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Research Paper

Multi-objective Optimization of Sansevieria Trifasciata Fibre Reinforced Vinyl Ester (STF/VE) Bio-composites for the Sustainable Automotive Industry

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Abstract

Bio-composite materials have taken an extensive interest in research over the years due to their excellent properties, such as excellent mechanical and physical properties, stiffness, and low density/lightweight. The exceptional properties of bio-composite materials have had a widespread application in several industries, such as; the packaging industry, construction, automotive, and other related engineering fields. This research investigates mechanical, physical, and microstructure properties of Sansevieria Trifasciata (STE) natural fiber, -reinforced Vinyl Ester (STF/VE) bio-composite. The mechanical and physical properties of STF/VE bio-composites, including the tensile strength and density, are investigated through fibre preparation, orientation, and fibre volume fraction parameters. The STF/VE bio-composite tensile strength coupon is manufactured using the bio-composite transfer moulding (BTM) process and with pressure moulding. The Taguchi experimental design and analysis of variance (ANOVA) are selected to investigate the effect of variables on the mechanical properties model. The alkali preparation of STF, unidirectional fibre orientation, and fibre volume fraction improve tensile strength. Non-alkali treatment and random fibre orientatio, on the other hand, result in a reduction of density. The results of the ANOVA analysis show that the fibre volume fraction (wt.%) is the variable that most significantly affects the tensile strength and density responses, with contributions of 50.57% of tensile strength and 51.34% of density, respectively. Based on the optimization results, the STF/VE with alkali treatment, unidirectional, and 15 w.t.% is chosen as the best bio-composite formulation, with the best tensile strength-density balance. It indicates that the optimum parameter was successfully achieved among the samples examined in this work.

Keywords: Alkali treatment; Bio-composite; Transfer moulding; Sansevieria Trifasciata fibres; Vinyl ester

1. Introduction

As nonrenewable resources become scarce, public awareness of renewable resources is growing. Composites are used in a variety of applications, including sports equipments, automotive parts, aerospace structures, and building materials [1], [2]. As a result, novel natural fibres or plants that provide organic reinforcing fibres emerge intensively in the research. Natural fibres were commonly used in three ways: as paper, textiles, and fabrics and as a reinforcing ingredient in composites [3], [4]. Natural fibres has gain interest in replacing glass fibres as reinforcement materials in various applications, including composite parts in the packaging, construction, and automotive industries [5], [6]. Thermosets as resin are increasingly used as common material for housing tool, automotive and electrical components, and motorcycle part [7]. In addition to being biodegradable [8], natural-based fibres operate as good as insulators in thermal and acoustic applications. Plant-based fiber-reinforced composites are also used in various automotive interior components, including door panels, cabin linings, and cushioned seats [9]. Cotton fibres from the textile industry and coconut fibers serve as insulators for interior components as well. Flax fibers reinforced epoxy resin as primary plant-based fibre is used for door panels. Plant-based fibres are lighter in weight than synthetic fibres, which benefits the automotive industry [10]. Natural fibre has several advantages over synthetic fibre, including lightweight, biodegradability, low cost, acceptable mechanical performance, and life-cycle superiority [11].

Several studies on synthetic and natural fibre as a bio-composite for reinforced vinyl ester composites were conducted by [12]–[14]. Research using synthetic glass fibre as a reinforcement in epoxy and vinyl ester was carried out by Singh et al. [12]. An experimental method was used for the investigation, with a resin and fibre proportion of 53:65 wt.%. Additional temperature treatments, room temperature, 50 °C, 70 °C, and 80 °C, were applied to the glass-epoxy and glass-vinyl during curing processes. Tensile strength, fatigue, and flexural properties were analysed to assess the performance of glass/epoxy and glass/vinyl ester composites. It was found that the ultimate tensile strength of a glass-epoxy composite was found between 330 and 370 MPa whereby the compressive strength of glass/vinyl ester composites has a range from 270 to 330 MPa. It was observed that post-curing strength increased the flexural strength of glass/epoxy composites by 32% and 16% for the case of glass/vinyl ester composites. Furthermore, the fatigue analysis show that cracks and defects grow faster at higher frequencies, resulting in a rapid drop in stress levels in the test samples. A Statistical analysis was employed to establish a link between mechanical and physical properties by several researchers. Manickam et al. [13] tried unsuccessfully to investigate of the mechanical and wear characteristics of untreated and treated Roselle fibre/vinyl ester composites with fibre content of ranging from 10% to 50%, with a 5% of interval. The experimental results showed that Roselle fibre with a fibre content of 40%, both alkaline and non-alkali treated, has better mechanical properties The analysis show that fibre content beyond 40% decreased significantly the tensile, flexural, and impact strength of samples. Furthermore, treated Roselle fibre outperforms untreated ones in all cases studied. The Roselle fibre was chemically treated using silane and alkaline solutions. The effect of chemical treatment on physical, mechanical, and water absorption characteristics has been investigated by Nadlene et al. [14]. The experiment successfully discovered that the alkaline treatment enhances chemical properties. The treated fibre outperformed the untreated fibre in terms of water repellence. Alkaline-treated Roselle fibre absorbs more water compared to untreated fibres. Thermal gravimetric analysis of treated and untreated Roselle/vinyl ester composites showed that alkaline-treated Roselle fibre was more thermally stable than unthreaded fibers. As for silane-treated fibres, scenario was reversed. An SEM analysis was performed to ensure that the fibre and matrix were adequately bonded. It demonstrates that treated fibres outperform untreated fibres in terms of adhesion. Through mechanical characteristics tests, treated Roselle fibres have better tensile and flexural strengths but lower impact strength than untreated. The parameters studied were fibre content, fibre length, and fibre diameter. And the process factors were optimized using the Box-Behnken (BB) experimental response surface methodology (RSM) method.

Shah et al. [15] evaluated a partially biodegradable composite material produced from green vinyl ester resin (GVER)-reinforced commercial resin as well as pure GVER. The amount of GVER volatile organic compounds were observed to improve mass production by using styrene with relative viscosity of 20% to 40%. Kong et al. [16] developed a car cover made by natural flax fibre for reinforcement to produce automobile covers using transfer moulding fabrication method. The automobile's cover using flax fibre-reinforced vinyl ester composite, was primarily structurally investigated using FEA method fulfilling structural safety, stability, and weight requirements. The analysis values demonstrated a great correlation between the strain and deflection and correlate with the analytical values as well. The total weight of the cover design of 4.4 kg was found, which improved with a reduction of weight by 31.7 percent.

Gopinath et al. investigated the behaviour of a hybrid fibre-reinforced composite deck made of glass and hemp fibres embedded in a vinyl ester matrix. The evaluation of the flexural performance of the composite deck was performed using ANSYS finite element method software. The maximum deflection and strain values experienced by deck panels with stiffeners at the fuselage joints were less than those experienced by deck panels located in the centre of each cellular unit's upper flange. Deck performance with U and V-shaped stiffeners at the upper and lower body flange joints was found the best configuration, with significantly lower deflections and strains [17].

A few researchers focused on natural fibres ad bio-composite, such as Roselle fibre/vinyl ester composite [13], [11]; green vinyl ester resin [15]; natural flax fibre/vinyl ester composite [16] and glass and hemp fibres embedded in a vinyl ester [17] as natural/synthetic fibre bio-composite natural/synthetic fibre composite. So far, seldom researcher investigated on natural fibre using Sansevieria Trifasciata fibre/vinyl ester (STF/VE) as a bio-composite. This research aimed to minimise the balance between tensile strength and density of STF-reinforced VE bio-composite. The Taguchi experimental method using a 3-parameters and mixed design level is employed to achieve the objective. STF/VE bio-composite parameters such as alkali or non-alkali treatment for fibre preparation, fibre orientation, and fibre volume fraction (wt.%) are selected for further analysis.

2. Method

2.1. *Materials*

2.1.1. *Sansevieria Trifasciata Fibre (STF)*

This Fibre can be collected from Sansevieria Trifasciata (ST) leaves using a variety of techniques, including water rinsing. The extracted fibres were tested for each diameter parameter, fineness, tensile strength, and fibre elongation value. The diameter of Sansevieria Trifasciata fibre (STF) is about 50.8 microns with a fineness of 19.45 denier. The tensile strength and elongation of the fibre are 5.97 gram/denier and 3.3% [18]. The fibre's tensile strength increases as the length of the fibre increases. The Fibre length, on the other hand, has no effect on the elongation at break [19]. The combination of STF-matrix shows that fibre size of 125 mm gives the highest and more stable value of tensile strength. However, it does not significantly affect the thermal resistance of the composite [20].

There are various methods of extracting Sanseveria Trifasciata leaf fibre, namely retting and hand scrapping. The scrapping method is carried out using a knife or ceramic plate by placing the leaves of Sanseveria Trifasciata on a plate and scraping it repeatedly until the fibres are visible. The last step is to wash the extracted fibre with water and dry it under the sunshine. Within the first three days of harvest, hand scraping should be done. The leaves will dry out if left too long, making it difficult to extract the fibres. Then, the damaged or broken leaves are separated from the rest of the leaves that have been collected. The simplest and quickest way to extract mechanical fibres is to scrape them out. However, it requires a lot of hand energy and requires much labour [21]. A 3 % NaOH solution is used in the alkaline treatment of SFT. 3.0 grams of NaOH (99.8 % purity) are dissolved in 1 litre of water to make the solution. In addition, the dried STF are immersed in a NaOH solution with a fibre/NaOH solution mass ratio of 1:100 and heated in a reflux device at 100 °C for 2 hours. NaOH commercial-grade from Baratachem are selected for alkaline treatment [22]. **Figure 1** showed Sanseveria Trifasciata leaves and Sanseveria Trifasciata fibre.

The Chesson-Datta test determines the lignocellulose content in STF [23]. The STATIMAT ME+ automatic tensile tester machine was used to test its mechanical properties [24] following ASTM D 2256 standard. **Table 1** shows the results of chemical compositions and physical /mechanical properties.

2.1.2. *Vinyl ester (VE) resins*

Vinyl ester (VE) resins are now widely used in adhesives, coatings, and fibre-reinforced composite formulations due to high strength and modulus; excellent thermal stability, and low shrinkage [25]. The VE resin is a thermoset poly-

(a) (b)

Figure 1. Natural resource fibre reinforced Vinyl Ester as STF/VE bio-composites: (a) Sansevieria Trifasciata, (b) Sansevieria Trifasciata fibre (STF)

mer obtained from an epoxy resin and a carboxylic acid reaction. The VE resin, on the other hand, hardens as it cures [26]. Combining VE with an elastomer [27], another thermoset [28], a thermoplastic [29], and inorganic nanoparticles increased its toughness [30]. The VE resin's properties include curing at room temperature and reasonably short ageing time; having good mechanical properties, especially toughness; having good water and chemical resistance compared to polyester; and lower price than epoxy. Mechanical properties and chain structure of vinyl ester resin are presented in **Table 2** and **Figure 2** respectively [25], [26].

Natural Fibre-reinforced VER composites can be made in several ways. One of which is the most popular and cheapest method known as hand lay-up. This is accomplished by bleaching and spray coating the mold with a gel layer before heating it in an oven. Hand lay-up involves manually feeding Fibre layers into a mold with resin and catalyst sprayed on each layer. Then a certain amount of pressure is applied to form a dense and firm thin layer [31].

Table 1. The chemical composition and mechanical properties of single STF

Test parameters	Test result
Extractive substances (%)	3,11 %
Hemicellulose (%)	33,21 %
Lignin (%)	8,91 %
Cellulose (%)	54,77 %
Density (kg/m3)	1100
The tensile strength (gram/denier)	5.97
Elongation (%)	3.3

Table 2. Mechanical and physical properties thermoset comparison of VE resins and epoxy.

Parameters	VE Resins [32]	Epoxy [32]
Density @ 20 °C (g/cm3)	1.03 – 1.15	1.15-1.3
Modulus elasticity (GPa)	3.1 – 3.8	2.7-4.1
Tensile strength (MPa)	16-95	40-65
Tensile stress (MPa)	77-88	100 - 200
Compressive strength (MPa)	82	116-404
Elongation (%)	2.5-9	3-5
Shrinkages (%)	1.65	0.001-0.13
Water Absorption,@ Temp. 23 °C (%)	0.1	2-5

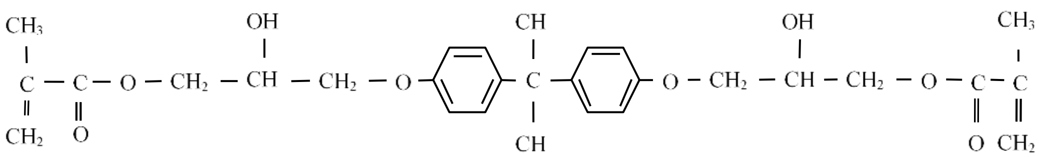


Figure 2. Chain structure of VE resins [25], [26]

2.2. *Preparation of composites*

The test sample refers to the ASTM D3039 Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials. Based on the ASTM D3093 standard, all sample dimensions are in mm and specified tolerances. **Figure 3** showed the profile and sample dimensions for tensile tests [33].

The following steps demonstrate the STF/VE composite transfer moulding process for tensile strength coupons:

a. Ensures that the top and bottom mold are symmetrical and in line.
b. Stir the VE resins to make certain homogeneity.
c. Coat the top and bottom molds with oil/grease to simplify STF/VE bio-composite release.
d. The next step is to apply VE resins to the top and bottom mold surfaces.
e. Place the fibre in the top and bottom molds according to the orientation of the matrix in iteration one described in **Table 2**.
f. Assemble the upper and lower molds for the VE resin casting process. The mold is then tilted about 10 degrees so that VE resins can quickly pour the entire cavity.
g. Using a funnel, pour the VE resins into the mold's lower hole, ensuring the vent hole on the top side is filled.
h. Place the mold on the press machine with a pressure of 130 bar and allow it to dry for approximately 120 minutes.
i. Open the mold cavity and remove all burry of the tensile strength coupons STF/VE bio-composite.
j. Clean the top and bottom prints, then repeat steps a–i for iterations 2–18.

Figure 4 illustrates the STF/VE bio-composite transfer moulding process for tensile strength coupons at each step.

2.3. *Taguchi Orthogonal Array*

The Taguchi techniques are chosen for the research investigation in this study. The Taguchi practical approach is widely used in industries such as textiles [24], machining processes [34], painting applications [35], metal forming [36], and resistant welding [32]. The orthogonal array (OA) is a balanced parameter matrix that can separate the effects of parameters experiments. To ensure a balanced comparison of each critical parameter,

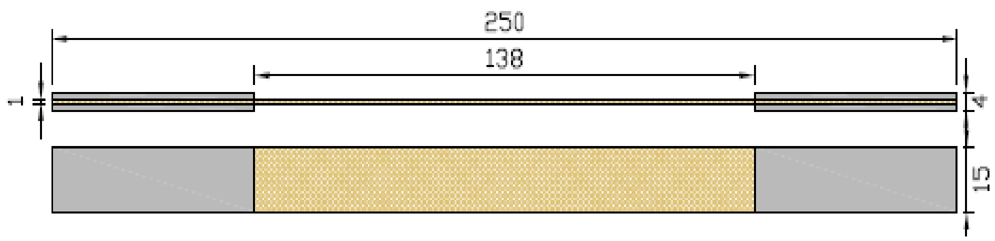


Figure 3. Geometry and dimensions of STF/VE bio-composite tensile strength coupon.

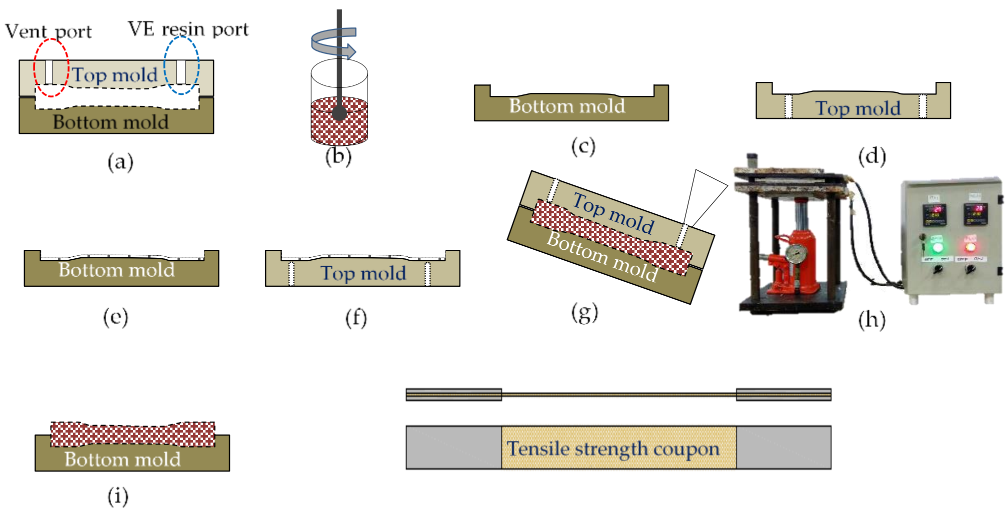


Figure 4. Schematic representation of the STF/VE bio-composite transfer moulding process for tensile strength coupons.

the Taguchi OA employs a matrix in general. The AO matrix is used to determine samples from a given group precisely. The orthogonal array (OA) is a balanced parameter matrix in which the effects of parameters can be separated experimentally. In general, the Taguchi OA employs a matrix to maintain a balanced comparison of each key parameter. The AO matrix is used to determine selected samples from a target segment accurately. It usually allows us to define specifications for groups of efficiently produced models. The OA matrix is widely used for empirical research based on the critical parameter and the practical level evolved.

This work provides a three-factor and mixture-level design, yielding 17 degrees of freedom. The Taguchi experimental's three factors input has been identified as follows: There are two types of preparation: alkali treatment and non-alkali treatment; fibre orientations are random, woven, and unidirectional; and fibre volume fractions (wt.%) are 5, 10, and 15. Fibre treatment is typically used to address natural fibre incongruence and poor adhesion in a polymer matrix [11]. **Table 3** shows the process parameters for optimization. L18 (2^1 3^3) orthogonal array (OA) has 17 degrees of freedom to choose in this work. The experimental layout for natural fibre (sansevieria trifasciata) reinforced vinyl ester composites factors using L18 OA is presented in **Table 4**.

Generally, Taguchi provides three characteristics data of the signal to noise ratio (SN ratio): "lager is better", "nominal is the best", and "smaller is better" [37]. To maximize tensile strength (MPa) and modulus elasticity (GPa) of STF/VE bio-composite, the SN ratio "larger is better" characteristic data has been selected. While to minimize the density of STF/VE bio-composite, the "smaller is better" characteristic data has been provided. SN ratio with data characteristics "smaller is better" is a non-negative quality feature with a 0 (zero) limit value [36]. The desired value of the SN ratio decreases or approaches zero. The SN ratio "larger is better" and "smaller is better" can be estimated by using equations 1 and 2, respectively [38], [39].

Table 3. Parameters of the Taguchi experimental

Code	Process parameters	Experimental Level		
		1	2	3
A	Fibre preparation /FP.	Non A-T*)	A-T*)	
B	fibre orientation /FO.	Random	Woven	Unidirectional
C	Fibre Volume Fratcion/ FVF. (w/t.%)	5	10	15

*) Non A-T = Non alkali treatment, A-T = Alkali treatment.

Table 4. Experimental layout based on an L18 (2^1 3^2) orthogonal array

Run	FP*	FO*	FVF * (wt.%)	Tensile Strength (MPa)	Density (kg/m3)	Matrix experiment
1	1	1	1	52.87	1140	A1B1C1
2	1	1	2	60.58	1130	A1B1C2
3	1	1	3	72.32	1160	A1B1C3
4	1	2	1	59.82	1175	A1B2C1
5	1	2	2	68.32	1172	A1B2C2
6	1	2	3	74.61	1196	A1B2C3
7	1	3	1	64.56	1170	A1B3C1
8	1	3	2	82.69	1170	A1B3C2
9	1	3	3	104.74	1200	A1B3C3
10	2	1	1	60.52	1140	A2B1C1
11	2	1	2	71.63	1240	A2B1C2
12	2	1	3	75.86	1240	A2B1C3
13	2	2	1	61.16	1168	A2B2C1
14	2	2	2	73.45	1216	A2B2C2
15	2	2	3	81.23	1232	A2B2C3
16	2	3	1	65.86	1160	A2B3C1
17	2	3	2	98.43	1220	A2B3C2
18	2	3	3	121.11	1260	A2B3C3

FP =Fibre preparation, FO= fibre orientation, FVF= Fibre Volume Fraction

Larger is better:

$$SN\ ratio = -10 \log \frac{1}{n_0} \sum_{i=1}^{n_0} \frac{1}{y_i^2} \quad (1)$$

Smaller is better:

$$SN\ ratio = -10 \log \sum_{i=1}^{n_0} \frac{y_i^2}{n_0} \quad (2)$$

Where n, y, and $\bar{y}$ are the number of samples, response variable/output factor, and an average of the response variable, respectively.

2.4. *Characterization*

2.4.1. *Tensile properties*

The mechanical testing aims to determine the composite material's tensile strength and modulus elongation of STF/VE. The tensile strength and tensile modulus elongation at the break of composites were evaluated using a TENSILOR ® universal testing machine (RTF 1310). This test was carried out following the ASTM D 3039/D 3039M specifications. The testing speed was 5 mm/min. In each case, at least two samples were tested for each iteration, and the mean values are shown in **Table 4**.

2.4.2. *Density*

Density testing aims to determine the density of the composite material reinforced with STF/VE. The density test follows ASTM D792 Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement. Density testing was carried out using a 250 mL pycnometer and a digital scale with an accuracy of 0.0001 grams. Equipment for the density testing is presented in **Figure 5**.

The calculation of resin and composite density, ρ can be done using the Eq. 3:

$$\rho = \frac{W_s \times \rho_m}{W_{p+m} \times (W_s - W_{p+m})} \quad (3)$$

where W_p is the empty pycnometer mass (kg), W_m is the mass of oil (kg), W_a is the mass of water used (kg), W_{p+m} is the mass of the pycnometer in kg, W_s is the mass of the sample to be tested.

2.4.3. *SEM microscopy*

The scanning electron microscopy (SEM) test evaluates the fracture morphology of the natural fibre STF/VE bio-composites. SEM images taken by JEOL JEC-3000PC with an accelerating potential of 10.0 kV were used to observe the composite microstructure of samples. To reduce electron charging, the fracture surface of the tensile-tested composites was sputter-coated with platinum prior to morphological examination. The SEM images used were conducted in the Laboratory of mechanical engineering Polman Bandung.

3. Result and Discussion

3.1. *Mechanical and Physical Properties of STF/VE composites analysis*

Bio-composites with neat STF/VE resin as a matrix showed higher mechanical properties than VE-based. The maximum STF/VE bio-composite tensile strength was achieved in iteration number #18. In contrast, the minimize was achieved in iteration number #1. The maximum tensile strength achieved is 121.11 MPa with alkaline treatment for preparation, unidirectional for fibre orientation, and 15 w/t% for fibre volume fraction as parameters. The lowest tensile strength achieved is 52.87 MPa with non-alkaline treatment for preparation, random fibre orientation, and 5

Figure 5. Density testing apparatuses for STF/VE composite

w/t% for fibre volume fraction as parameters. The mechanical properties of STF/VE bio-composite have been improved by natural STF alkali treatment, fibre orientations, and fibre volume fractions. It was improved by 27.47% compared-to VE-based [32]. SFT/VE Bio-composite has higher tensile strength, about 38.65%, and 189,7%, compared with unidirectional aligned bagasse/VE fibre [13] and Roselle fibre/VE [10] bio-composite, respectively.

In the present study, the tensile strength of the DoE-based STF/VE bio-composites increases compared to VE-based optimum STF/VE bio-composites. Such an increase in tensile strength causes the STF/VE bio-composite rigidity, and it was attributed to the probable molecular interaction between STF with the vinyl ester surface. Thus, the reduction in crosslink density of VE resin due to STF/VE formation has been compensated for by these new possibilities of interaction during the formation of STF/VE bio-composite. A detailed result of the tensile strength and density is presented in **Figure 6**.

The lowest STF/VE bio-composite strength density was achieved in iteration number #2. In contrast, the highest density was achieved in iteration number #18. In the automotive application case, the lower density of STF/VE bio-composite material will have an effect on increasing automotive performance. The lowest density achieved is 1130 kg/m^3 with non-alkaline treatment for preparation, random for fibre orientation, and 10 w/t% for fibre volume fraction as parameters. The highest values is achieved for 1260 kg/m^3 alkaline treatment for preparation, unidirectional fibre orientation, and 15 w/t% for fibre volume fraction as parameters. Bio-composite STF/VE density has been improved by natural STF chemical treatment, fibre orientations, and fibre volume fractions. It was improved by 3.0% compared with VE-based maximum density [25]. SFT/VE bio-composite has higher tensile strength, about 38.65%, and 189,7%, compared with unidirectional aligned bagasse/VE fibre [10] and Roselle fibre/VE [7] bio-composite, respectively.

3.2. *SN Ratio Analysis*

SN ratio analysis was used to assess the effects of all input variables on the response variables. The input variables and Taguchi design of the STF/VE bio-composites parameter process are presented in **Table 2** and **Table 3**, respectively. The outcomes selected are the tensile strength and density of STF/VE bio-composites. **Figure 7** shows that the S/N ratio chart of the STF/VE bio-composite has been calculated using Eq. 1 and 2. **Figure 7** explains the input factor of STF/VE bio-composite. The fibre preparation, orientation, and volume fractions have been identified as A, B, and C, respectively. The characteristic tensile strength data are chosen as "larger is better". The characteristic data of "larger is better" means that tensile strength and modulus elasticity value will be directly proportional to quality. The higher value of tensile strength or modulus will have affected the higher quality of the product. **Table 5** shows the SN ratio value of all input tensile strength STF/VE bio-composite input parameters. Fibre volume fraction significantly affected the

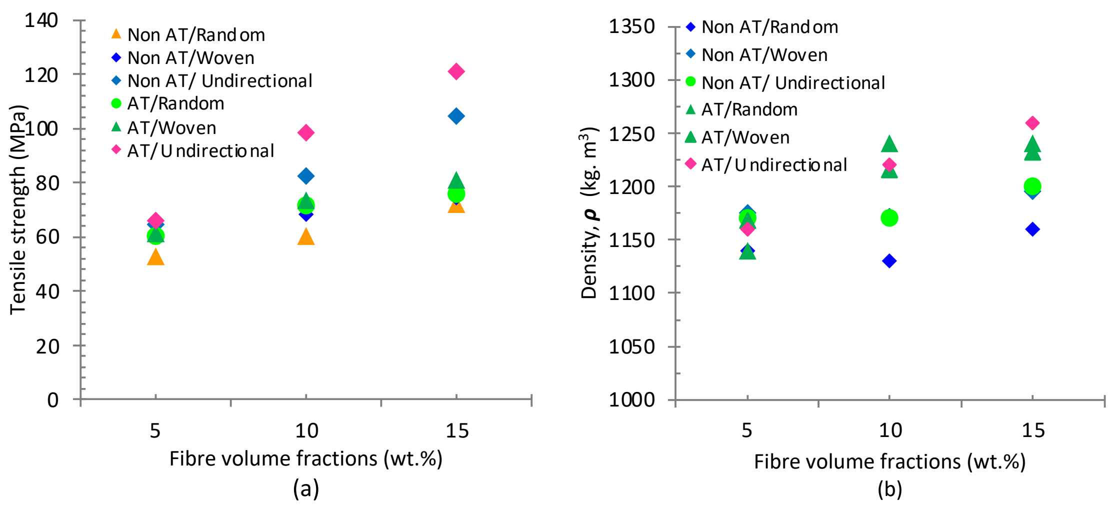


Figure 6. Fraction variations of STF/VE bio-composite: (a) tensile strength, (b) density

tensile strength/modulus of STF/VE bio-composite, followed by fibre orientation and surface preparation. These are reasonable because the delta SN ratio is higher than any other input variable. **Figure 7a** shows that the alkali treatment of STF has better tensile strength performance for STF/VE bio-composite than non-alkali treatment.

Alkali treatment has contributed to improving the tensile strength. This result follows previous research conducted [11]. Unidirectional fibre orientation significantly affects STF/VE bio-composite tensile strength, followed by woven and random fibre orientations. In this case, it can be explained that all fibres in the unidirectional fibre orientation of STF/VE bio-composite obtained the tensile shear strength during a tensile test. At the same time, some of the woven fibres and random STUFF/WE gained direct shear and tensile strengths simultaneously. The effect of fibre orientation follows previous research by [40], [41]. The fibre volume fraction is directly proportional to the experiment level. The higher fibre volume fraction has increased the tensile strength of the STF/VE bio-composite. The effect of fibre volume fraction on the STF/FE bio-composite tensile strength is in line with previous studies [42].

Density will be inversely proportional to quality because the smaller is better for characteristic data. The lower density of STF/VE bio-composites will imply the product's higher quality. **Table 6** shows the SN ratio value of all STF/VE bio-composite density input parameters. Fibre volume fraction significantly affected the STF/VE bio-composite density, followed by surface preparation and fibre orientation [43]. The delta SN ratio values of fibre volume fraction, Fibre preparation, and fibre orientations, in this case, are 0.41, 0.29, and 0.16, respectively. **Figure 7b** presents SN ratio interpretation data of STF/VE bio-composited density. The STF/VE bio-composite density performance is better with the STF non-alkali treatment than with the alkali treatment. Random fibre orientation had a minor effect on STF/VE bio-composite density, followed by woven and unidirectional fibre orientations. In this case, it can be explained that the unidirectional fibre orientation of STF/VE bio-composite is more solid and heavier than other fibre orientations [44]. The Fibre volume fraction is directly proportional to the experiment level. The high fibre volume fraction directly affected the STF/VE bio-composite density. This condition follows previous studies by [25].

3.3. ANOVA Analysis

The goal of ANOVA is to investigate the design factors and recognize the factors that seem to impact the outcome significantly. The overall mean of the average tensile strength and density was calculated during the experiment. The F-test value was used to identify the significant factors influencing the STF/VE bio-composites at a 95% confidence level. It also produced a total sum of squares (SS), and the variance will show the percentage contributions of each parameter [37]. The ANOVA has been analyzed and evaluated by providing statistical software. The ANOVA results for tensile strength and density of STF/VE bio-composites are shown in **Table 7**.

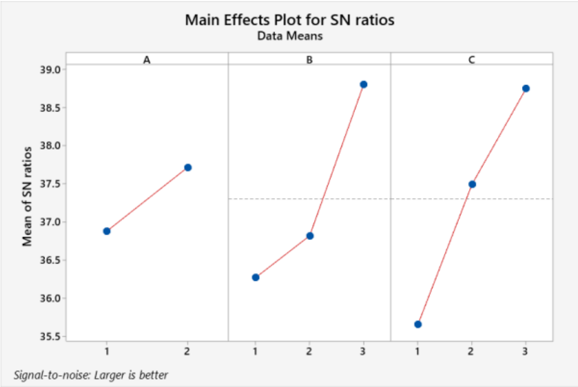
Table 7 shows the outcome of the ANOVA analysis. **Table 7** demonstrates that fibre volume

Table 5. Response table for SN Ratios of tensile strength

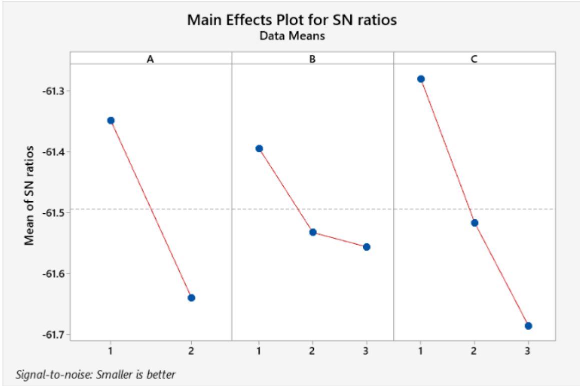
Code	SFT/VE bio-composite Parameters	Mean SN Ratio			Delta (max.-min)	Rank
		Level 1	Level 2	Level 3		
A	Fibre preparation	36.88	37.72	-	0.84	3
B	Fibre orientation	36.27	36.82	38.81	2.54	2
C	Fibre volume fraction (%)	35.66	37.5	38.75	3.09	1

Table 6. Response table for SN Ratios of tensile density

Code	SFT/VE bio-composite Parameters	Mean SN Ratio			Delta (max.-min)	Rank
		Level 1	Level 2	Level 3		
A	Fibre preparation	-61.35	-61.64	-	0.29	2
B	Fibre orientation	-61.39	-61.53	-61.56	0.16	3
C	Fibre volume fraction (%)	-61.28	-61.52	-61.69	0.41	1



(a)



(b)

Figure 7. Main effect plot for SN ratio of tensile strength (a), and density (b) of STF/VE bio-composites

Table 7. ANOVA result of tensile strength and density of STF/VE bio-composite.

Variable response	SFT/VE bio-composite Parameters	Square SS	F-Value	P-Value	% Contribution
Tensile strength	Fibre preparation	262.5	4.25	0.062	5.83%
	Fibre orientation	1964	15.89	0.0	43.60%
	Fibre volume fraction (wt.%)	2277.7	18.43	0.0	50.57%
Density	Fibre preparation	7320	12.24	0.004	39.83%
	Fibre orientation	1623	1.36	0.294	8.83%
	Fibre volume fraction (wt.%)	9436	7.89	0.006	51.34%

fraction, followed by fibre orientation, significantly affects the tensile strength of the STF/VE bio-composites studied in this work [43]. The percentage of contributions has a value of 50.57% and 43.60%, respectively. Unlike tensile strength, fibre volume fraction has significantly affected the density of STF/VE bio-composites, followed by fibre preparation. The percentage of contributions has a value of 51.34% and 39.830%, respectively.

The STF/VE bio-composite tensile strength is significantly affected by fibre volume fraction and fibre orientation. It is acceptable because the P-Value for each factor was less than 5% [14]. The P-Value value of the fibre volume fraction and fibre orientation variable was 0.0%. The percentage contribution for both parameters has confirmed these results. The percentage of contributions has a value of 50.57% and 43.60%, respectively. In another outcome, the fibre volume fraction and fibre preparation significantly affected the STF/VE bio-composite density. The fibre volume fraction and fibre orientation variables had P-Values of 0.6% and 0.04%, respectively. The percentage contribution for both parameters has confirmed these results. The percentage of contributions has a value of 51.34% and 39.830%, respectively. These results confirm previous research by [19], [20], [44].

3.4. *Interaction Plot of Parameters*

There was an interaction between variables when the change in response from lower to upper levels of one factor differs from the change in response between the two levels of the same second parameter. As a result, one factor's impact is influenced by the impact. An interaction plot is used to assess the relative strength of the variables impacts. An intersection plot can reveal the close interaction of response variables by looking at the charts intersection of each parameter measured. The intersection of each parameter in the charts indicates the interaction with each other for tensile strength and density. **Figure 8** and **Figure 9** show the interactions for tensile strength and density responses between fibre preparation and orientation (A*B), fibre preparation and volume fraction (A*C), and fibre orientation and volume fraction (B*C).

According to the interaction plot of tensile strength, interactions between the fibre preparation and fibre orientation (A*B), the fibre preparation and volume fraction (A*C), and the fibre orientation and volume fraction (B*C) did not affect the outcome (**Figure 8**). The fact that the two-parameter charts did not intersect demonstrates this [35]. In the other hand, the fibre preparation and fibre orientation (A*B) and the fibre preparation and volume fraction (A*C) substantially impacted the response. The intersection of the two charts on each parameter demonstrates this (**Figure 9**). At the same time, the fibre orientation and volume fraction (B*C) have no significant density response. The absence of the intersection of the two-parameter charts demonstrates this conditions [35].

3.5. *The Confirmation test*

The confirmation test involves examining the effect of a significant input parameter on the output parameter, particularly for STF/VE tensile strength. SEM analysis was included in this study to examine the fracture surface morphology of STF/VE mechanical testing. The image was captured using a JEOL SEM (JEC-3000PC) with a 10.0 kV accelerating potential. **Figure 10** presents the fracture surface morphology of STF/VE for iterations 2 and 18. The STF/VE bio-composite in iteration 2 has a matrix experiment code of A1B1C2. It means the STF/VE has been provided with a non-alkali treatment for fibre preparation, random for fibre orientation, and 10% for fibre fraction volume. In iteration 18, the STF/VE bio-composite has been identified as A2B3C3 STF/VE, which are prepared with an alkali treatment for fibre preparation, unidirectional fibre orientation, and 15% fibre fraction volume.

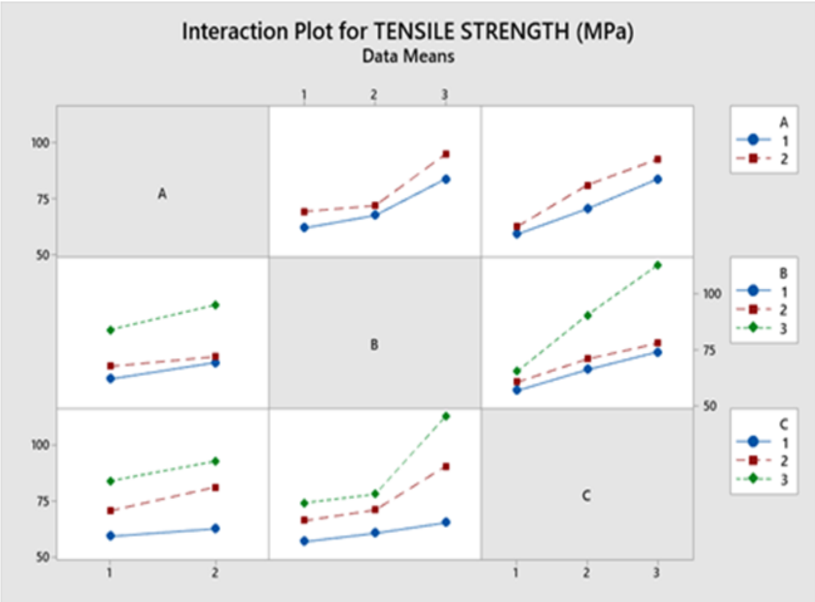


Figure 8. The interaction plot for data means responses to the tensile strength

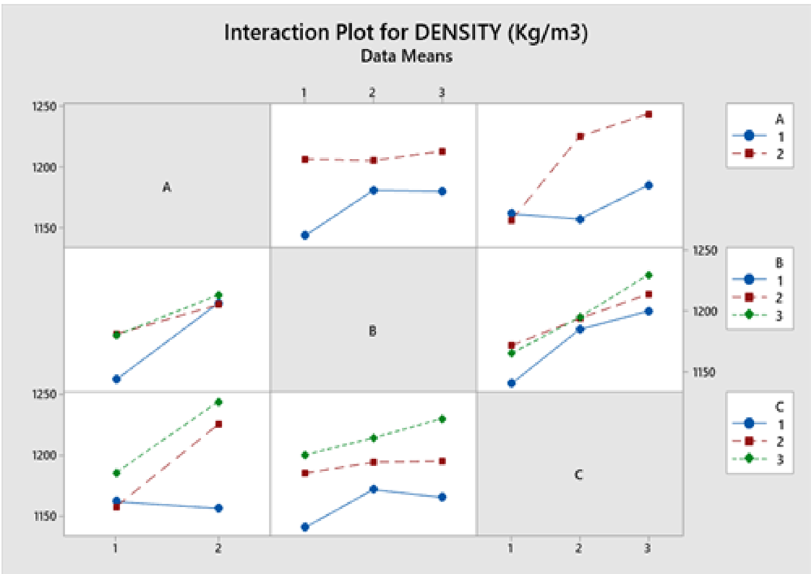
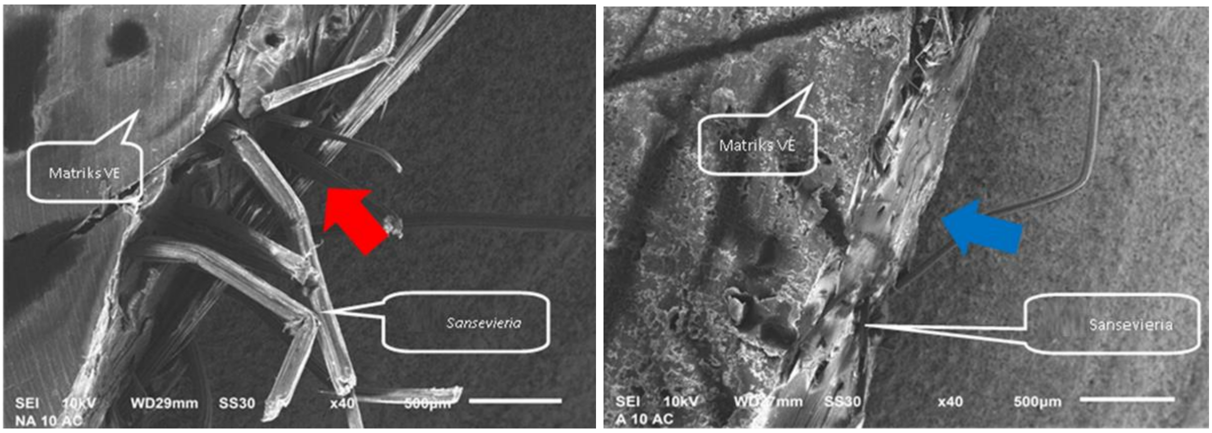


Figure 9. The interaction plot for data means responses to the density



(a) iteration 2 (b) iteration 18

Figure 10. SEM images of the fracture surfaces of STF/VE bio-composites

According to **Figure 10a**, the fracture morphology of the SFT/VE bio-composite fibres showed to be an irregular form. It indicates that some fibres run into both tensile shear strength and direct tensile strength. Irregular fracture morphology indicated fibres run into direct tensile strength. This condition contrasts with **Figure 10b**, where the fracture morphology of the fibres appears uniform and in standard form. These indicate that all STF/VE bio-composite coupon fibres went through tensile shear strength. This result confirms previous studies that tensile shear strength is higher in the same object/material than the direct tensile strength [45]. The confirmation test success fully improved STF/VE bio-composites with alkali treatment fibre orientation and fibre volume fractions. This result follow the studied by [13], [11], [16].

The decrease in the void volume fraction and increase in the fibre volume fraction of STF/VE bio-composite may be due to an increase in STF volume, which causes the distance between the compression process to be smaller. Even though all bio-composites receive the same load, the shorter distance between the fibres makes it appear as if the blank receives more significant stress on the bio-composite with a larger volume fraction. The significant pressure can cause voids to form in the bio-composite, which has a higher volume fraction than the bio-composite with a lower volume fraction, resulting in a decrease in the volume fraction with an increase in the volume of the boundary fibre. The range of % voids up to 5% is still permitted for automotive applications, allowing ST/VE to be used as a bio-composite for automotive components, one of which is a recliner [46].

4. Conclusion

This paper successfully optimized the tensile strength and density of STF/VE bio-composite for supporting sustainable automotive industries. Process parameters, Fibre preparation, fibre orientation, and fibre volume fraction have appropriately been worked with some summary as follows:

a. The SN ratio analysis revealed that STF/VE bio-composites tensile strength was primarily influenced by fibre fraction volume, followed by fibre orientation. The greater the volume of the fibre fraction, the greater the effect. The Taguchi technic proposed an alkali fibre treatment, unidirectional fibre orientation, and 15% fibre fraction volume to yield the best tensile strength.
b. In a different case of SN ratio analysis for density of STF/VE bio-composite majority affected by fibre fraction volume followed by fibre treatment. The Taguchi technic proposed non-alkali fibre treatment, random fibre orientation, and 05% fibre fraction volume to yield the optimum density. The increased die opening, punch angel, and bending parameters will decrease the spring-back/spring-go factor.
c. The ANOVA result has measured for all design parameters. In this work, fibre volume fraction and fibre orientation significantly influenced the average tensile strength of STF/VE bio-composites. Fibre volume fraction and fibre preparations significantly influenced the average density of STF/VE bio-composites.
d. The SEM for unstable fracture morphology revealed that the majority of the STF/VE fibres

are subjected to direct tensile strength. The fracture morphology of the fibres was uniform and standard, indicating that shear strength was tested on the majority of the STF/VE bio-composite coupon fibres.

The Taguchi experimental comprehensively investigated the tensile strength and density of STF/VE bio-composites with good and expected results. Further research will conduct in the areas of modulus elasticity (GPa), impact testing (kJ/mm^2), and void percentage (%).

Author's Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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The authors declare no competing interest.

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