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Effect Analysis of Fabrication Parameters on Mechanical Behaviours of Al2O3/SiC Filled Jute Fiber Reinforced Polyester Matrix Hybrid Composite Using Taguchi Technique

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Abstract: In this research work, an investigation was completed by varying concentrations of Al_2O_3/SiC/jute fibre reinforced in polyester matrix composites. The composites were made-up by hand lay-up technique and also the physical and mechanical properties like density, void fraction, water absorption, micro hardness, tensile strength, flexural strength, and microstructure test of the fabricated composites were conducted. From the results, it was revealed that the mechanical properties of the composites were enhanced with the rise in filler content. Composites filled with 18% ceramic powder exhibited maximum tensile strength, flexural strength, inter-laminar shear strength (ILSS), and hardness. As ceramic powder increases, the water absorption of the sample decreases. The interface between ceramic filler, fibre content, and the matrix was observed through optical microscope analysis revealing that there was good adhesion between fibres and therefore the matrix, and also Al_2O_3/SiC powder was distributed uniformly throughout laminated composite that created good mechanical behavours of the composite.

Keyword: Al_2O_3/SiC powder, jute fibre, composite material, mechanical properties

1. INTRODUCTION

Composite material is generally a material composed of a mixture or combination of two or more micro- or macro constituents materials with considerably different physical or chemical properties, that once combined, produce a material with attributes different from the single elements. The individual elements remain separate and distinct within the finished structure. The matrix material a continuous material that's used for binds the reinforcement provides the composite shape and determines the quality of the surface. The matrix materials can be metallic, ceramic, or polymeric. In composite material, the role of the discrete material called reinforcement is increasing the mechanical properties of the matrix material, because of key portion of the applied load distributed and brought by the reinforcement part, whereas the surrounding matrix keeps them within the desired location and orientation, acts as a load transfer medium between them, and protects them from environmental damages because of elevated temperatures and humidness [1]. The reinforcing part will either be fibres or particulates in nature. Fibres are basically two types, natural and synthetic. The natural fibre is a fibre that comprises of an animal, plant fibres, and minerals such as flax, hemp, jute, coir, cotton, wool, bamboo, banana, sisal, and abaca. Nylon, glass, and carbon are some samples of synthetic fibres.

Synthetic fibres (SFs) are utilised to reinforce polymers for a variety of applications in aerospace, automobiles, boats, sporting goods, and packaging materials owing to their high strength and stiffness. However, synthetic fibre like glass, carbon, and boron fibre has serious drawbacks in relations of their no biodegradability, low density, toxicity, initial processing costs, recyclability, energy consumption, machine abrasion, health hazards, cause to environmental pollution problems, etc [2]. Natural Fibre-Reinforced polymeric (NFRP) composite are quickly springing up in relations of research and industrial application as a result of they're low cost, easy productivity, they're friendly to the environment, lightweight, renewable, recyclable, available in huge quantities, high specific strength to weight ratio, and high specific mechanical performance [3]. NFRP composites have attracted in the investigation area more than synthetic fibre reinforced composites because of the growing global energy crisis and ecological risks. Therefore, the material scientists and researchers are forced to shift their attention from synthetic fibres to natural fibres due to increasing environmental awareness, to reduce greenhouse gas emissions. This is important especially in interior transportation applications as it leads to a decrease of vehicle weight for higher fuel efficiency, energy-saving, and reduction in cost.

NFRP composites applied within the vehicle interior and external application like engine sub frame, interior panels, headliners, seatbacks, dashboards, and frontal bumpers subsystems, owing to their high specific strength, modulus, and high damping capability, reduce noise and vibration and reduce the vehicle weight [4]. Additionally thereto, composites have a really high resistance to fatigue and corrosion. It can also be implemented on household products for preparing door and windows, chairs, tables, flooring, partition walls, kitchen cabinets, etc. Ceramic-fillers reinforced polymer matrix composites have the potential to substitute traditional materials. The benefits of using fillers as reinforcement in composite, improving toughness, mechanical and tribological properties.

Numerous investigations demonstrated that jute fibre is a plant having noble mechanical properties, biodegradable, renewable, and versatile material. However, certain limitations are realized within the natural fibres like inferior mechanical strength related to the synthetic fibres, high moisture absorbing, and lower melting temperature. As a means of solution for the matter mentioned above, are fibre pre-treatment, hybridized two or more fibres, and adding of different fillers. Ceramic is used in polymer composite for altering the chemical and physical properties of the polymer matrix to increase the mechanical behavior of the material. Ethiopia has an excess amount of jute plant, which is not investigated well in composite materials and industrial sector, due to lack of awareness about this plant, availability of experimental tools, and low manufacturing process capability.

The main aim of this research work is to analyse the mechanical behavours of Al_2O_3/SiC filled jute fibre reinforced polyester resin composite for automotive application.

2. MATERIALS AND METHODS

2.1. Unsaturated Polyester Resin

The resin utilised for this research work is Unsaturated Polyester (TOPAZ-1110 Phthalic Anhydride). Unsaturated polyester resin is a thermoset and is capable of being cured from a liquid to a solid-state when subject to the right condition. Low viscosity for fast wet-out, convenient for hand lay-up applications, low cost, exhibits good mechanical and good chemical resistance, low-pressure molding capabilities and capability to cure at room temperature are the benifits of unsaturated polyester when related to other thermosetting resins. The ratio of catalyst is 2 % to the total volume of resin to be used. Generally, it is mixed with polyester resin at normal atmospheric temperature. It's supplied by World Fiber Glass and Water Proofing Engineering.

2.2. Alumina (Al_2O_3)

Alumina (figure 1) is a ceramic material used as the filler in the present investigation was purchased from Bangalore Fine chem-Bangalore, India. These Al_2O_3 powder with an average particle size of 80-100 micron has a density of 3.65 gm/cm^3. Al_2O_3 is chosen over other ceramics because it's hard and wear-resistant, has high strength and stiffness, and also it serves as filler in plastics.

Fig. 1 Alumina

2.3. Silicon Carbide (SiC)

Silicon carbide (figure 2) is together of the foremost promising structural materials due to high-temperature strength, good oxidation and thermal shock resistance, high hardness, and low specific weight. It is utilised in abrasives, refractories, ceramic, and numerous high-performance applications. In the research work, the silicon carbide was purchased from Bangaiore Fine chem-Bangaiore, India. These SiC powder with an average particle size of 80-100 micron has a density of 3.21 gm/cm^3.

Fig. 2 Silicon carbide

2.4. Jute fibre

Jute (figure 3) is one in every of the foremost promising materials among all the natural fibre-reinforcing materials. Jute is a long, soft, shiny vegetable fibre that can be spun into coarse, strong threads. It's produced from plants in the genus Corchorus, family Tiliaceae [4]. It is one amongst the most cheap natural fibre and is second only to cotton in amount produced and variety of uses.

Jute takes nearly three months, to grow to the desired height, then cut and bundled and kept immersed in water for the "retting" process, then the outer plant gets separated to form fibres. There are around 5- 6 thousand tons of jute production per year in Ethiopia [5]. Jute fibres used in this research work were sourced from the southern part of Ethiopia where it grows mostly and takes from Ethiopia fiber (qacaa) factory.

Fig. 3 Jute fiber

2.5. Alkali treatment of jute fibre

The chemical treatment aims to enhance poor interfacial adhesion between fibre and matrix that cause the poor wetting of fibre with the matrix, improve bond strength, lowers the water absorption, increase fibre strength, and improving mechanical properties of the composite materials. The jute fibres cleaning with alkali treatment using sodium hydroxide (NaOH) is to maximize the effectiveness of the fibre as reinforcement. For this study to perform a chemical treatment of jute fibre 4gm of NaOH pellet was mixed with 5 liters of water at ambient temperature. In this method the solution of the jute fibre and NaOH must be kept under the vacuum, to reduce absorb moisture in the solution. After soaking jute fibre in the solution for four hours the fibre was washed by distilled water much time to neutralize it. Then, the fibres were allowed to dry in sunlight for at least 2 days.

2.6. Design of experiment (DOE)

In DOE Taguchi method is commonly used because it is a problem-solving tool that can improve the performance of the product, process design, and system. DOE is a technique of shaping and investigating all possible conditions involving variables, multiple factors, and parameters in an experiment. To observe the most influential process parameters in the fabrication of Al_2O_3/SiC/jute fibre reinforced polyester composite namely particle content, jute fibre content, fibre direction at three levels were considered. The selected process parameters, levels, and values at different levels are given in Tables 1.

Table 1. Process parameters and levels

S.No	Factors	Parameters Designation	Level 1	Level 2	Level 3
1	Jute fibre content	A	15	25	25
2	Fibre direction	B	Unidirectional	Bidirectional	Chopped
3	Al_20_3 content	C	3	6	9
4	SiC content	D	3	6	9

The selection of a particular orthogonal array was based on the number of levels of various factors, Here, to conduct the experimental 4 factors each at 3 levels were selected.

Now the Degree of Freedom (DOE) can be calculated by the formula as given below:

$$DOE = P^* (L - 1) \tag{1}$$

P = number of factors L = number of levels

$$DOE = 4 * (3 - 1) = 8$$

However, the total number of the experiment of the orthogonal array (OA) should be greater than or equal to the DOE required for the experiment. Therefore L9 orthogonal array was selected to make the further experiments are shown in Table 2.

Table 2. L9 Orthogonal array center

Expt.No.	**A**	**B**	**C**	**D**
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

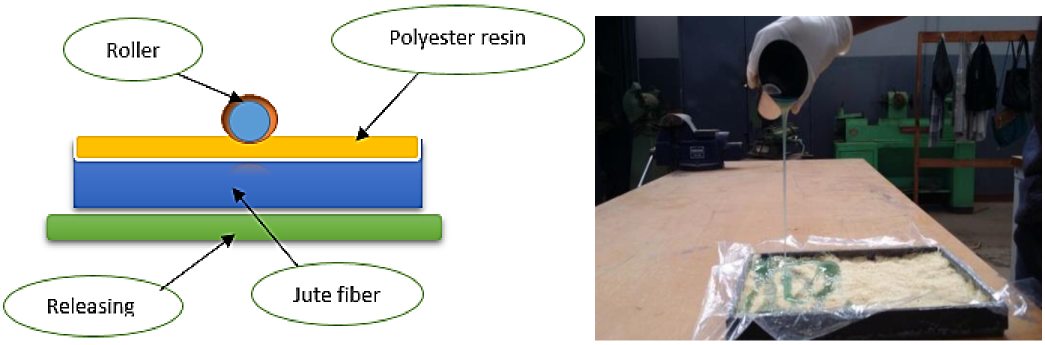
The weight fraction of the particulate, fibre, and the matrix content of the composite are shown in Table 3.

Table 3. Composition of particulate, fiber, and resin used for specimen preparation

S1	**Polyester + Unidirectional jute fibre (15 Wt%) + Al_2O_3 (3Wt%) + SiC (3Wt%)**
S2	Polyester + Unidirectional jute fibre (25 Wt%) + Al_2O_3 (6Wt%) + SiC (6 Wt%)
S3	Polyester + Unidirectional jute fibre (35Wt%) + Al_2O_3 (9Wt%) + SiC (9 Wt%)
S4	Polyester + bidirectional jute fibre (15 Wt%) + Al_2O_3 (6Wt%) + SiC (9 Wt%)
S5	Polyester + bidirectional jute fibre (25 Wt%) + Al_2O_3 (9Wt%) + SiC (3Wt%)
S6	Polyester + bidirectional jute fibre (35 Wt%) + Al_2O_3 (3Wt%) + SiC (6Wt%)
S7	Polyester + chopped jute fibre (15Wt%) + Al_2O_3 (9Wt%) + SiC (6Wt%)
S8	Polyester + chopped jute fibre (25Wt%) + Al_2O_3 (3Wt%) + SiC (9Wt%)
S9	Polyester + chopped jute fibre (35Wt%) + Al_2O_3 (6Wt%) + SiC (3Wt%)

2.7 Hand lay-up

It is the simplest method of processing the thermosets based fibres composite. Benefits of this method are the relatively lower mold costs, the tools required for production are readily available and the molds are easy to maintain. In this technique, thin plastic sheets was used on the bottom of the mold and then a releasing agent was sprayed on it to escape the sticking of polymer to the surface of the mold and to get a good surface finish of the product. Jute fibers as a reinforcement placed at the upper surface of the mold. Then the mixture of polyester risen, Al_2O_3/SiC powder, and hardener was poured on the surface of fibre already placed in the mold. The polymer was uniformly spread with the help of a brush and a roller was used to remove air as well as excess matrix present. After placing the plastic sheet, the release agent was sprayed on the inner surface of the top mold which was then kept on the achieved thickness and during curing a compression load of 35 kg was applied on the mold and the air gaps formed between the jute fiber and mixture was released owing to the application of the load. It was kept for one day to acquire a perfect sample, after curing at room temperature, the mold was opened and the developed composite part was taken out [6]. Figure 4(a) shows a molding sketch map and figure 4(b) shows composite molding.



(a) **(b)**

Fig. 4 Al_2O_3/SiC filled Jute fibre reinforced polymer composite: (**a**) molding sketch map and (**b**) Composite molding at manufacturing workshop

2.8. Specimen cutter

The prepared specimen (figure 5) was cut using a circular cutter and grinder and finally polished by polished paper according to the ASTM standards in different sizes. For microstructure and micro hardness, specimens was produced by using an abrasive cutter.

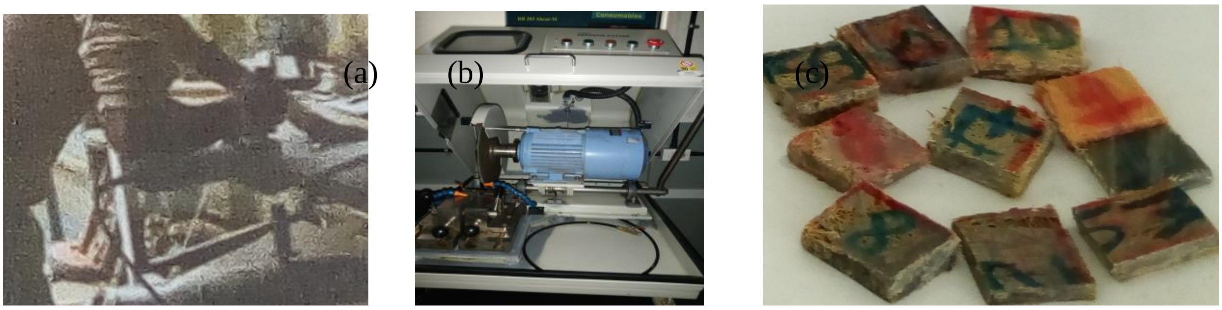


Fig. 5 Cutters and specimen :**(a)** abrasive cutter and circular cutter, (**b)** Tensile Test specimen, and (**c)** density and void fraction specimen

2.9. Universal testing machine (UTM)

UTM (figure 6) is a machine suitable for conducting tests like the tensile, compression, bending, and shear test for all kinds of metals and nonmetals by changing the jaws and modes of operations [7]. The main components of the UTM are, actuator, attachment kit, safety devices frame, engine, and gear, screws, and crosshead grips extensometer, hardware, and software control.

Fig. 6 Universal testing machine testing system working sketch map

For this study, all the material properties testes were done by means of the Computer Controlled universal testing machine which has a capacity of up to 50 K.

3. RESULTS AND DISCUSSIONS

3.1. Density and void fraction

The densities of composite materials are measured using one of three methods: The Archimedes method, the sink-float method, or the density gradient method. For this work, the actual density (ρa) of the composite is determined by the Archimedes principle using rainwater as the medium. This method is covered in ASTM standard D 570. Archimedes principle states that an object fully or partially immersed in a fluid is buoyed up by a force equal to the weight of that the object displaces [9]. This is demonstrated by simple experiments using graduated beakers (figure 7).

(a) (b)

Fig. 7   Measuring the actual density of an object: *(a) weight of the sample in air and (b) weight of the sample in water*

The density of the composite is obtained by using Eq. (2)

$$\rho_a = \frac{\rho_w \, W_a}{W_a - W_w} \tag{2}$$

Where ρa and ρw is the actual/measured density of composite and density of water,

Wa is the weight of the sample in air and Ww is the weight of the sample in water.

The theoretical density of composite materials (ρ_t) in terms of weight fraction can easily be obtained as per the following equation given by Agarwal and Broutman [10].

$$\rho_t = \frac{1}{W_f/\rho_f + W_m/\rho_m + W_P/\rho_{Al2O3} + W_P/\rho_{Sic}} \tag{3}$$

$$W_f = \left(\frac{\frac{\rho_f}{\rho_c}}{\frac{\rho_f}{\rho_c} * v_f + v_c} \right) * v_f = \frac{m_f}{m_c} \tag{4}$$

Where W and ρ represent the weight fraction and density respectively. The suffix p, f, and m stand for the particulate filler, fibre, and matrix material respectively.

It is observed that the values of theoretical density are not equal to the experimental density of the prepared composites. This difference in the composites is the measure of voids or pores present in it. The existence of voids will add to the total volume, but not the weight of the composite. Vv is the void content which is expressed as:

$$V_v = \frac{\rho_t - \rho_a}{\rho_t} \tag{5}$$

Table 4. Measured and theoretical densities along with the void fractions of the jute - polyester composite with Al_2O_3/SiC fillers.

Composite sample	Measured density (gm/cc)	Theoretical density (gm/cc)	Volume fraction of voids (%)
S1	1.211	1.238	2.135
S2	1.294	1.321	2.041
S3	1.389	1.417	1.961
S4	1.127	1.141	1.238
S5	1.302	1.322	1.462
S6	1.287	1.318	2.317
S7	1.307	1.339	2.343
S8	1.248	1.287	3.011
S9	1.270	1.321	3.795

It is observed from Table 4 that the density of composites increases with increasing fibre content and the density of copped fibre-reinforced composite increases as related to uni and bidirectional composites, owing to the copped fibre may not belong to cause fibre entanglement which leads to the creation of voids. Owing to the presence of large amounts of the hydroxyl group in jute fibres makes them hydrophilic, this hydrophilic nature of jute fibre-based polyester composites results in high moisture absorption that leading to increasing fibre swelling, density, and voids in the fibre-matrix interface, but filler reduces the void contented of the composites. This is because the Al_2O_3/SiC filler fills the gap among matrix and fibre, owing to the dense structure, reduces the chance of air entrapment which reduces the existence of pores and voids.

3.2. Tensile test

The aim of the tensile test was to assess the in-plane tensile properties of Al_2O_3/SiC filled jute fibre reinforced polyester composite material (figure 8). The specimens prepared for conduct a tensile test are ASTM D-3039 standards for size and features. For tensile strength evaluation, there were 30 specimens under tensile loading for different weight fractions of Al_2O_3/SiC/jute fiber/polyester resin composite specimen. Tensile testing is one of the fundamental tests to know maximum tensile stress that can be developed in the material. The ultimate tensile strength (UTS) is the maximum stress a material can withstand before fracture.

$$\text{UTS}=\frac{\text{ultimate force}}{\text{original cross-sectional area}} = \frac{F}{A} \tag{6}$$

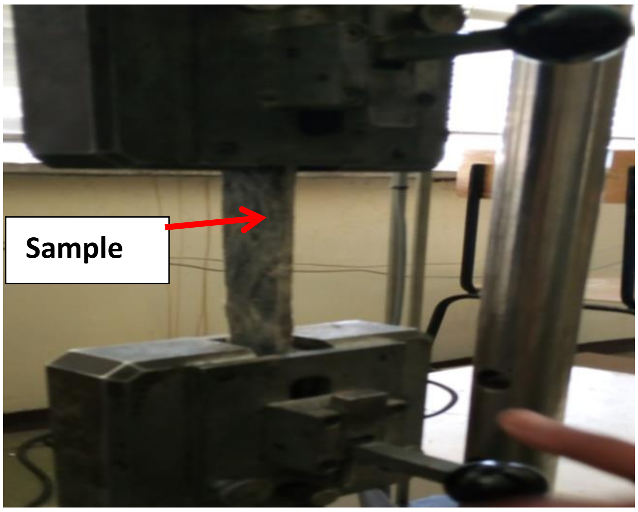


Fig.8. Typical tensile specimen under the tensile test.

Table 5 Tensile strength and elongation results are taken from the universal tensile test machine

S.No	Tensile strength (MPa)			
	Sample			
	Tria.1	Tria.2	Tria.3	Average
S1	21.64	26.88	24.48	24.33
S2	46.48	31.12	43.96	40.52
S3	39.52	46.88	37.12	41.14
S4	19.43	24.1	19.92	21.15
S5	27.1	28.03	22.48	25.87
S6	18.48	19.22	22.96	20.22
S7	11.84	11.92	9.04	10.60
S8	8.08	11.21	8.76	9.35
S9	13.20	10.6	9.43	11.07

It is observed from Table 5 that as the fibre content increases, the tensile strength in the composite between 15% to 35wt% fibre content is increase. The jute fibre orientation affects the tensile strength of the jute fibre reinforced polyester resin composite. Therefore the composite with unidirectional fibre orientation has confirmed a factor of improvement in tensile strength when related with the bidirectional and copped fibre orientation. The results exposed that the incorporation of ceramic fillers lower the tensile strengths of the composites than unfilled one, due to the existence of pores at the interface between the filler particles and the matrix, the interfacial adhesion may be too weak to transfer the tensile stress. The SiC ceramic powder specimen exhibits lower tensile as the filler content increases in the unsaturated resin. This may be owing to the rigidity of the composites increased with an increase in the contented of SiC ceramic powder in the composite.

3.3. Effect of process parameters on Al_2O_3/SiC filled jute fiber-reinforced composite

The parameters that influence the physical and mechanical properties of composite material are the volume fraction of the fibres, fibre length, fibre aspect ratio, fibre-matrix adhesion, concentration distribution and orientation of the reinforcement, stress transfer at the interface, particle size, shape, and filler content. In this investigation work, Al_2O_3/SiC filled jute fibre reinforced polyester resin hybrid composite were fabricated with different fibre direction, jute fibre content, the content of ceramic powder to understand this effect of process parameters on the composite. The fibre direction, jute fibre content, the content of ceramic powder plays a vital role in shaping the physical and mechanical properties of the composites.

3.3.1. Taguchi Design of Experiments

Taguchi's orthogonal arrays are highly fractional orthogonal designs. Orthogonal array designs focus primarily on main effects. This method can be used to estimate the main effects of using only a few experimental runs. Taguchi's Signal – to- Noise ratios (S/N) are the log functions of desired output, serve as objective functions for optimization, help in data analysis, and prediction of optimization results. Table 6 presents the process parameters selected for optimization and their levels.

Table 6. Experimental results and operating conditions for each parameter and level

ExNo	Casting parameters				Tensile strength in (MPa)	Volume fraction of voids (%)
	Fibre direction	Jute Content	Al_2O_3	SiC		
	A	B	C	D		
1	Unidirectional	15	3	3	24.33	2.135
2	Unidirectional	25	6	6	40.52	2.041
3	Unidirectional	35	9	9	41.14	1.961
4	Bidirectional	15	6	9	21.15	1.238
5	Bidirectional	25	9	3	25.87	1.462
6	Bidirectional	35	3	6	20.22	2.317
7	chopped	15	9	9	10.60	2.343
8	chopped	25	3	6	9.35	3.011
9	chopped	35	6	3	11.07	3.795

S/N Ratios

In the Taguchi method, response variation is studied with the help of signal- to noise (S/N) ratio. The uncontrollable parameters are affected by the quality of the characteristics. The undesirable parameter values are expressed as "noise" (standard deviation) and desirable parameter values are termed as "signal" (mean). Specimens are prepared based on L9 orthogonal array and the S/N ratio is calculated using MINITAB 17 software. From the S/N ratio for "larger is better" is used to identify the optimum parameter for the tensile strength of composite and for "smaller is better" is used to identify the optimum parameter for the void content of composite. Related to the S/N ratio for each experiment to maximize the response values, create a response table, and determine the parameters that have the highest and lowest effect on the tensile strength and void content.

3.3.2. S/N ratio response values for tensile strength

Table 7 shows the tensile strength signal to noise ratios in which larger value is better. Table 8 shows tensile strength response table in which larger value is better.

Table 7 Tensile strength signal to noise ratios

Exp. No.	Fiber direction (A)	Jute fiber content (B)	Al_2O_3 (C)	SiC (D)	S/N. ratio	Mean
1	1	1	1	1	27.72	24.33
2	1	2	2	2	32.15	40.52
3	1	3	3	3	32.28	41.14
4	2	1	2	3	26.50	21.15
5	2	2	3	1	28.25	25.87
6	2	3	1	2	26.11	20.22
7	3	1	3	2	20.50	10.60
8	3	2	1	3	19.41	9.35
9	3	3	2	1	20.88	11.07

An example calculation is shown for factor B (Jute fiber content).

$$S/N_{B1} = \frac{27.72 + 26.50 + 20.50}{3} = \mathbf{24.90} \qquad S/N_{B2} = \frac{32.15 + 28.25 + 19.41}{3} = \mathbf{26.60}$$

$$S/N_{B3} = \frac{32.28 + 26.11 + 20.88}{3} = \mathbf{26.44}$$

Table 8. *Tensile strength response table*

Level	Fiber direction(A)	Jute fiber content (B)	Al_2O_3 (C)	SiC (D)
1	30.72	24.91	24.42	25.62
2	26.96	26.61	26.51	26.26
3	20.27	26.43	27.02	26.07
Δ	10.45	1.70	2.60	0.64
Rank	1	3	2	4

The effect of this factor is calculated by determining the range:

Δ= Max – Min = 30.72 – 20.27 = 10.45

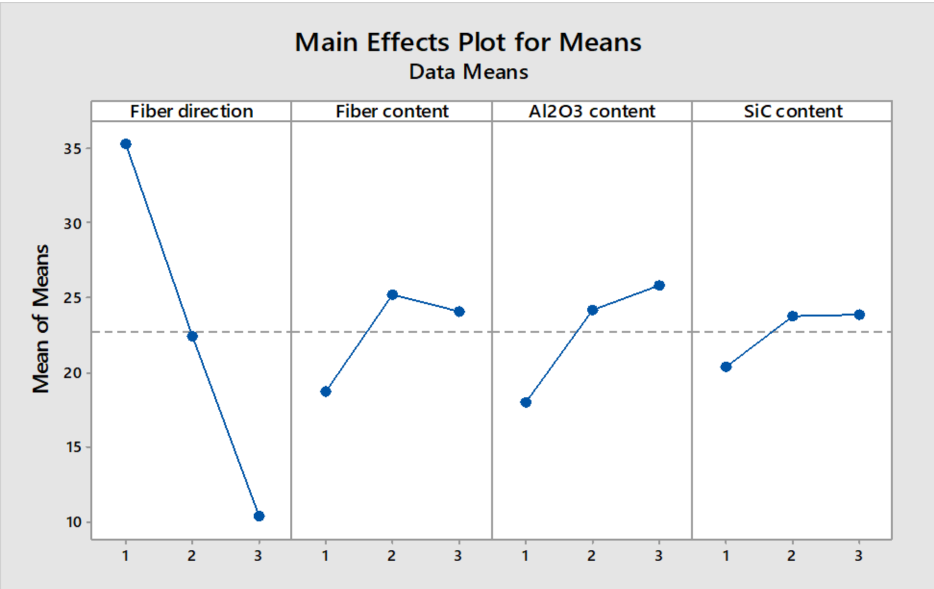


Fig. 9 Main effects plot for Means for tensile strength

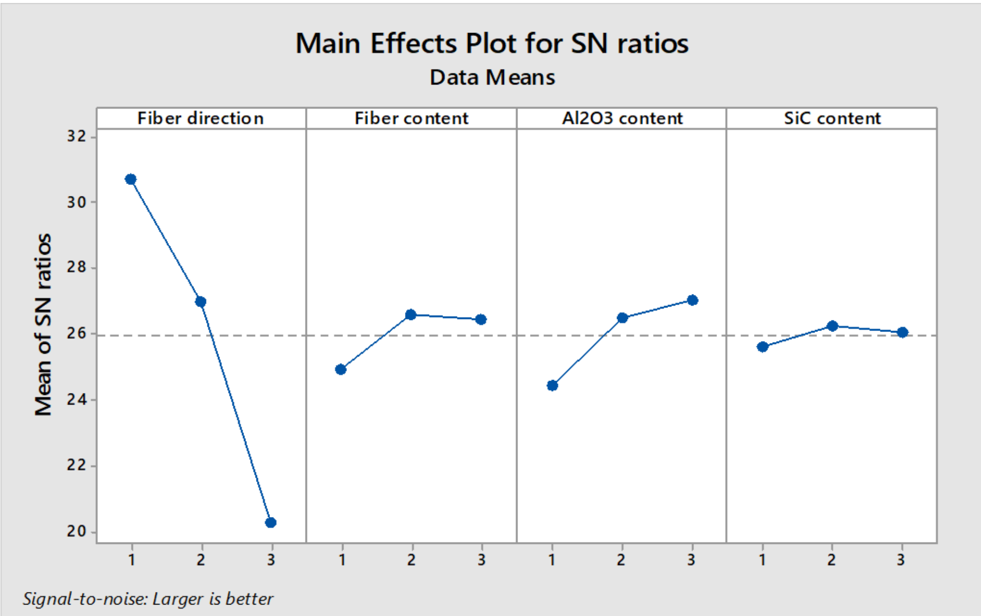


Fig. 10 Main effects plot for S/N ratios for tensile strength

Figure 9 shows the main effects plot for mean value of tensile strength and Figure 10 shows the main effects plot of S/N ratios for tensile strength. Jute fibre direction has the largest effect on the tensile strength and SiC ceramic particular has the smallest effect on the tensile strength.

3.3.3. S/N ratio response values for the volume fraction of voids (%)

Table 9 shows the volume fraction of voids (%) of signal to noise ratios which indicates that smaller value is better. Table 10 shows the volume fraction of void response table in which smaller value is better.

Table 9. Volume fraction of voids (%) of signal to noise ratios

Exp. No.	**Fiber direction(A)**	**Jute fiber content (B)**	**Al_2O_3 (C)**	**SiC (D)**	**S/N. ratio**	**Mean**
1	1	1	1	1	-6.58	2.135
2	1	2	2	2	-6.19	2.041
3	1	3	3	3	-5.84	1.961
4	2	1	2	3	-1.85	1.238
5	2	2	3	1	-3.29	1.462
6	2	3	1	2	-7.29	2.317
7	3	1	3	2	-7.39	2.343
8	3	2	1	3	-9.57	3.011
9	3	3	2	1	-11.58	3.795

An example calculation is shown for factor C (Al_2O_3 content).

$S/N_{C1} = \frac{-6.58 - 1.85 - 7.39}{3}$ = **-5.27**

$S/N_{C2} = \frac{-6.19 - 3.29 + -9.57}{3}$ = **-8.23**

$S/N_{C3} = \frac{-5.84 - 7.29 - 11.58}{3}$ = **-4.35**

Table 10. Volume fraction of voids (%) response table

Level	**Fiber direction (A)**	**Jute fiber content (B)**	**Al_2O_3 (C)**	**SiC (D)**
1	-6.21	-5.27	-7.82	-7.15
2	-4.15	-6.35	-6.54	-6.96
3	-9.51	-8.24	-5.51	-5.75
Δ	5.36	2.96	2.30	1.39
Rank	1	2	3	4

The effect of this factor is calculated by determining the range:

Δ = Max – Min = -2.96 + 8.24 = 2.96

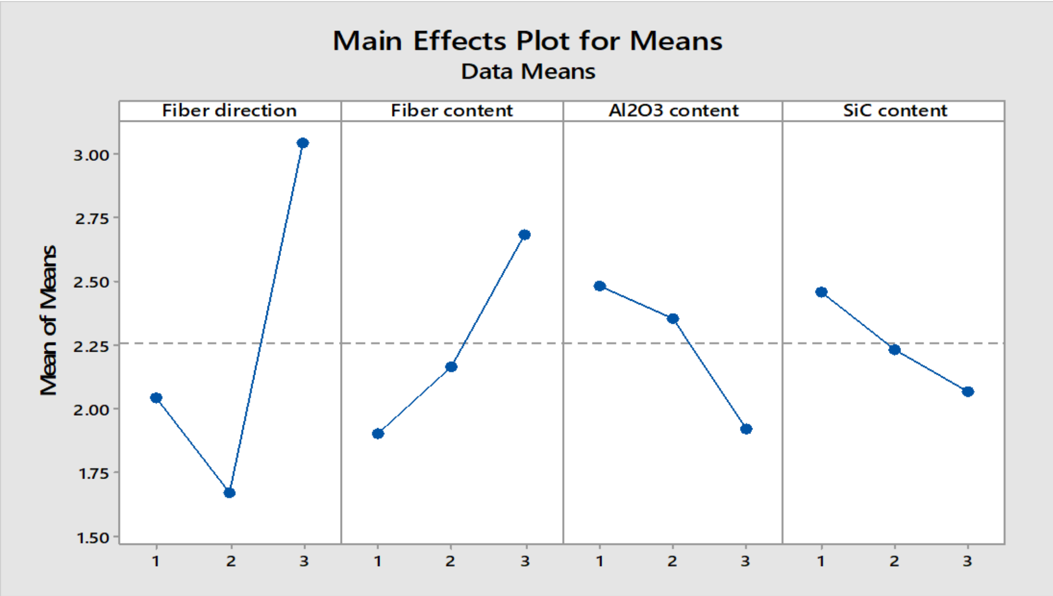


Fig. 11 Main effects plot for Means for the Volume fraction of voids (%)

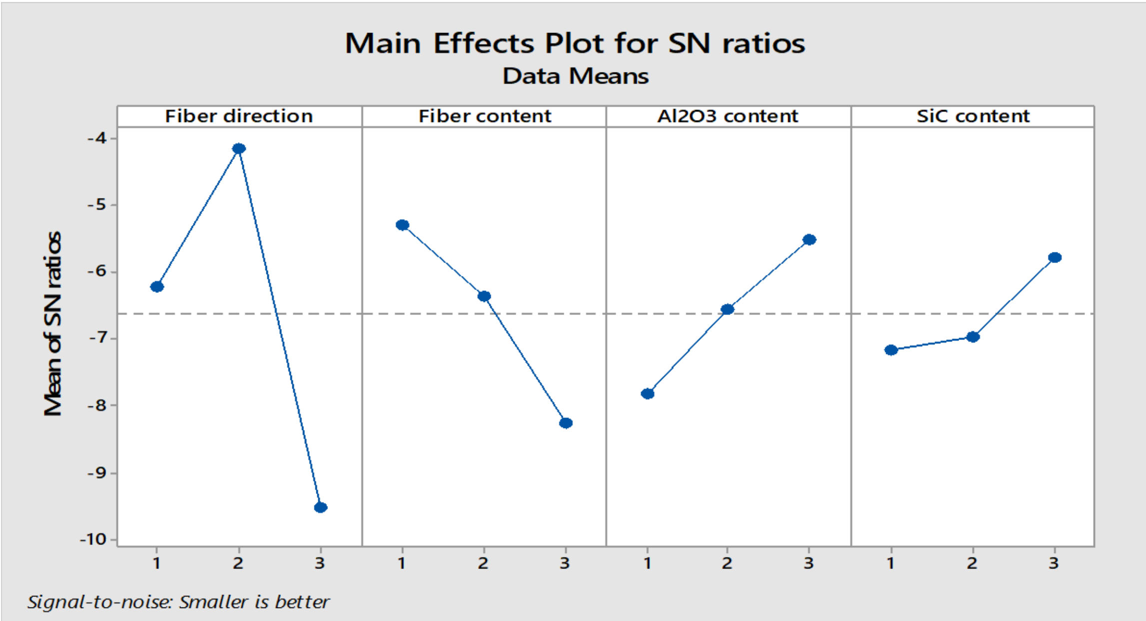


Fig. 12 Main effects plot for S/N ratios for the Volume fraction of voids (%)

Figure 11 shows the main effects plot of means for the volume fraction of voids (%) and figure 12 shows the main effects plot of S/N ratios for the volume fraction of voids (%). SiC ceramic powder has the largest effect on the volume fraction of voids (%) and the fibre direction has the smallest effect on the volume fraction of voids (%).

Tensile strength and Void content S/N ratio values using MINI TAB 17 software

The S/N ratio values at different levels for the responses of tensile strength and Volume fraction of voids (%) are analyzed using MINITAB 17 software are as shown in table 11.

Table 11. Optimal parameter values

S. No	Fiber direction (A)	Jute fiber content (B)	Al_2O_3 (C)	SiC (D)
Tensile strength	Unidirectional jute fiber	25 wt %	9 wt%	6 wt%
Volume fraction of voids (%)	Bidirectional jute fiber	15 wt%	9 wt%	9 wt%

Fiber direction, fibre content, and Al_2O_3/SiC content play a vital role in determining the physical and mechanical properties of this composite. In both tables (8) and (10), it was found that the jute fibre orientation contributes a larger impact on tensile strength and SiC ceramic powder is the optimum parameter that affects the Volume fraction of voids (%) of the composites. 3

4. CONCLUSION

Al_2O_3/SiC filled jute fibre reinforced polyester hybrid composites were prepared by Taguchi's experimental design, and their fabrication parameters and the properties were analyzed signal-to-noise. The results revealed that the fibre direction is the most dominant fabrication parameter for the tensile strength among the four different parameters. In void content, the dominate fabrication parameter is also found to be the fibre content. From the main effect plots of tensile strength, it can be seen that the tensile strength of composite increases with the increase of the filler content and fibre content. Similar observations were also obtained for the void content for its main effect plot. The optimal combination of fabrication parameters was obtained by the Taguchi analysis for both the tensile and void content of Al_2O_3/SiC filled jute fibre reinforced polyester hybrid composites. The results of the optimal fabrication parameters were the maximum tensile and minimum void content.

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