongation at break) of sisal fibres as a function of fiber diameter, test length, and test speed. The result revealed that UTS, YM, AM and percent elongation lie in the range 530 to 630MPa, 17 to 22 GPa, 9.8 to 16.5 GPa and 3.64 to 5.12% respectively for fibres of diameters ranging between 100 and 300 µm. No significant variation of mechanical properties with change in diameter of the fibres was observed [9]. Munawar et al. found that, the sisal fibre has a tensile strength of 375 ± 38 MPa, specific tensile strength of 493MPa, Young's modulus of 9.1 ± 0.8 GPa, specific young's modulus of 12.1 GPa, and toughness of 10.7 ± 1.2 MPa [10].

Abilash and Sivapragash made successful study on sisal and jute composite. In this Sisal and Jute fibers were fabricated and reinforced with polypropylene composite using compression molding technique. At the end, the author conclude that sisal based polypropylene composite has higher tensile strength than jute based composite and jute based polypropylene composite has higher compressive strength than sisal-based polypropylene [11].

Kuruvilla et al. He found that Sisal fibres have good potential as reinforcements in polymer (thermoplastics, thermosets and rubbers) composites. Due to the low density and high specific properties of sisal fibres, composites based on these fibres may have very good implications in the automotive and transportation industry [12].

Andressa Cecília Milanese et al. Here Sisal/polyurethane composites with 44 wt. (%) of reinforcement and sisal/phenolic composites with 33 wt. (%) of reinforcement were prepared by compress molding technique at room temperature. Tensile tests of resins and composites were performed using a universal machine and results were compared as follows, thermal treatment of sisal fabric reinforcement applied before molding the polyurethane composite was suitable when considering its tensile behavior, once the treatment increases notable tensile strength [13].

M. Ramesh et al worked-on glass –sisal- jute fiber reinforced epoxy composites and their aim of the study is to evaluate mechanical properties such as tensile and tensile properties of hybrid glass fiber-sisal/jute reinforced epoxy composites. Microscopic examinations are carried out to analyze the interfacial characteristics of materials, internal structure of the fractured surfaces and material failure morphology by using Scanning Electron Microscope (SEM). The results indicated that the incorporation of sisal fiber with GFRP exhibited superior properties than the jute fiber reinforced GFRP composites in tensile properties and jute fiber reinforced GFRP composites performed better in tensile properties [14].

In the present work it has been proposed to develop a hybrid composite composing of sisal fiber, glass fiber and Alumina with an intention to obtain improved mechanical properties such as tensile and tensile strength. They are some following objectives of the projects are: 1. The main objective of this dissertation work is to prepare composite material with sisal fiber, glass fiber with Alumina that composite material is to replace for roofing and in automotive parts. 2. The natural fiber used to make roofing and automotive parts are sisal fiber and glass fiber with Alumina and to present a survey of composite material with natural fiber as ingredient, and to indicate their typical properties and functions. 3. The combination of natural fiber and synthetic fiber with particle reinforced are prepared through various processes and are subjected to various mechanical tests. This test results are compared to that of only natural or synthetic fiber [15-17].

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II. MATERIALS AND METHODS

A. Materials

The reinforcement materials and matrix materials used in the present research are tabulated in Table 1.

Table 1: Specifications of the materials used

Sl No	Materials	Density
01	Epoxy resin LY 556 Hardener HY 951	1.15 g/cm^3
02	Aluminum oxide calcined 99% extra pure	3.95 g/cm^3
03	Glass Fiber	2.54 g/cm^3
04	Sisal Fiber	1.45 g/cm^3

B. Optimization Of Reinforcement

1) *Design Of Experiments:* The determination of design factors is the critical stage for the design of trials. There are many outline factors, for example, filler content, load, speed, sliding distances and so forth, which will influence the test consequences of friction coefficient and weight reduction. In a systematically designed set of experiments, having included parameters of importance are changed for a specified range, this is good approach to gain systematic data. In Mathematical language, such a full set of experiments is set to give required results. In such cases number of experiments and resources essential are possibly large. Many times, researchers decide to carry out a subset of the total set of experiments to save efforts and money. Even though, it does not simply provide itself to understanding of art behind the phenomenon. The investigation is not so simple and obvious effects of different parameters on the practical data are not readily noticeable.

2) *Experimental Design*

The steps applied for Taguchi optimization in this study are as follows.

a) Select noise and control factors.
b) Select Taguchi orthogonal array.
c) Conduct Experiments
d) Flexural Strength Measurement
e) Analyse result (signal to noise ration)
f) Predict optimum performance
g) Confirmation Experiment

3) *Signal to Noise Ration:* S/N ratio is used as measurable value instead of standard deviation due to the fact that, as the mean decreases, the standard deviation also decreases and vice versa. In other words, the standard deviation cannot be minimized first and mean brought to the target. In practice, the target mean value may change during the process development. Two of the application in which the concept of S/N ratio is useful are the improvement of quality through variability reduction and the improvement of measurement. The S/N ration characteristics can be divided into three categories given by Equation.

a) Larger is the better characteristics $S/N = -10 * \log(\Sigma(1/Y2)/n$.................... (1)
b) Nominal is the better characteristics $S/N = -10 * \log(\sigma 2)$...(2)
c) Smaller is the better characteristics $S/N = -10 * \log(\Sigma(Y2)/n))$ .... (3)

Where 'n' is the number of trials and 'y' is the experimental value.

C. Taguchi Method

Taguchi is an effective tool in designing of high-quality systems. Taguchi method is to enhance the procedure parameter to accomplish best quality execution, with relatively low cost. Conventional methods are complex in nature and difficult to use and time consuming also high cost. On the off chance that the quantity of process parameter increments, there are lot of trials must be directed to get the optimized parameter. To make the undertaking simple, Taguchi technique utilizes plan of orthogonal array (OA) to study the procedure parameter with modest number of tests.

The Taguchi technique includes lessening the variety in a procedure through powerful plan of investigations. The general goal of the strategy is to deliver high quality product requiring little to no effort to the producer. The Taguchi strategy was created by Dr. Genichi Taguchi, a technique for planning trials to research how extraordinary parameters influence the mean and fluctuation of process execution qualities that characterizes how well the procedure is working. The Taguchi technique gives the S/N proportion as the execution record to assess the characteristics of the product or process. It tends to be effortlessly characterized as the proportion of the mean (signal) to the standard deviation (noise) by S/N proportion. The S/N proportions might be relied upon the specific kind of performance characteristics, including smaller is-better or larger is-better. The process parameters of reinforcements in different level as shown in Table 2. The taguchi design for fabrication is designed in MINITAB 19 is as shown in Table 3.

Table 2: Process parameters

Process parameters	Level 1	Level 2	Level 3
Sisal fiber % (A)	20	30	40
Glass fiber % (B)	20	30	40
Al2O3 % (C)	2	3	4

Table 3: Taguchi design for fabrication

EXP NO.	Sisal %	Glass%	Al2O3 %
1	20	20	2
2	20	30	3
3	20	40	4
4	30	20	3
5	30	30	4
6	30	40	2
7	40	20	4
8	40	30	2
9	40	40	3

D. Hand Lay-Up Technique

The assembling system known as 'hand layup' includes physically setting down individual layers or 'employs' of a type of support known as 'prepreg as shown in Figure 1. This comprises of thousands of filaments, which are pre-impregnated with sap and packaged into tows and organized either in a solitary unidirectional utilize or woven together.

Epoxy pitch with hardener was picked in a proportion according to handle boundaries by weight for creation of composite. Slashed sisal and jute strands were utilized to plan example. The polymers composites are manufactured by hand lay-up method. Composite examples with different fiber stacking were made and exposed to post relieving for 24 hours at room temperature. This strategy is most appropriate for thermosetting polymer - based composites. Any mix of filaments and lattice material can be utilized in this technique and furthermore capital and infrastructural necessity are not exactly different strategies. a portion of the disadvantages we face in this procedure resemble uniform circulation of tar inside texture is absurd, development of voids in the covers, nature of eventual outcome relies on abilities of work. One of the main downsides we face in this technique is less creation rate and hard to get high volume part of support. The cycle is appropriate for creation of wind turbine sharp edges, boat and engineering forming and so forth The strategy executed in the creation of sisal fiber, glass fiber and Alumina powder-based cross breed composite is hand lay-up method and it is a shut trim procedure done physically.

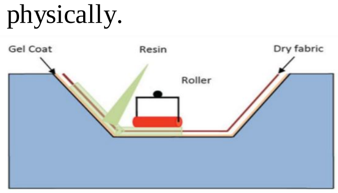

Figure 1 :Hand layup technique

E. Flexural Test

Flexural strength is the ability of the composite material to withstand bending forces applied perpendicular to its longitudinal axis. Flexural test was performed using 3-point bending method as per ASTM D790-03 standard. The Figure 2 depict the dimensions of the test specimen. The tests were carried out using 100 KN Kalpak computerized universal testing machine and loading arrangement for the test is shown in Figure 2. The tests were conducted with a cross head speed of 10 mm/min and test was carried out at room temperature.

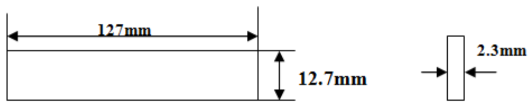

Figure 2: Flexural test specimen dimensions

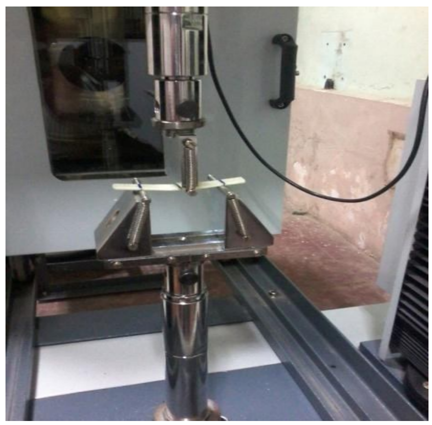

Figure 3: Loading arrangements for flexural test

Composite laminates fabricated as per the stacking sequence listed in Table.3. were used to estimate flexural properties. The test specimens used for flexural test as per ASTM D 790-03 standard are as shown in Figure 4

Figure 4: Flexural test specimen samples

III. RESULTS AND DISCUSSION

A. Optimum Composition of Reinforcements of Composite with flexural strength

A new class of hybrid composite comprising of sisal fiber, glass fiber and alumina powder is being developed by Hand layup technique using epoxy resin as the matrix material. The optimum composition of reinforcement is determined and added for maximum flexural strength of the hybrid composite developed. After determining the range of reinforcements from compliance testing, using Design of Experiments L9 Orthogonal array was selected. The results of experiments conducted are tabulated below, Table 4 shows the flexural strength and flexural strength and signal to noise ration of hybrid composite for different combination of volume fractions of the reinforcements used. After determining the range of reinforcements from compliance testing, using Design of Experiments L9 Orthogonal array was selected. The optimum composition of reinforcement of composition for maximum flexural strength as shown in Table 5.

Table 4: Experimental results and their calculated S/N ratios.

Exp. Runs	Controllable process parameters			Experimental results	S/N ratios of results
	Sisal fiber	Glass fiber	Alumina	Flexural strength Mpa	Flexural strength
1	20	20	2	145.97	43.2853
2	20	30	3	70.76	36.9958
3	20	40	4	144.71	43.2100
4	30	20	3	100.18	40.0156
5	30	30	4	87.06	38.7964
6	30	40	2	109.52	40.7899
7	40	20	4	87.26	38.8163
8	40	30	2	116.09	41.2959
9	40	40	3	48.29	33.6771

Table 5: Optimum Composition of Reinforcements of Composite with flexural strength

Process Parameters	Optimization of reinforcements for Flexural Strength		
	Levels	Optimum value (wt %)	Flexural strength (MPa)
Volume fraction of sisal fiber (%)	20	15.87	145.97
Volume fraction of glass fiber (%)	20	15.87	
Volume fraction of alumina (%)	2	1.587	

In this Experiment S/N ratio for ‘Larger the better ‘is used to design the experiment. Below Table 6 shows the response Table.

Table 6: Response table of S/N Ratio for flexural strength

Experiment number	Levels (A)	Levels (B)	Levels (C)	S/N ratio
1	1	1	1	43.2853
2	1	2	2	36.9958
3	1	3	3	43.2100
4	2	1	2	40.0156
5	2	2	3	38.7964
6	2	3	1	40.7899
7	3	1	3	38.8163
8	3	2	1	41.2959
9	3	3	2	33.6771

The analysis is made using the popular software specifically used to design of experiment applications known as MINITAB 19. Before any attempt is made to use this simple model as a predictor for the measure of performance, the possible interactions between the control factors must be considered. Thus factorial design incorporates a simple means of testing for the presence of interaction effects. Analysis of the result leads to the conclusion that factors combination of A1, B1 and C1 gives maximum flexural strength. As for maximization of flexural strength is concerned factors A, C have significant effect whereas factor B has least as shown in Table 6. The improved flexural strength, the composition of reinforcements used to include sisal fiber, glass fiber and alumina particle are optimized based on Taguchi technique. After determining the range of reinforcements from compliance testing, using Design of Experiments L9 Orthogonal array was selected. The results of experiments conducted are tabulated below, Table 7 shows the flexural strength and signal to noise ratio of hybrid composite for different combination of volume fractions of the reinforcements used.

Table 7 : S/N ratio values for Flexural strength by factor level
Response Table for Signal to Noise Ratios
Larger is better

Level	SISAL FIBER	GLASS FIBER	ALUMINA
1	41.16	40.71	41.79
2	39.87	39.03	36.90
3	37.93	39.23	40.27
Delta	3.23	1.68	4.89
Rank	2	3	1

The main effect plot for S/N ratio for all the three Factors is plotted using MINITAB 19 Software and the factors provide the optimum result will be identified as shown in Figure 5.

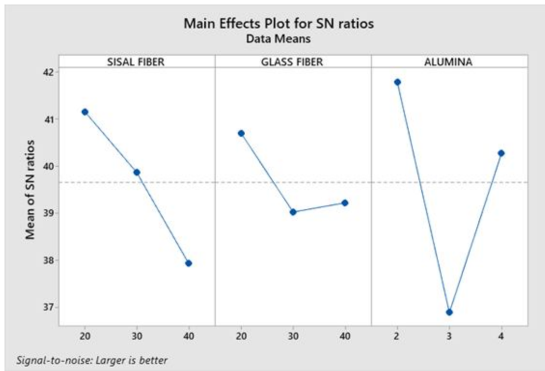

Figure 5: Main effects plot for S/N ratios for Flexural strength

The improved flexural strength, the composition of reinforcements used to include sisal fiber, glass fiber and alumina particle are optimized based on Taguchi technique. After determining the range of reinforcements from compliance testing, using Design of Experiments L9 Orthogonal array was selected.

B. Empirical Relation to Determine Predicted values of Output Characteristics Based on S/N ratio Plots

For validating the Taguchi predicted optimum conditions, conformation tests need to be performed. The predicted S/N ratio (ε)was used to estimate and verify the response at predicted optimum cutting conditions and it was calculated by using Eqn.4.

$$\varepsilon\ \text{predicted} = \varepsilon\ 1 + \sum_{i=1}^{x} (\varepsilon\ 0 - \varepsilon\ 1) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (4)$$

Where

ε_1= Total mean S/N ratio

ε_0 = Mean S/N ratio at optimal level

X = No. of input process parameters

At the Taguchi predicted optimum conditions, the conformation experiments were performed and results were shown in Table 5 for flexural strength. The predicted optimum conditions flexural strength gives an improvement in the performance characteristic results. From Table 8 it was observed that S/N ratios of predicted and optimal condition are very close for flexural strength. The S/N ratio improvement found at the optimal condition for maximum flexural strength is 145.97 MPa. when compared to initial parameter settings as shown in Table 8.

From the conformation experiments, it was found that the Taguchi predicted optimum conditions of gives favourable results over the initial parameter conditions. From the Taguchi predicted optimum cutting conditions, flexural strength found to be 1.32% reduced, when compared to initial parameter conditions.

Table 8: Conformation test results for Flexural strength

	Prediction	Experimental
Level	A1B1C1	A1B1C1
S/N Ratio	44.35	43.28
flexural Strength	147.29	145.97
Improvement in S/N ratio	1.07%	
Percentage reduction in FS	1.32	

C. ANOVA for Flexural strength

In order to understand a reinforcement composition flexural strength of various factors and their interactions, it is desirable to develop analysis of variance (ANOVA) table to find out the order of significant factors as well as interactions. Table shows the results of the ANOVA with the flexural strength[18].

Table3.7 ANOVA test results for the average flexural strength

Source	DF	Seq SS	Adj SS	Adj MS	F	P
SISAL	2	15.893	15.893	7.946	1.02	0.495
GLASS	2	5.039	5.039	2.520	0.32	0.756
ALUMINA	2	37.663	37.663	18.831	2.42	0.293
Residual Error	2	15.579	15.579	7.790		
Total	8	74.174				

The critical value (5% of level of significance) from the f-tables is $F_{2,4} = 6.94$ and since both of the calculated f values are less than 6.94, we conclude that we do not have sufficient evidence to reject either null hypothesis

D. Regression Analysis for Flexural Strength

Problems in engineering often involve the exploration of the relationship(s) between two or more variables. The relationship(s) between variables are of interest to engineers who may wish to determine the degree of association existing between independent and dependent variables. Knowing this often helps engineers to make predictions and, on this basis, to forecast and plan. Essentially, regression analysis provides a sound knowledge base from which accurate estimates of the values of a dependent variable may be made once the values of related independent variables are known. It is worth noting that in practice the choice of independent variable(s) may be made by the engineer on the basis of experience and/or prior knowledge since this may indicate to the engineer which independent variables are likely to have a substantial influence on the dependent variable. In summary, we may state that the principle objectives of regression analysis are: (a) to enable accurate estimates of the values of a dependent variable to be made from known values of a set of independent variables; (b) to enable estimates of errors resulting from the use of a regression line as a basis of prediction. Note that if a regression line is represented as y = f(x) where x is the independent variable, then the actual function used (linear, quadratic, higher degree polynomial etc.) may be obtained via the use of a theoretical analysis or perhaps a scatter diagram (see below) of some real data. Note that a regression line represented as y = f(x) is called a regression line of y on x. The Minitab software was used to formulate the regression equations (5) that predict the average response of flexural strength and flexural strength of the hybrid composite as a function of processing parameters (sisal fiber, glass fiber and alumina). The levels of the process parameters used in the regression model and their corresponding codes are shown in Figure 6 [19].

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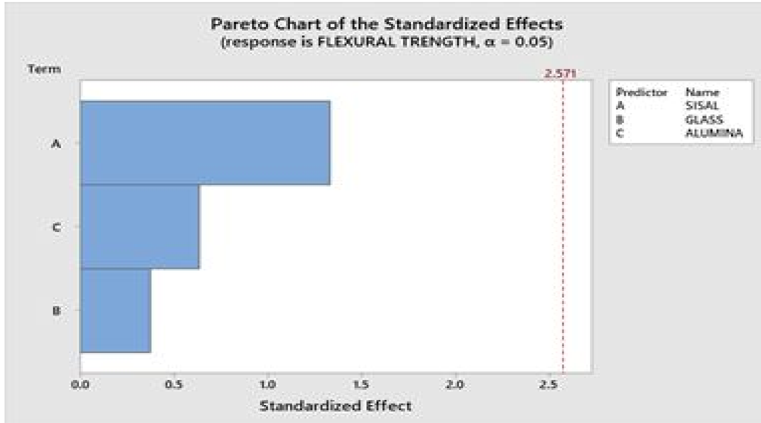
1) *Regression Analysis:* Flexural Strength versus sisal, glass, alumina

Flexural Strength =197.7 - 1.83 SISAL - 0.51 GLASS - 8.8 ALUMINAR-sq= 79%



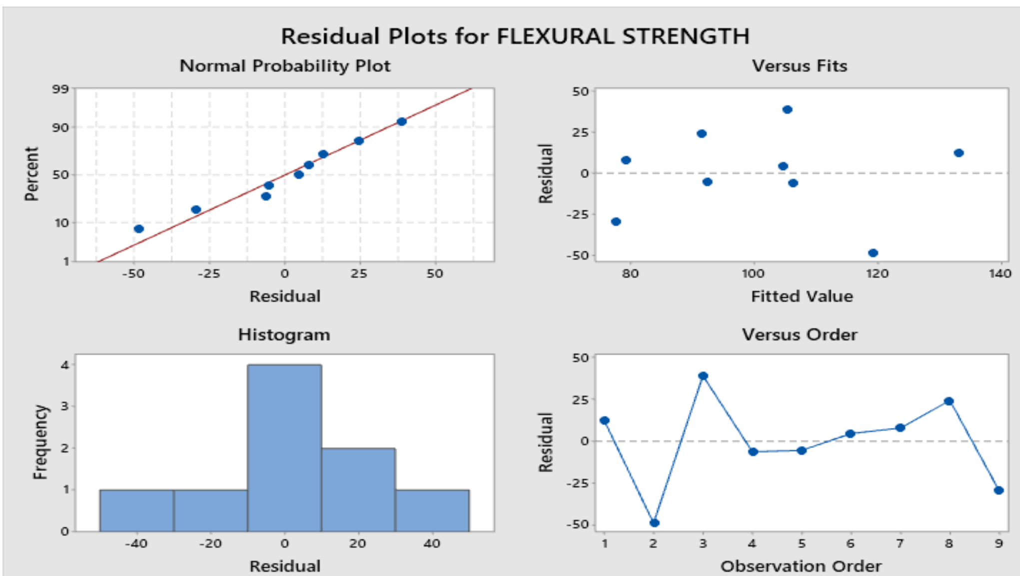


Figure 6: Regression analysis of flexural strength v/s sisal fiber, glass fiber and alumina

The flexural strength of the predicted by regression model are compared with experimental results with the different weight percentages of fibers and alumina reinforcement in epoxy resin as in Fig 6. It is observed that the maximum error 1.32% for regression model when compared to experimental results which shows better agreement with experimental results for L1 of hybrid composite. Finally, the regression analysis found for flexural strength is above 75%, therefore the experimental results are accepted

IV. CONCLUSIONS

In the present research, an application of Taguchi and regression analysis by ANOVA for selecting optimum combination of hybrid composite laminates with different wt.% of fiber, Alumina and matrix to study the strength. The conclusion of present study was drawn as follows.

A. Flexural strength of composites was estimated as per ASTM standard to know the flexural characteristics. It is observed from the results that glass-polyester (L1) composite laminate exhibits better flexural strength as compared to other composite laminates.

B. Enhancement in the flexural strength is due to better bonding, adhesion and uniform dispersion of the fiber in the matrix. Composite laminates fabricated L7 and L6 exhibits lower flexural strength due to the presence of pores at the interface between the fiber and the matrix and the weak interfacial adhesion.

C. Further, it is also observed that the hybrid composite laminates L2 and L9 hybrid composites laminates exhibits better flexural properties compared to L1, L3, L4 and L5 laminates. Use of natural (sisal) fibers, synthetic (glass) fibers along with alumina enhances mechanical properties, hence use of natural fiber in the manufacturing of composite laminates increases the biodegradability and ease of disposal at the end of their service life without harming the environment. Continues use of natural fibres reinforced composite minimizes cost of production.

D. Optimum condition combination for obtaining the high Flexural strength was found as sisal fiber=20% volume fraction, glass fiber = 20%volume fraction and alumina= 2 volume fraction (L1) using Taguchi method and it was observed that 1.32% improvement of flexural strength was found at the Taguchi determined optimum cutting condition.

E. From the ANOVA, it was observed that flexural strength and flexural strength significantly affected with a contribution of 1.32 % , followed by flexural strength.

F. With respect to formability the following process can be adopted to manufacturing the component using the developed composite material.

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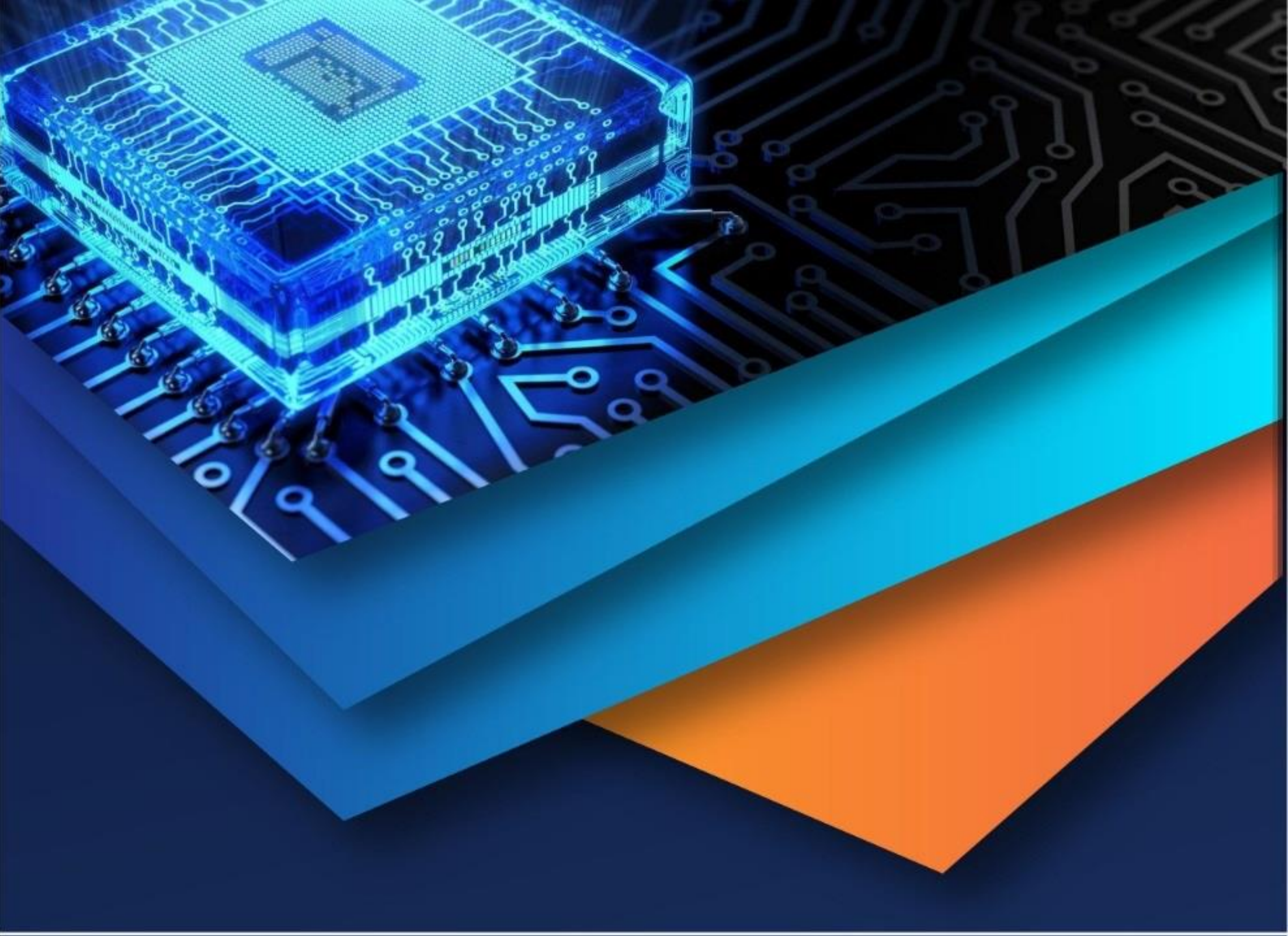

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