Journal of
Composites Science

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Evaluating the Hybridization and Treatment Effects on the Mechanical Properties of Enset and Sisal Hybrid Composites

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Abstract: Natural fibers are among the most employed reinforcements in the manufacturing process of innovative fiber-based composite materials. As with any composite materials, the properties of composites depend on the type and properties of the fiber, fiber structure, composition (hybridization), and treatment. In this study, the composite was fabricated by using hand lay-up with 100/0, 75/25, 50/50, 25/75, and 0/100 Enset/Sisal (E/S) hybridization ratio. Three cases, i.e., untreated, 5%, and 10% NaOH treatment were considered. The effects of hybridization and treatment on the mechanical and water absorption properties of woven and unidirectional orientation of E/S hybrid composite were evaluated by using a two-factors analysis of variance. The fiber–matrix interfacial fractured surface was characterized by scanning electron microscopy. The treated (5% NaOH) and woven fiber orientation exhibited better mechanical properties than untreated and unidirectional hybrid composites. The flexural and tensile strength of the woven composite was improved by 5% and 9%, respectively, when compared with woven untreated 50/50 volume ratio of composites. In both samples and orientations, the hybridization effects show a higher percentage contribution to the mechanical properties. But, in both orientations of composite samples, the treatment effects show a higher percentage contribution for water absorption properties.

Keywords: natural fiber; fiber treatment; hybridization; mechanical properties; fiber orientation

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Citation: Bekele, A.E.; Lemu, H.G. Evaluating the Hybridization and Treatment Effects on the Mechanical Properties of Enset and Sisal Hybrid Composites. *J. Compos. Sci.* **2024**, *8*, 377. https://doi.org/10.3390/jcs8090377

Academic Editor: Chensong Dong

Received: 14 July 2024
Revised: 15 September 2024
Accepted: 18 September 2024
Published: 21 September 2024

1. Introduction

Natural fibers (NFs) are alternative materials to environmentally harmful synthetic fiber materials. Nowadays, natural fibers used as alternative reinforcements in polymer composites have received a lot of attention in research and in various industries due to their advantages over glass and carbon fibers because of their low environment impact, light weight, low energy consumption, abundance, and wide range of applications [1]. Natural fiber-based composites have a wide range of applications in automotive and construction industries [2]. In addition to the fiber and matrix properties, fiber treatment, fiber orientation, fiber volume and hybridization are the most common factors that govern the properties of natural fiber composites [3–6].

Fiber treatment is one way of reducing its hydrophilic tendency for improving compatibility with the matrix materials [7]. Alkali (mercerization) treatment is the most common fiber chemical treatment method using Sodium hydroxide (NaOH), which is widely employed to modify the cellulosic molecular structure by removing the amorphous contents like lignin, wax, and oils that cover the external surface of the fiber and make a strong link between the fiber and the matrix [8]. To improve the physical, mechanical, chemical, morphological, and thermal properties of natural fibers, the composites fibers are chemically treated using Alkali (NaOH), Acetic acid, Silane, Benzoyl peroxide, Isocyanate treatment, etc. [9–12]. Alkali treatment (mercerization) is the most common chemical treatment method using Sodium hydroxide (NaOH), which is widely employed to modify the crystal structure by modifying the cellulosic molecular structure of fibers. It removes weak components like lignin and hemicelluloses, wax, oil, and other impurities that cover the parts of the fiber surface to increase the roughness of the surface of the fibers [8,13]. The effect of treatment on the mechanical property of the Cordia dichotoma fabric was studied and the result shows that the 5% alkali-treated fabric shows better mechanical (tensile) strength than bleached and untreated fabric [14]. The percentage of alkali affects the fiber surfaces, which determines the mechanical properties of the composite. High percentages of alkali may cause fiber surface damage, leading to a decrease in the mechanical properties. As the percentage of alkali concentration decreases, only a few impurities are removed from fiber surface. This affects the fiber–matrix interfacial and influences the mechanical properties of the composite [15,16].

The mechanical behavior (tensile, flexural, and impact strength) of an untreated and a NaOH-treated sisal-jute fiber hybrid epoxy composite was studied and the results showed that the treated-fiber composite improved in all cases of mechanical properties [17]. In addition to fiber treatment, fiber volume and fiber orientation, a hybrid of two or more different fibers improves the mechanical properties of its composites [18,19].

When fiber volume is increased, the composite becomes stiffer and harder leading to decreased elongation at the break point of the composites. With increasing fiber loading, the tear strength of the composites increases due to the fiber, which makes the tear path more difficult for crack propagation. In the article reported in [20], oil palm empty fruit bunch (EFB)/jute fiber reinforced epoxy bi-layer hybrid composites were fabricated by the hand lay-up technique with a total fiber loading of 40% by weight (1:4) and the effect of jute fiber loading on the tensile, storage modulus, loss modulus, and damping properties were studied in comparison with the pure EFB and jute composite. The result showed that the storage modulus of EFB and jute (4:1) hybrid composite was the lowest. It also showed that when jute fiber loading increased, the effectiveness of stress-transfer increased. Hybrid composite materials exhibit unique properties compared with EFB and jute composite. These properties suggest potential applications of oil palm–epoxy composite with jute fibers [21]. The effects of hybridization for sisal/glass, jute/glass, and sisal/jute/glass polyester reinforced composites were studied and the hybrid composite (sisal/jute/glass) had better mechanical strength [22]. The mechanical properties (tensile, flexural, impact, and hardness) of natural fiber-based composites (jute/epoxy, hemp/epoxy, flax/epoxy) and their hybrid composites (jute/hemp/epoxy, hemp/flax/epoxy, and jute/hemp/flax/epoxy) were characterized and the results showed that hybrid composites had better mechanical properties [23]. Similarly, in pure jute, jute/sisal, and jute/curaua composites the hybrid composite had better mechanical properties [24].

Enset provides fiber as a byproduct of decorticating leaf sheaths. In rural areas, the Enset fiber is used to make sacks, bags, ropes, cordage, mats, construction materials (such as tying materials that can be used in place of nails), sieves, etc. Similar to other cellulosic natural fibers, enset fiber is chemically composed of cellulose, hemicellulose, lignin, pectin, moisture, wax, and oils [25–27].

Alkali treatment of fiber modifies the interfacial adhesion of fiber and the matrix, which improves the mechanical properties of enset polyester composites. Alkali-treated enset fiber, treated with 5.0% NaOH, exhibited the highest Young's modulus, flexural modulus, static, and dynamic properties compared to untreated enset fibers [26]. The promising application of 5.0% alkali-treated enset fiber polyester composite is for automotive components like parcel shelves, dashboard, seat cushion, door trim panel, backrests, and cabin linings. They can also be used in non-structural applications like in packaging industries (egg shelves), consumer products, and sports items (hubbub handle, bicycle frame) [25,28]. The mechanical properties of sisal-banana hybridized natural fiber composites with a distinct weight fraction were investigated and the results showed that the flexural strength value could be improved by decreasing the proportion of banana fiber and that the tensile strength improved by adding a greater proportion of banana fiber [29].

Moisture absorption is a chief hindrance that leads to poor fiber–matrix adhesion, a decrease in the interfacial bonding between the fiber and the matrix, and a decrease in the mechanical properties of the composite. The high cellulose content of natural fibers contributes to higher water absorption of the composite. Greater water absorption leads to fiber swelling, which develops the stresses that cause failure in the composite [30]. As observed from different literature [3,31,32], hybridization and treatment are the main parameters considered for the enhancement of the mechanical and water absorption properties of natural fiber-based composites.

The most common thermosetting polymer composite fabrication methods are hand lay-up, resin transfer molding, and pultrusion. Composite manufacturing using the hand lay-up technique is the simplest method which has low mold costs, low processing costs, the ability to manufacture complex designs, availability of the tools required for production, and uses molds that are easy to maintain. The process is also known for having long processing times and being labor intensive, which are among the few disadvantages associated with the technique [33,34].

Modifications have been major topics in natural fiber reinforced composites to improve the interfacial adhesion and, in turn, to improve the overall properties of the composite product. It is known that poor adhesion between the fiber and matrix affects the mechanical properties of composites. Furthermore, fiber treatment is used to improve the hydrophilic character of natural fibers, which make poor interfacial interactions with hydrophobic polymeric materials that limit the stress transfer between the composite components. In addition, fiber hybridization and fiber orientation are both promising strategies to improve the mechanical and physical properties of the composite. When two or more types of fibers are combined in a matrix of composite materials, the drawback of the type of fibers is mitigated by keeping the benefits obtained from the others.

As observed from the literature, better mechanical properties of the composite can be obtained when the fiber orientation is aligned in the load direction, while the composite is too weak when loaded at an angle that is different from the fiber orientation. Therefore, fiber hybridization is a promising strategy to improve the mechanical properties of natural fiber-based composite to mitigate the drawbacks of the type of fiber, while keeping other benefits. Furthermore, the mechanical properties of hybrid composites are affected by the fiber volume ratio, fiber orientation, and the treatment of fibers. Thus, the aim of the research reported in this article is to investigate the effect of chemical treatment and hybridization on the mechanical- and water-absorption properties of E/S hybrid composite, which are not sufficiently addressed in the existing published works.

2. Materials and Methods

2.1. Materials

For this study, enset (false banana) and sisal fibers were collected from Southwest Ethiopia, where these plants are widely distributed. The leaf parts of the Agava sisalana plant were used to extract sisal fiber, while the pseudostem part of the enset plant was used to obtain enset fiber. Ensete ventricosum is widely cultivated in East Africa and is mostly known as a wild species in Ethiopia; it is abundantly concentrated in the southern highlands and southeastern parts of the country. Enset, however, is usually larger than banana, with the largest plants up to ten meters tall and with a pseudostem up to one meter in diameter. The pseudostems, which may be two to three meters tall, contain an edible pulp and quality fiber. The rest of the materials, such as wax, hardener, and unsaturated polyester resin, were bought from a local supplier called World Fiber Glass in Addis Ababa, Ethiopia.

2.2. Composites Fabrication Methods

The mold used to prepare the composite was prepared from wood and had a dimension of 300 mm × 300 mm × 5 mm. The hand lay-up method was applied to manufacture the E/S hybrid composite. To make the hybrid composite, a total E/S fiber volume ratio of

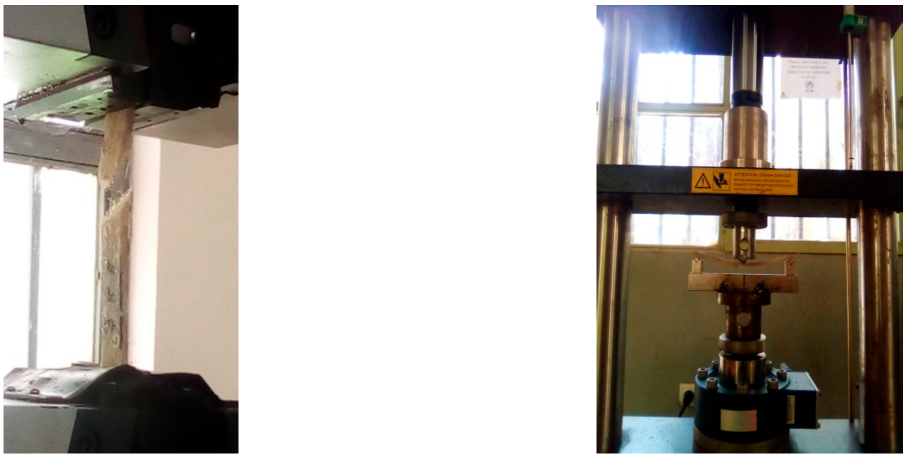
30% and a total volume of polyester ratio of 70% were used. After calculating the volume and mass of each composite using the rule of mixture, the hybrid composite was prepared considering three cases: (1) untreated, (2) 5% treated, and (3) 10% treated with NaOH, and varying hybridization ratios of E/S (i.e., 100/0, 75/25, 50/50, 75/25, and 0/100) were used with unidirectional and woven orientations. The mechanical (tensile, flexural) and water absorption properties were investigated.

2.3. Composite Mechanical Testing

The test specimens were prepared before undergoing different mechanical testing (i.e., tensile test and flexural test) and moisture absorption per the relevant ASTM standards. Five specimens were tested for each set of samples and the average value was taken for analysis.

2.3.1. Tensile Test

Tensile tests were used to measure the force required to break the test specimens and the extent to which the specimens stretched or elongated up to the breaking point. The specimen dimension used for the tensile tests was 250 mm × 25 mm × 5 mm (length × width × thickness) per the ASTM D3039 standard [35]. The test was carried out using a universal test machine (Bairoe, Shanghai, China) with a 50 kN capacity and a test speed of 5 mm/min crosshead speed and 150 mm gauge length. The test setup is displayed in Figure 1a.



(**a**) (**b**)

Figure 1. Test setup using UTM test machine for (**a**) tensile test and (**b**) flexural test.

2.3.2. Flexural Test

A flexural test was carried out to find the ability of the material to resist the deformation under a three-point bending load, which promotes failure by inter-laminar shear. Rectangular cross-section test specimens were cut from the molded samples. This test was conducted using a UTM (WP 310 universal material tester (Gunt, Germany)) per the ASTM D790 standard [36] with a test speed maintained between 0.5 and 1 mm/min. For this study, the lowest test speed, i.e., 0.5 mm/min was used. The specimen dimension was 127 mm × 13 mm × 5 mm. The setup for this test is displayed in Figure 1b.

2.4. Water Absorption

Testing the water absorption properties of enset/sisal hybrid composites in water at room temperature was recommended. A water absorption test was carried out per the ASTM D570 standard. To study the water uptake, the specimens were immersed in water at room temperature. The samples were taken out periodically and weighed immediately, followed by cleaning of the surfaces of the samples with a dry cloth. Then, the samples were weighed using a precise 4-digit balance to find out the content of absorbed water [37,38]. All the samples were dried in an oven until a constant weight had been reached before immersing them again in the water. The percentage of water absorption was determined using the formula in Equation (1).

$$WA(\%) = \frac{m_2 - m_1}{m_2} \quad (1)$$

where WA = water absorption, m = 1 and m = 2 are the weight of dry and wet samples of composites respectively.

2.5. Analysis of Variance

Analysis of Variance (ANOVA) is a statistical technique which can infer some important conclusions based on analysis of the experimental data. This method is rather useful for revealing the level of significance of the influence of factor(s) or their interaction on a particular response. Most of the time, a key result of ANOVA is determined by the *p*-value (denoted by alpha (α)) or by comparing the F-value and F_{crit}. value, in which case the factor is considered statistically significant if F is greater than F_{crit}. [39].

2.6. Morphological Surface

The morphological characterization of the composite fracture surface was conducted using a scanning electron microscope (SEM), a Gemini SUPRA 35VP (Carl Zeiss, Jena, Germany) equipped with EDAX type Energy Dispersive Spectroscopy (EDS). The fractured surface was examined following the tensile test for woven (untreated, 5%, and 10% NaOH treated) and unidirectional (untreated, 5%, and 10% NaOH treated).

3. Results and Discussion

3.1. Flexural Test Results

The flexural strength of untreated, 5%, and 10%NaOH treated unidirectional and woven enset/sisal fiber hybrid composite are shown in Figure 2a,b. It was observed that in all the hybrid composites, the flexural strength increased with increasing sisal fiber volume percentages. It was observed that in all the hybrid composites, the flexural strength increased with increasing sisal fiber volume percentages. The flexural strength increased by 8.47%, 12.65%, and 15.20%, 8.31%, 10.88%, and 48% for 75/25, 50/50, and 27/75 enset/sisal hybrid composites, respectively, when compared with the 100/0 enset/sisal composite. These results agree with some published materials such as reported in [30,31,33]. Improved interfacial adhesion due to treatments was found to reduce the defragmentation of fibers from the matrix, increasing the properties of the hybrid composites [40]. Besides, from earlier research [41], it was found that the flexural properties of hybrid composites were also influenced by the composition and adhesion levels of the fibers. Similar to tensile strength, the 5% NaOH treatment has better flexural strength than untreated and 10% NaOH treated. This indicates that untreated fiber contains amorphous elements and the 10% NaOH damages the fiber which affects the properties of the composite materials.

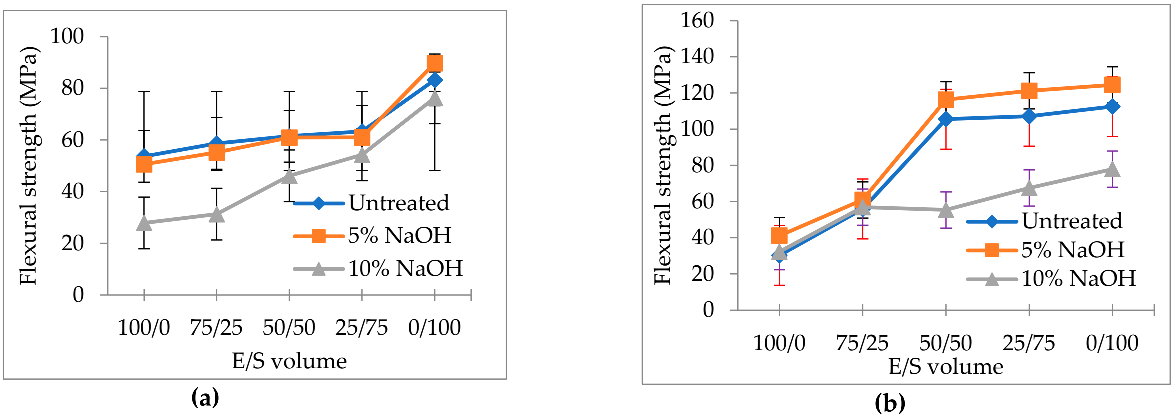


Figure 2. Flexural test results of (**a**) Unidirectional composite and (**b**) Woven composite of E/S polyester composite.

3.2. Tensile Test Results

Figure 3a,b show the test results of the tensile strength of untreated, 5%, and 10% alkali-treated enset/sisal hybrid composites for unidirectional and woven composites respectively. From the plots of the tensile strengths, positive hybrid effects are observed for the composites. It can also be noted that increasing the sisal fiber content in the composite resulted in increased tensile and flexural strength of the composites. The tensile strength of E/S hybrid (75/25, 50/50, and 25/75) for the unidirectional composite were improved by 28%, 38%, and 47%, 8.06%, 20.58%, and 36.02%, 20.18%, 30.02%, and 42.11%, respectively, compared with the 100/0 composites. Similarly, the tensile strength of the woven composites improved by 29.27%, 51.29%, and 55.84%, 29.43%, 41%, and 45.81%, 34%, 61.54%, and 56.81%, respectively, compared with the 100/0 composites. The works reported in [30,31,33] closely support our findings in this research. In both cases, the tensile strength increases almost linearly with the sisal fiber. In other words, positive effects of hybridization on the composites are observed. Hybridizing high-strength sisal fibers with enset and using treated fibers as reinforcement can be attributed to the enhancement in the properties of both types of fiber orientation hybrid composites. Fiber treatment with 5% NaOH showed better tensile strength than untreated and 10% NaOH treatment. Thus, it can be concluded that 5% NaOH treatment is the optimum treatment for both enset and sisal fiber, which is used to improve the fiber–polymer interfacial bond resulting in better tensile strength of composite material. As can be observed from the results, the tensile strength of 5% NaOH treatment provided a better tensile strength than untreated and 10%NaOH treated.

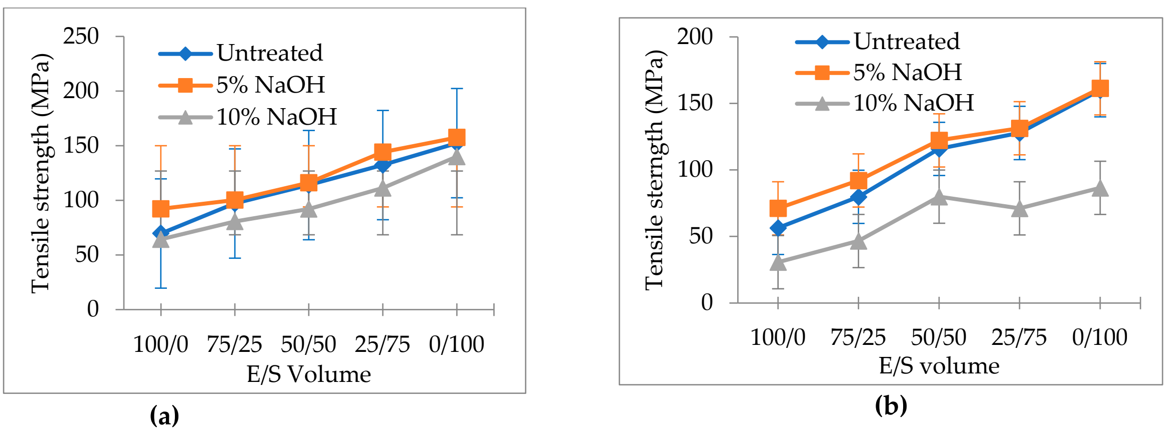


Figure 3. Tensile test results of (**a**) Unidirectional composite and (**b**) Woven composite of E/S polyester composite.

The tensile strength of untreated enset/sisal of 100/0 is 67.92 MPa and 0/100 is 152.32 MPa for unidirectional composites due to the sisal fiber having a higher tensile strength and better interfacial bonding with the polyester materials. The tensile strength of untreated enset/sisal of 100/0 is 56.42 MPa and 0/100 is 159.94 MPa for woven composites.

3.3. Water Absorption Results

The water absorption of untreated, 5%, and 10%NaOH treated unidirectional and woven enset/sisal fiber hybrid composites are shown in Figure 4a,b, respectively. The results show that as the volume ratio of enset increases, more water is absorbed in the hybrid composites. This indicates that hybridization of the sisal fiber in the composite is used to improve the properties of the enset polyester composite. In all types of composites, a woven type of composite absorbs less water than a unidirectional composite. The treated fiber composite exhibits lower water absorption than an untreated composite in all types of volume composites and in both fiber orientations. As the NaOH treatment concentrations increase, the water absorption properties of the E/S hybrid composites improved. The better interfacial bonding of fiber and polymer leads to improved mechanical and water absorption properties of the composites. Similar to the mechanical test results, the woven fiber orientation-based composites exhibit less water absorption following 5% NaOH treatment, which is similar to the findings reported in [30].

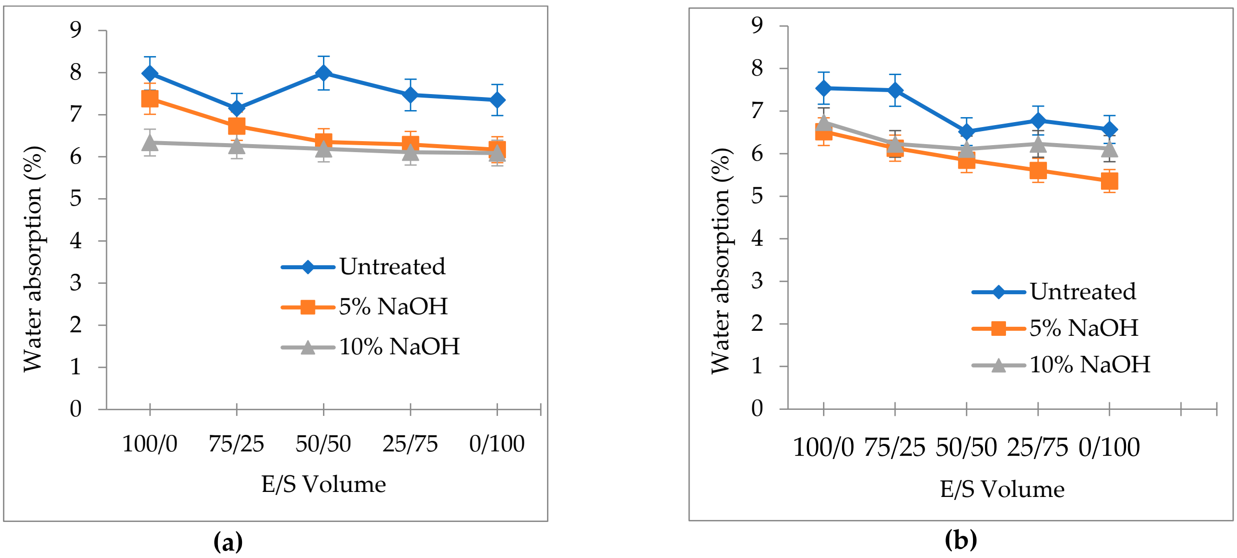


Figure 4. Water absorption properties of (**a**) unidirectional composite and (**b**) Woven composite of E/S polyester composite.

3.4. Morphological Surface Analysis of the Composite

In composite materials, better mechanical results are obtained due to surface adhesion between the matrix and reinforcement. From the fractured surface, fiber breakage, fiber fracture, matrix breakage, debonding, and voids are observed. Wettability of the fiber matrix determines the quality of a composite, which reduces fiber breakage [42]. From the SEM images shown in Figure 5, the optimum result was chosen for both fiber orientation. Figure 5a–f shows the SEM morphological images of the fractured tensile test of 5% NaOH treated, for 50/50 E/S of woven and unidirectional composite, respectively.

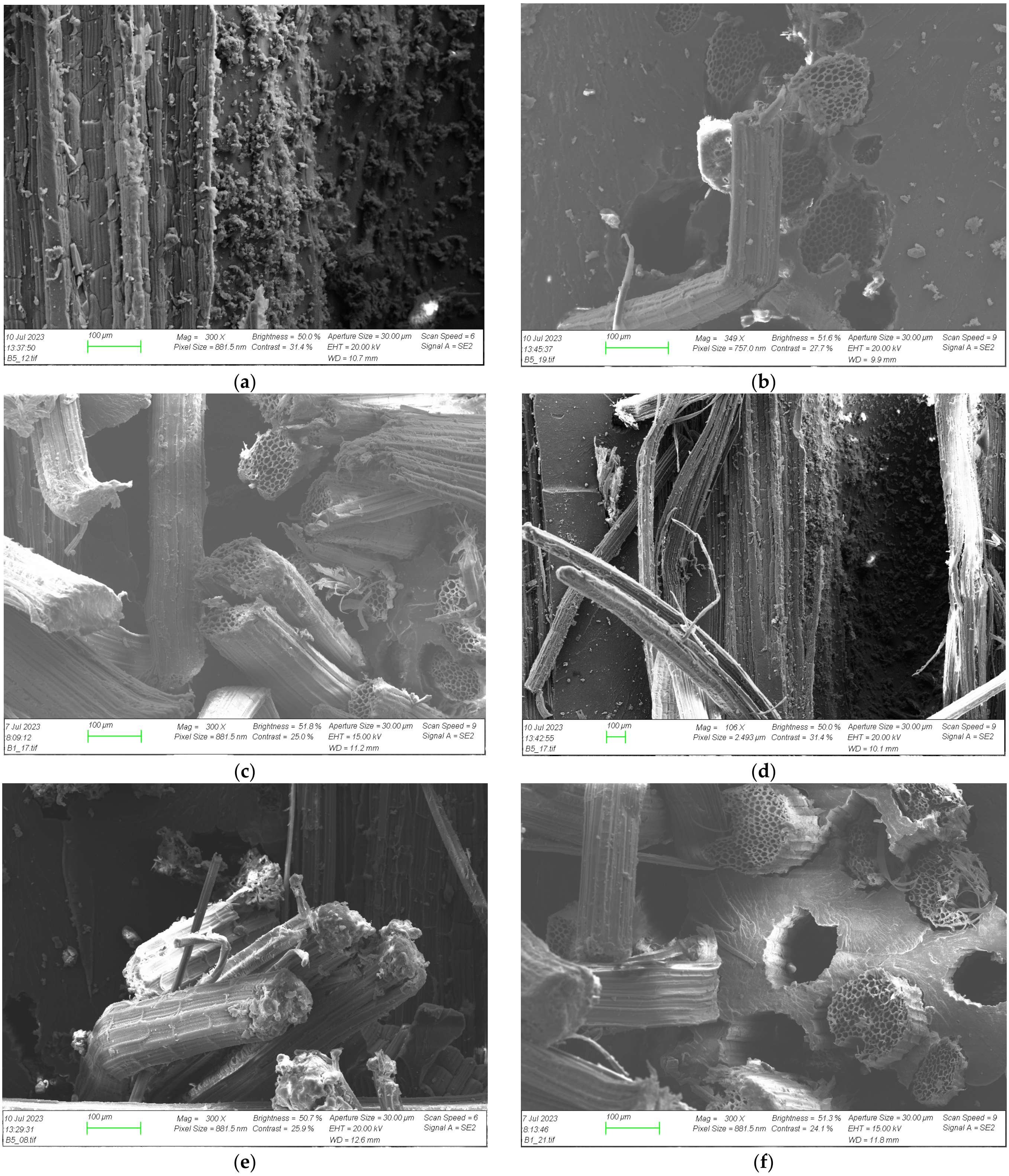


Figure 5. SEM image of 50/50 fiber volume of enset/sisal hybrid composite for woven samples (**a**) untreated, (**b**) 5% NaOH, and (**c**) 10%NaOH, and unidirectional samples (**d**) untreated, (**e**) 5% NaOH, and (**f**) 10%NaOH after tensile test.

Good fiber matrix adhesion resulting from physical modification like formation of rough surfaces, and defibrillation that occur on the fiber surfaces during alkali treatment improved the properties of enset composites. Figure 5a–c shows the SEM images of the tensile fractured surfaces of the enset/sisal hybrid woven composites, for untreated, 5% and 10% treated, respectively. It can be observed from the SEM image of 50/50 enset/sisal that better bonding exists in the enset/ sisal hybrid composite. As shown in Figure 2, the woven types of composites have a higher flexural strength than unidirectional composites. The flexural strength of 5% NaOH treated was improved by 9.2% when the woven type was compared with the untreated composites. From the mechanical test results, a higher tensile strength was obtained for the woven types of enset/sisal hybrid composite than that of unidirectional types of hybrid composites. From the mechanical test results, the 5% NaOH treated fiber hybrid composite has a higher mechanical strength than the untreated and 10% treated fiber hybrid composite. This is due to the lack of removal of impurities from the fibers, which results in weak fiber–matrix interfacial strength and greater optimal conditions for delignification, which causes weakening and damage of fibers. The removal of impurities improves the interfacial strength of fibers with the matrix, which leads to improved mechanical and water absorption properties of the composites. The SEM images also confirm that a better fiber–matrix surface interfacial exists for the 5% NaOH treated woven hybrid composite, as shown on Figure 5b.

3.5. Results of the ANOVA

In experimental studies, ANOVA is widely used because it effectively interprets experimental parameters [43]. It compares the average values of the factors in consideration to find the degree of difference or similarity between them. Among others, the Pareto ANOVA technique and the signal-to-noise ratio are widely used [44,45] because they are relatively easy to implement. In addition to assessing the percentage contribution of the factors, the key results of ANOVA analysis are mostly determined by the *p*-value (denoted by alpha (α)) or by comparing the F-value and $F_{crit.}$-value. While most people take 0.05 as a traditional cutoff for the *p*-value, i.e., α-value, for example in [46,47], where a significance level of 0.05 indicates a 5% risk of concluding that no actual difference in the observation exists, a *p*-value below 0.05 is considered significant for the result variation. The factor is also statistically significant if F > Fcrit, in which case the null hypothesis is rejected, indicating that not all population means are equal.

In other words, if the *p* value is less than or equal to the difference between the results, some of the mean values are statistically significant indicating that the null hypothesis can be rejected, and it can be concluded that not all population means are equal. If the *p* value is greater than the difference, it implies that some of the means are not statistically significant. In this case, there is not enough evidence to reject the null hypothesis that the population means are equal.

In this study, a two-way ANOVA was conducted to investigate the effect of hybridization and treatment on the mechanical properties of woven and unidirectional E/S hybrid composites. The ANOVA test results are given in Tables 1–6. From the effects of hybridization and treatment on tensile strength for the woven types of E/S composites (Table 1), it can be observed that they make a 59.08% and 37.06% contribution, respectively, implying that hybridization has a higher effect on influencing the tensile strength. Both factors present statistical significance as the *p*-values were less than the traditional cutoff value ($\alpha < 0.05$) and $F > F_{crit}$.

Table 1. ANOVA for tensile strength for woven composites.

Source of Variation	SS	DF	MS	F	*p*-Value	F_{crit}	%Contr.
Hybridization	12,891.09	4	3222.77	30.64	6.7×10^{-5}	3.83	59.08
Treatment	8087.48	2	4043.74	38.45	7.88×10^{-5}	4.45	37.06
Error	841.21	8	105.15				3.85
Total	21,819.78	14					

DF—degrees of freedom, SS—sum of squares, MS—mean squares.

Table 2. ANOVA for tensile strength for unidirectional composites.

Source of Variation	SS	DF	MS	F	p-Value	F_{crit}	%Contr.
Hybridization	10,383.43	4	2595.85	99.42	7.44×10^{-7}	3.84	85.71
Treatment	1522.19	2	761.09	29.15	0.0002	4.46	12.56
Error	208.86	8	26.10				1.72
Total	12,114.5	14					

DF—degrees of freedom, SS—sum of squares, MS—mean squares.

Table 3. ANOVA for flexural strength for unidirectional composites.

Source of Variation	SS	DF	MS	F	p-Value	F_{crit}	%Contr.
Hybridization	2766.07	4	691.51	26.78	0.0001	3.83	71.09
Treatment	917.83	2	458.91	17.77	0.0011	4.45	23.59
Error	206.57	8	25.82				5.30
Total	3890.48	14					

DF—degrees of freedom, SS—sum of squares, MS—mean squares.

Table 4. ANOVA for flexural strength for woven composites.

Source of Variation	SS	DF	MS	F	p-Value	F_{crit}	%Contr.
Hybridization	10,953.55	4	2738.38	12.67	0.0015	3.83	69.02
Treatment	3186.40	2	1593.20	7.37	0.0153	4.45	20.07
Error	1728.83	8	216.10				10.89
Total	15,868.79	14					

DF—degrees of freedom, SS—sum of squares, MS—mean squares.

Table 5. ANOVA for water absorption for unidirectional composites.

Source of Variation	SS	Df	MS	F	p-Value	F_{crit}	%Contr.
Hybridization	0.89	4	0.22	2.54	0.1210	3.83	13.23
Treatment	5.14	2	2.56	29.35	0.0002	4.45	76.36
Error	0.70	8	0.08				10.40
Total	6.73	14					

DF—degrees of freedom, SS—sum of squares, MS—mean squares.

Table 6. ANOVA for water absorption for woven composites.

Source of Variation	SS	Df	MS	F	p-Value	F_{crit}	%Contr.
Hybridization	1.72	4	0.42	9.47	0.0039	3.84	33.64
Treatment	3.02	2	1.51	33.38	0.0001	4.46	59.25
Error	0.36	8	0.04				7.09
Total	5.10	14					

DF—degrees of freedom, SS—sum of squares, MS—mean squares.

Table 2 shows the effects of hybridization and treatment on the tensile strength for unidirectional types of E/S hybrid composites, where an 85.71% and 12.56% contribution on the unidirectional composite, respectively, were observed. Both factors are statistically significant as the *p*-values are less than the traditional cutoff value ($\alpha < 0.05$) and $F > F_{crit}$.

The ANOVA results shown in Table 3 indicate the effects of hybridization and treatment on the flexural strength for unidirectional types of E/S hybrid composite. The percentage contribution of hybridization was 71.09% and the percentage contribution of treatment was 23.59%. Both have statistical significance as the *p*-values are less than the cutoff value ($\alpha < 0.05$) and $F > F_{crit}$.

Similar effects on the flexural strength for woven types of E/S hybrid composite were also observed as depicted from the ANOVA results shown in Table 4. In this case, hybridization and treatment made percentage contributions of 69.02% and 20.07%, respectively. These values indicate that the effects on woven-type composites is slightly less than the effects on unidirectional-type composites. We also found that both results were statistically significant as the *p*-values were less than the cutoff value ($\alpha < 0.05$) and $F > F_{crit.}$

The ANOVA result of water absorption for the unidirectional E/S hybrid composites is tabulated in Table 5. The percentage contribution of hybridization was 13.23% and percentage contribution of treatment was 76.36%. In this test, hybridization presents no statistical significance as the test *p*-value is greater than the traditional cutoff value ($\alpha > 0.05$), but the treatment presents statistical significance as the test *p*-value is less than the cutoff value ($\alpha < 0.05$) and $F > F_{crit.}$ On the other hand, the ANOVA results of water absorption for the woven E/S hybrid composites (Table 6) indicates the statistical significance of both hybridization and treatment. The percentage contributions were 33.64% and 59.25%, respectively.

Generally, it has been observed from this ANOVA study that the treatment factor is statistically significant for the considered cases (i.e., tensile, flexural, and water absorption properties) for both woven and unidirectional composite samples. On the other hand, the hybridization factor is statistically significant for the tensile and flexural strength of the woven composites, while it was found to be statistically insignificant in the case of the water absorption property of the woven samples. As reported in published research [44,45], the importance of the ANOVA technique is to calculate the percentage contribution and identify the relative effect based on the calculated percentage. As shown in Tables 1–4, the ANOVA results for tensile and flexural strength show that the hybridization factor makes a higher percentage contribution for the unidirectional and woven composite samples compared with the treatment factor. This implies that, for the enhancement of tensile and flexural strength, hybridization is better than treatment. On the other hand, the treatment factor for both composite samples (Tables 5 and 6) shows the highest percentage contribution in water absorption properties. This is because the water absorption properties are enhanced by NaOH treatment of the fibers rather than by hybridization of the two natural fibers.

4. Conclusions

The results of this investigation allowed us to generally reach the following conclusions:

- The mechanical (tensile and flexural) properties enhanced as the sisal fiber volume increased and water absorption improved as the enset fiber volume increased in the E/S hybrid composite.
- A hybridization and treatment effect showed significant improvement for the mechanical and water absorption properties in both types of composite orientations.
- Higher tensile and flexural strength was obtained for 5% NaOH in both unidirectional and woven types of fiber orientation composites when compared with untreated and 10% NaOH treated composites.
- For tensile and flexural strength, the hybridization factor made a higher percentage contribution for unidirectional and woven samples of composite than treatment. The treatment factor, on the other hand, had more influence on the water absorption properties in both E/S composites than hybridization factors.
- The morphology of untreated and 10% NaOH composite specimens after tensile testing was affected. This is due to the hydrophilic nature of natural fibers which absorb moisture, resulting in fiber swelling, fiber fracture, debonding and dislocation.

Author Contributions: Conceptualization, A.E.B.; methodology, A.E.B.; software, A.E.B.; validation, H.G.L.; formal analysis, A.E.B.; investigation, A.E.B.; resources, H.G.L.; data curation, A.E.B.; writing—original draft preparation, A.E.B.; writing—review and editing, A.E.B. and H.G.L.; visualization, A.E.B. and H.G.L.; supervision, H.G.L.; project administration, H.G.L.; funding acquisition, H.G.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Acknowledgments: Authors wish to thank Wakshum M. Tucho at University of Stavanger for his help in capturing the SEM images.

Conflicts of Interest: The authors declare no conflicts of interest.

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