Influence of Fiber Orientation on Impact Resistance Behavior of Woven Sisal Fiber Reinforced Polyester Composite

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Woven natural fiber reinforced polymer composites have better tensile, flexural, and compressive strength compared to the mechanical properties of unidirectional and randomly oriented NFRPC because of the interlacing of fiber bundles. However, the characterization of impact behavior with different fiber orientation such as 30°/60°, 0°/90°, 30°/−45°, and 45°/−45° woven sisal fiber reinforced polyester composite was not studied vigorously. Thus, this paper focuses on the experimental characterization of the impact resistance behavior on woven sisal fiber reinforced polyester composite materials for semistructural part by using Izod impact testing setup. The 30°/60°, 30°/−45°, 0°/90°, and 45°/−45° woven sisal fiber was prepared using nailed wooden frame as a warp and weft guider. The woven sisal fiber was impregnated in order to make woven sisal fiber dimensionally stable. Using 40% by weight of fiber and 60% by weight of polyester, the composite was developed using hand layup process. The morphology and cross-sectional elemental detection was carried out using scanning electron microscope (SEM) assessment in leather development institute (LDI). Finally, impact tests were carried out using Izod impact testing setup in Addis Ababa Science and Technology University (ASTU). The average impact strength of a 40 wt% fiber 45°/−45° WSRFPC test specimen with consecutive warp and weft tow spacing of 2 mm was 342.67 J/m and this was greater energy compared to the other orientations. But the average impact strength of a 40 wt% fiber 30°/60° WSRFPC of test specimen with consecutive warp and weft tow spacing of 2 mm was 241.33 J/m.

1. Introduction

Natural fiber reinforced polymer composites have been used in industry as semistructural materials. These semistructural applications include interior automotive body panels, interior automotive door panels, dashboard, and back seats [1]. They can also be used for door frames, door shutters, window frame, and mirror casing [2]. Besides, many of the woven natural fibers are rising as a viable option to glass fiber reinforced composites in industrial applications like packaging, paper making, and composite materials [3]. The impact load on these engineering semistructural materials can create internal damage, which significantly reduces their structural strength, and this phenomenon remains a major concern for structural components. Sisal fibers offer a good reinforcement compared to other natural fibers, owing to the less extraction cost. Thus, in addition to selecting semistructural material for suitable application and loading condition, studying the impact resistance behavior of sisal fiber reinforced plastic composite for semistructural application is important so that we can use it in suitable application. Recent interest has been grown more in fiber reinforced polymer composites compared to conventional materials because of their unique properties such as high strength-to-weight ratio, lightweight, low processing temperature, high fracture toughness, and high corrosion resistance. Among the two types of fibers (synthetic and natural) that are used as reinforcement in polymer
composites, nowadays, natural fibers are drawing attention over synthetic fibers (man-made glass and carbon fibers) in structural and semistructural material developments. This is because of their specific properties such as biodegradability, recyclability, low cost, being environmental friendly, and reduced energy consumption [4]. In addition, natural fibers have better crash absorbance, flexibility in usage, and good sound insulation properties [5]. Among natural fibers, plant-based fibers are preferred reinforcements for structural and semistructural applications because of their high strength property. The content of composition of cellulose in plant-based fibers governs their mechanical properties due to the different cell geometric conditions. Henequen, ramie, and sisal have better tensile, compressive, and flexural strength among other plant-based natural fibers. In addition, sisal fiber has the lowest environmental impact compared to all other natural fibers because this fiber has the lowest embodied energy [6]. The thickness of the secondary wall having the highest content of cellulose determines the mechanical property of sisal fibers [5]. The core of the sisal fiber contains lumen, while the middle lamella, on the other hand, is responsible for firmly attaching the whole micron-sized fiber onto it, maintaining its physical strength as reinforcement element. Most vegetable fibers used as a reinforcement in composite manufacturing are thermally unstable above 200°C [7]. Because of the limitation of this thermal property, those thermoplastics (e.g., polyethylene, polypropylene, polyvinylchloride, and polyolefin), which can be softened below 200°C, and thermosets (e.g., unsaturated polyester, epoxy, polyurethane, and vinyl ester), which can be cured below 200°C, are used as a matrix material for natural fiber reinforced polymer composites. Thermoset polymers are used as matrix material in the development of most structural composites because of their low viscosity, simple processing technique (e.g., hand layup, vacuum bagging, and compression molding technique), high thermal stability, and high-dimensional stability and stiffness [8]. Unsaturated polyester resin is the most widely used matrix due to its advantages like good adhesion to other materials, high strength, low volatility during cure, low shrink rate, good dimensional stability, and low viscosity. Because of this relative advantage and its availability, unsaturated polyester resin was used as a matrix material for the experimental investigation on impact resistance behavior of sisal fiber reinforced polymer composite. Fiber extraction method is one of the many factors that affect the performance of natural fiber reinforced composites [7]. To separate fiber bundles from the bast of fiber plant, two techniques are usually employed: decortications and retting (biological or chemical). Unlike chemical extraction methods, water retting does not significantly affect the microstructure of sisal fibers. The other factor that affects the performance of natural fiber reinforced polymer composite is the interfacial bonding between the fiber and the matrix [7]. Water/moisture absorption property of natural fibers can be a cause for the presence of voids and weak bonds between the fiber and the matrix, dimensional instability, and thickness swelling of the fiber [9]. To avoid this limitation of natural fibers, fiber treatment is required. Among the treatment methods, alkali treatment leads to fiber fibrillation, which breaks down fiber bundles to smaller fibers; as a result, the wettability of the fiber by the matrix increases and better fiber matrix interface adhesion with increased mechanical properties can be obtained [7, 10]. However, when the concentration of NaOH exceeds the optimum value, the property of the fiber degrades. Mechanical properties (tensile and flexural) of Enset fiber reinforced unsaturated polyester have improved as the concentration of NaOH solution increased from 2.5% to 5% but when the concentration further increases to 7% NaOH solution, the mechanical properties (tensile and flexural) become degraded [11]. After mercerization treatment (slacked or under tension) [10], the fracture stress and Young’s modulus have increased, while fracture strain and toughness have decreased. The alkaline treatment reduced both hemicellulose and lignin contents, resulting in an increase in the cellulose content of the fiber. In case of tension-M sisal fibers, the fracture stress and Young’s modulus much improved by about 35% and 110%, while the fracture strain and toughness decreased by about 39% and 32%, respectively. Even though slack-M fibers showed better power and stiffness, this improvement may be primarily dependent on the boom inside the cellulose content material. The impact strength of treated sisal fiber was lower than the untreated sisal fiber [12]. Because of the hemicellulose content in natural fibers besides the hydroxyl groups, natural fibers absorb moisture [5] unless treated using treatment methods. Even though untreated natural composites have high impact resistance, in this study, treated sisal fiber was used as a reinforcement, since it is obvious that untreated natural fibers have low stiffness compared to treated natural composites, but in most semistructural applications, we need both stiff and tough composite materials. The treated fiber can be randomly oriented, chopped, unidirectional, or multidirectional with different fiber orientation in the preparation of sisal fiber reinforced polyester composite. Oriented fiber (weave) reinforced polymer composites showed evidences of impact properties as compared to powdered and randomly oriented fibers [3, 13]. Woven fiber with different fiber orientations can be a good choice as there is tightness between warp and weft direction of weave. The +45°/-45° layup hemp/epoxy showed better tensile-tensile fatigue strength compared to 0/90° [14]. The tensile, flexural, and impact properties of +45°/-45° banana-kenaf hybrid epoxy composite were better than those of the 0/90° oriented composite [15]. During the fabrication of sisal woven fiber, a specially designed warp yarn guider can be used so that a fiber or portion of a fiber cannot be misaligned from the line of orientation during impregnation with a polymer resin. Woven sisal fiber with orientations 30°/60°, 30°/45°, 0°/90°, and 45°/45° was impregnated and when cured it was used in interply form to get the required sisal fiber reinforced polyester composite fulfilling ASTM D256 requirement [16]. Specially designed rectangular wooden frame containing nails that acted as the warp yarn guider on both of its sides can be used during woven preparation [17].
Manually decorticated sisal fiber was used. The impact property of sisal fiber reinforced epoxy composite showed better impact strength [1]. Therefore, in this study, 40% by weight of fiber with 60% by weight resin was used. Selecting suitable manufacturing process to transform the composite to the final shape has a direct impact on the performance of the NFRPC. Desired properties, processing characteristics of raw materials, shape and size of final specimen, and cost can be criteria for selecting the processing technique. The impact strength and impact energy of fiber reinforced epoxy composite have increased as the length of fiber in randomly oriented jute fiber reinforced epoxy composite has increased from 5 mm to 20 mm [18]. Betelie et al. [1] have shown better impact strength (about 24.49 kJ/m²) of 40 wt% sisal fiber reinforced epoxy composite when the percentage by weight of fiber reached 50%. The impact property of sisal fiber reaches 50%, the impact energy has dropped, which may be due to the difficulty in wetting up the fiber by epoxy matrix during vacuum bagging process. The impact strength of 40 wt% sisal fiber reinforced epoxy composite showed better impact strength [1]. Therefore, in this study, 40% by weight of fiber with 60% by weight resin was used. Selecting suitable manufacturing process to transform the composite to the final shape has a direct impact on the performance of the NFRPC. Desired properties, processing characteristics of raw materials, shape and size of final specimen, and cost can be criteria for selecting the processing technique. The impact strength and impact energy of fiber reinforced epoxy composite have increased as the length of fiber in randomly oriented jute fiber reinforced epoxy composite has increased from 5 mm to 20 mm [18]. Betelie et al. [1] have shown better impact strength (about 24.49 kJ/m²) of 40 wt% of fiber chopped sisal epoxy composite manufactured using hand layup technique. The specific objective of this study was to determine the influence of fiber orientation on woven sisal fiber reinforced polyester composite. In this study, the experimental characterization of the impact resistance behavior of woven sisal fiber reinforced polyester composite was investigated.

2. Materials and Methods

2.1. Materials. Manually decorticated sisal fiber was purchased from the local market. Unsaturated polyester resin was purchased from world fiber glass and water proof engineering. The hardener is methyl ethyl ketone peroxide (MEKP) purchased from world fiber glass and water proof engineering and its grade was K10. NaOH was purchased from Atomic Educational Materials Supply PLC. The ratio of unsaturated polyester resin to the catalyst was 10 : 1 according to previous studies and manufacturer’s recommendation. Even though the fiber property can vary due to soil type, geographical location, and weather condition, the property of local sisal fiber can be approximated to property of sisal fiber grown in other areas (see Tables 1–4).

In most recent studies, 40% by weight of fiber with 60% by weight of resin was shown as the best fiber matrix strength, giving better mechanical property than other fiber matrix combinations. In this study, 40:60 fiber matrix by weight ratio was used as shown in Table 5.

2.2. Dimension. The dimensions of impact test specimens are prepared according to the ASTM D256-10 standard (Figure 1). Notch was also provided according to the standard. The notch in the Izod specimen serves to concentrate the stress, minimize plastic deformation, and direct the fracture to the part of the specimen behind the notch.

2.3. Test Specimen Preparation. Sisal fiber was soaked in 5% NaOH solution for 2 hours (Figure 2) and put into acetic acid solution to neutralize the alkali. Finally, sisal fiber was washed with distilled water and dried by 48-hour dry sun exposure.

The fiber treatment process (Figure 2) can be used to get sisal fiber with better mechanical property but when the duration of immersion increases, it becomes very difficult to separate fiber bundles without breakage.

The wooden frame was manually constructed, and it contained nails that acted as the warp yarn guide on both of its sides. Sisal fiber prepregs were prepared with 30°/60°, 30°/45°, 0°/90°, and 45°/45° orientation (see Figure 3). To reduce the influence of composite fabricating process on fiber orientation, fiber preimpregnation was carried out using hand layup technique (Figure 4).

To laminate the impregnated plies, hand layup was used. During the hand layup process, rolling was carried out in order to distribute the resin uniformly and possibly to remove trapped air (Figure 5).

Required size of test specimens was measured and cut on cured composite laminates (Figure 6).

2.4. Conditions

2.4.1. Impact Load. The specimen was gripped at one end only which allows the cantilevered end to be struck by the pendulum. The load applied on the impact test specimen was impact load at low impacting velocity with cantilever beam arrangement using Izod impact testing machine setup. The maximum impacting load used for this experimental investigation was 90 J. In this experimental investigation, low velocity impact test at a speed of 5.25 m/s was carried out.

2.4.2. Test Rig. The mass of each woven sisal fiber for 30°/60°, 30°/45°, 0°/90°, and 45°/45° orientations was measured using digital weight measuring balance.

Specimen notching was done on a milling machine according to ASTM D256 standard. The JSM-IT300LV scanning electron microscope (SEM) was used for cross-sectional morphology and elemental SEM analysis. Izod pendulum impact testing machine in Addis Ababa Science and Technology Institute/ASTU was used to measure the absorbed energy (see Figure 7). This impact testing machine, brand name TE, model JWT-406, operates with pneumatic hammer release and console.

3. Results and Discussion

Bar graphs were used for impact energy presentation of 40% by weight volume fraction of 30°/60°, 30°/45°, 0°/90°, and 45°/45° orientation sisal fiber reinforced polyester composite.

3.1. Results. A total of 20 specimens, 5 specimens of each type, were tested using Izod impact testing setup integrated to a computer. The computer integrated to the Izod impact
A testing setup was used to display absorbed energy and toughness. The impact strength of woven sisal fiber reinforced polyester composite was obtained using the absorbed energy and thickness or notch cross-sectional area of the test specimen.

Average values of toughness, absorbed energy, and impact strength (ASTM and ISO) can be presented as shown in Figure 8. According to the test result, the toughness and absorbed energy of a 45°/−45° WSFRPC were greater than the toughness and absorbed energy of other orientations. The absorbed energies of most of the test specimens were different, but the absorbed energies of some of the test specimens were similar. All 30°/60° WSFRPC test specimens showed 0.01 J/mm² toughness energy. This could be because the Izod impact testing machine is less sensitive to a small change of absorbed energy. Similarly, all 30°/45° WSFRPC test specimens showed 0.01 J/mm² toughness energy but slight difference of absorbed energy. Even though the toughness of 30°/60° WSFRPC test specimen and that of 30°/45° WSFRPC test specimen were similar, 30°/45° WSFRPC test specimens showed greater absorbed energy. Some of the 0°/90° WSFRPC test specimens showed 0.02 J/mm² toughness energy and this test specimens showed greater absorbed energy.

### 3.2. Discussion and Interpretation.

The energy absorbed during impact test can be a measure of toughness. The impact strength of the specimen tested can be determined from the absorbed energy. ASTM impact strength of WSFRPC was obtained by dividing the absorbed energy by

### Tables

#### Table 1: Properties of sisal fiber and other materials.

| Fiber type | Cellulose (wt%) | Lenin (wt%) | Hemicellulose (wt%) | Pectin (wt%) | Wax (wt%) | Reference |
|------------|----------------|-------------|---------------------|--------------|-----------|-----------|
| Sisal      | 67–78          | 8–11        | 10–14.2             | 10           | 2         | [19]      |

#### Table 2: Sample orientation, volume fraction, and their property.

| Orientation type | Volume fraction (wt%) | Constituent of composite | Absorbed energy (J) | Impact strength (N/m) |
|------------------|-----------------------|--------------------------|---------------------|-----------------------|
| 30°/60°          | 40 : 60               | 40% by wt of fiber       | 0.72                | 241.33                |
| 30°/45°          | 40 : 60               | 40% by wt of fiber       | 0.78                | 261.33                |
| 0°/90°           | 40 : 60               | 40% by wt of fiber       | 0.91                | 302                   |
| 45°/45°          | 40 : 60               | 40% by wt of fiber       | 1.03                | 342.67                |

#### Table 3: Matrix material property.

| Material type          | Grade       | Specific gravity at 25°C | Viscosity | Tensile strength (MPa) | Flexural strength (MPa) | Tensile modulus (MPa) | Reference |
|------------------------|-------------|--------------------------|-----------|------------------------|-------------------------|------------------------|-----------|
| Unsaturated polyester resin | RG01       | 0.95                     | 400–500 cps | 55–65                  | 182–195                 | 3600–3800              | Supplier catalog |

#### Table 4: Experimental data representing absorbed energy and impact strength for 30°/60° and 30°/45° orientation.

| Item no. | 30°/60° toughness (J/mm²) | 30°/60° absorbed energy (J) | 30°/60° ASTM impact strength (J/m) | 30°/60° ISO toughness (J/mm²) | 30°/45° absorbed energy (J) | 30°/45° ASTM impact strength (J/m) | 30°/45° ISO toughness (J/mm²) |
|----------|---------------------------|-----------------------------|-----------------------------------|-----------------------------|-----------------------------|-----------------------------------|-----------------------------|
| 1        | 0.01                      | 0.64                        | 213.33                            | 112.28                      | 0.01                        | 0.84                              | 280                          | 147.36                  |
| 2        | 0.01                      | 0.78                        | 260                               | 136.84                      | 0.01                        | 0.75                              | 250                          | 131.57                  |
| 3        | 0.01                      | 0.71                        | 236.67                            | 124.56                      | 0.01                        | 0.78                              | 260                          | 136.84                  |
| 4        | 0.01                      | 0.7                         | 233.33                            | 122.81                      | 0.01                        | 0.77                              | 256.67                       | 135.09                  |
| 5        | 0.01                      | 0.79                        | 263.33                            | 138.59                      | 0.01                        | 0.78                              | 260                          | 136.84                  |

#### Table 5: Experimental data representing absorbed energy and impact strength for 0°/90° and 45°/45° orientation.

| Item no. | 0°/90° toughness (J/mm²) | 0°/90° absorbed energy (J) | 0°/90° ASTM impact strength (J/m) | 0°/90° ISO toughness (J/mm²) | 45°/45° absorbed energy (J) | 45°/45° ASTM impact strength (J/m) | 45°/45° ISO toughness (J/mm²) |
|----------|---------------------------|-----------------------------|-----------------------------------|-----------------------------|-----------------------------|-----------------------------------|-----------------------------|
| 1        | 0.01                      | 0.84                        | 280                               | 147.36                      | 0.02                        | 1.02                              | 340                          | 178.95                  |
| 2        | 0.02                      | 0.97                        | 323.33                            | 170.18                      | 0.02                        | 0.98                              | 326.67                       | 171.92                  |
| 3        | 0.01                      | 0.96                        | 320                               | 168.42                      | 0.02                        | 1.05                              | 350                          | 184.21                  |
| 4        | 0.02                      | 0.98                        | 326.67                            | 171.93                      | 0.02                        | 1.02                              | 340                          | 178.95                  |
| 5        | 0.01                      | 0.78                        | 260                               | 136.84                      | 0.02                        | 1.07                              | 356.667                      | 187.72                  |
the thickness of test specimen. Similarly, ISO impact strength was obtained by dividing the absorbed energy by the notch area of the test specimen.

All the 45°/45° WSFRPC test specimens showed 0.02 J/mm² toughness energy and superior absorbed energy compared to the other orientation type test specimens. The sample standard deviation for 30°/60°, 30°/45°, and 45°/45° WSFRPC was zero. This is because there is no variance in the toughness energy of these test specimens, which may be a result of the fact that the Izod impact testing machine is insensitive to insignificant change in absorbed energy. But 0°/90° WSFRPC has a standard deviation of 0.0055 J/mm² toughness energy. This variance might be from inaccuracies during specimen cutting, specimen mounting on the Izod anvil, or nonuniformity in the material composition of the test specimen. On all orientation test specimens, either the test specimen is completely broken and divided into two pieces or the fiber bundles hold the two pieces together.
Figure 4: Prepared prepregs (dimension: 280 mm × 150 mm).

Figure 5: Hand layup process: (a) adding resin mixture and (b) roving rolling to remove air.

Figure 6: Prepared specimens according to ASTM D256.

Figure 7: (a) Izod impact machine; (b) computer integrated to impact testing machine; (c) SEM.
The smallest energy absorbed was 0.64 J for 30°/60° WSFRPC test specimen and the maximum absorbed energy recorded was 1.07 J for 45°/45° WSFRPC test specimen. The absorbed energy sample standard deviation of 30°/60° WSFRPC test specimen was 0.061 J, whereas the absorbed energy standard deviation of 30°/45° and 45°/45° WSFRPC test specimens was 0.034 J. But the absorbed energy standard deviation of 0°/90° WSFRPC test specimen was 0.09 J. This result showed that there are more accuracy and precision in 30°/45° and 45°/45° WSFRPC test specimens. But the slight variance among the samples for both absorbed energy and ASTM impact strength may come from the variation in the physical properties of the test specimens such as slight difference in dimension, slight variation in the uniformity of chemical composition of the composite, or variation in speed of cutting the test specimen. The variation may also result from inaccuracy and less precise specimen mounting procedure on the Izod impact testing machine anvil. When we compare the standard deviation of absorbed energy and ASTM impact strength of 30°/45° and 45°/45° WSFRPC test specimens, they have almost similar variance, respectively. Thus, there are more precision and accuracy in these test specimens. Compared to the chopped sisal epoxy composite [1], the test specimens in this experimental investigation showed greater absorbed energy. The ASTM impact strength depends on the thickness of the test specimen. It was obtained by dividing absorbed energy by the thickness of the test specimen. For similar test specimen thickness, 45°/45° WSFRPC showed greater ASTM impact strength. A 45°/−45° WSFRUPC test specimen showed high precision result, since individual absorbed energy and impact strength have minimum deviation from the average value compared to the other test specimens. The average absorbed energy and impact strength for 45°/−45° WSFRUPC test specimens were 1.03 J and 180.35 KJ/mm², respectively. But most of the 30°/60° and 30°/−45° orientation WSFRPC test specimen completely separated except one 30°/60° test specimen. This specimen showed relatively higher impact strength (138.59 kJ/mm²) compared to the other 30°/60° test specimens. Meanwhile most of the 45°/−45° orientation WSFRUPC test specimens showed an absorbed energy of 1.02 Joule and the fiber holds the two pieces together as shown in Figure 9.

This shows that 45°/−45° orientation WSFRPC has greater absorbed energy values than the other WSFRPC test specimens.

The force displacement curve was plotted using discrete data values recorded on a computer and force displacement relationship (Figure 10). The force displacement curve shows that until the reaction force reaches its maximum value during impacting instant, there is negligible test specimen displacement. But after the impacting force becomes maximum, the displacement of the specimen increases, even though the impacting force decreases due to the absorption of impact energy (see Figure 11).

Even though the test conditions and method of composite fabrication are different and difficult to compare, average ASTM impact strength of a 40% by weight of fiber 45°/−45° WSFRPC was 342.67 J/m, which was about 70 J/m greater than the ASTM impact strength of chopped sisal fiber reinforced polyester composite (having impact strength of 250–300 J/m [20]) manufactured using resin transfer molding. But average ASTM impact strength of a 40% by weight of fiber 30°/−45° WSFRPC was 261.33 J/m which was comparable to ASTM impact strength of chopped sisal fiber reinforced polyester composite manufactured using resin transfer molding. In addition, the result in this investigation showed greater impact strength compared to the impact strength (>200 J/m) of braided woven fabric jute-banana reinforced 0/90° polyester composite [21]. Compared to the impact energy (maximum impact energy is 0.8) and impact strength (maximum impact strength is 30 KJ/m²) of short fiber sisal fiber reinforced epoxy composite fabricated keeping 30% by weight of fiber and treated with 5% NaOH solution [22], 0/90° and 45°/−45° test specimen used in this investigation showed greater impact energy and impact strength. When compared to short randomly oriented bent grass reinforced polyester composite which showed impact strength of 70.86 J/m for 40% by volume of fiber (treated with 5% NaOH concentration), the results from this experimental investigation showed greater impact strength.
Similarly, even though the test conditions, test standard, composite fabrication, and fiber form are different, the average ISO impact strength of 30°/60° WSFRPC (127.01 KJ/m²), 30°/−45° WSFRPC (137.54 KJ/m²), 0/90° WSFRPC (158.94 KJ/m²), and 45°/−45° WSFRPC (180.35 KJ/m²) was less comparable to ISO Charpy impact strength of short randomly oriented sisal fiber reinforced polyester composite (284.1 KJ/m²) [23] fabricated using hand layup and compression molding. This is because the Charpy impact test has a slightly different test procedure. In addition, all 30°/60° WSFRPC (average impact strength is 127.01 KJ/m²), 30°/−45° WSFRPC (average impact strength is 137.54 KJ/m²), 0/90° WSFRPC (average impact strength is 158.94 KJ/m²), and 45°/−45° WSFRPC (average impact strength is 180.35 KJ/m²) showed greater impact strength than sisal epoxy composite (24.49 KJ/m² [1]) processed using the hand layup process. The impact strength result of this experimental investigation on all cases (45°/45°, 0°/90°, 30°/60°, and 30°/45° orientations) is greater than the impact strength of short sisal fiber reinforced unsaturated polyester composite which showed impact strength of 3.581 Nm for untreated fiber and impact strength of 1.962 Nm for treated sisal fiber at 6 mm specimen thickness and 30 wt% [12]. Woven kenaf fiber reinforced epoxy composite fabricated by hand layup technique (impact strength of around 10 KJ/m²) with 0/90° orientation and woven Kevlar fiber reinforced epoxy composite (impact strength around 10 KJ/m²) fabricated using similar

Figure 9: (a), (b), (e) and (f) 45°/45° test specimen fiber breakage; (c) and (d) 30°/45° test specimen fiber breakage; (g) and (h) 30°/60° test specimen fiber breakage.

Figure 10: A force versus displacement curve for average data values (imported from Excel sheet).

Figure 11: Energy vs time graph.
procedure were tested by Charpy impact test [24]. But the results in this experimental investigation showed greater impact energy. In addition, the impact strength of test specimen used in this experimental investigation was greater than the impact strength of short randomly oriented sisal fiber reinforced epoxy composite (65.63 J/m [22]) and the impact strength of unidirectional 0,90,0 sisal fiber reinforced epoxy composite (1.35 kJ/m² [22]). This may be mainly due to woven fiber form used in this study and 40% fiber weight fraction. The Izod impact strength of 5% NaOH solution treated, dried at 70°C oven, and 100°C heat treated chopped sisal fiber reinforced polyester composite (40% vol. of fiber) was around 300 J/m [20] and, compared to this, 0/90° and 45°/−45° woven sisal fiber reinforced polyester composite treated with 5% NaOH solution showed greater Izod impact energy value (average impact strength is 342.67 J/m).

The data values for 45°/45° orientation sisal fiber reinforced polyester composite are more precise compared to the other values (Figure 12). This shows that 45°/45° orientation sisal fiber reinforced polyester composite specimens are more uniform than the other specimen types. Cross observation of impacted test specimen shows that the mode of failure is more favorable to matrix cracking than fiber breakage and delamination. Because there was no delamination of the test specimen after impact, shear yielding of the matrix can be a reason for matrix failure and it may be a result of applied impact load, presence of impurities in the resin, or poor composite lamination. Matrix cracking can be encountered as a result of poor composite fabrication process (hand layup), fiber bridging, or porosity as a result of trapped air. The maximum impacting work that can be done by Izod impact testing machine was 274.08 Nm, while the impacting work absorbed by the test specimen can be obtained from energy versus time graph. The area under the energy versus time graph gives the work done on the test specimen due to impacting load. The work done on the test specimen by the impactor knife can also be calculated analytically from the impactor knife movement and the change in rise and falling angle.

3.3. SEM Assessment. The scanning electron microscope was employed to investigate cross-sectional EDS and morphology of sisal fiber reinforced unsaturated polyester composite. The SEM was taken on the prepared specimen of the type having greater absorbed energy. Because, with the available SEM setup, it is not convenient to use a specimen of impacted portion, in this instance, the specimen is gold-coated in its sputtering process to make it conductive. The 10 μm resolution SEM micrograph’s cross-sectional morphology and elemental detection system result, as shown in Figure 13(a), showed that unsaturated polyester resin yields earlier than the reinforcing sisal fiber. Possibly a number of factors can influence the earlier yielding or failure of the unsaturated polyester resin. Porosity, opening between warp and weft thread, and matrix deformation can be the main reasons for matrix failure or yielding.

Large opening between warp and weft thread can result in matrix failure but small opening between warp and weft thread may result in high crimp effect which in turn results in fiber bridging. Optimum opening between warp and weft threads can minimize matrix failure. Large opening between warp and weft threads, high crimp effect or fiber bridging, and the trapping of air during composite lamination can be a reason for porosity. When porosity exists in the laminated composite, shear failure or matrix yielding may occur. In addition, matrix yielding may occur as a result of matrix deformation due to the applied impact load. The applied impact load can initiate crack in the matrix. As can be seen in Figure 13(b), from SEM micrograph result, crack has propagated along the matrix material. This crack propagation can be a reason for shear failure of the matrix and thus failure of laminated WSRPC. From visual inspection of the impacted test specimen and from the result of SEM micrograph analysis, good fiber matrix adhesion can be shown. This good fiber matrix adhesion may be due to good alkali treatment procedure. As a result, it can be said that failure of the laminated composite is due to shear failure of the matrix material rather than delamination of the campsite. Even though fiber breakage is not the primary cause for the failure of this laminated WSRPC, it can be seen that, on some of the test specimens, there is fiber breakage as well as complete separation of test specimen, as shown in Figure 9(h). These test specimens that showed fiber breakage and complete separation have comparatively less impact strength. In contrast to these, there are specimens where the fiber hardly breaks, as shown in Figure 9(b), and these test specimens showed comparatively high impact strength. The 50 μm SEM micrograph result showed that there is good adhesion of fiber and matrix during impregnation of each ply. But the crack-like structure and the dark line around the fiber thread showed that there is either a delamination (during specimen cutting or due to the applied load) or poor adhesion of resin to the impregnated fiber during composite lamination. Thus, test specimen cutting process for impact testing and test specimen cutting process for SEM analysis may have a residual stress effect.

3.4. Main Findings. Characterization of impact resistance behavior of woven sisal fiber reinforced polyester composite showed the increased absorbed energy for 0/90° and 45°/−45° test specimens compared to other 30°/60° and 30°/−45° test specimens. A 45°/45° oriented woven sisal fiber reinforced polyester composite showed better average toughness energy (0.02 J/mm²) and average absorbed energy (1.03 J). It has also showed better average impact strength of 342.67 J/m compared to other woven sisal fiber reinforced polyester composites used in this study. Since similar procedure has been followed in the specimen preparation and testing, it can be concluded that 45°/−45° oriented woven sisal fiber reinforced polyester composite has better impact strength. When compared to previous studies, the test specimens tested in this study showed greater impact energy than nonwoven sisal epoxy composite fabricated using hand layup process and tested using Izod impact testing setup. The
SEM micrograph analysis result showed that there was a matrix yielding or failure as a result of crack propagation. This crack propagation might be due to the porosity induced in the composite material or shear failure of matrix material as a result of the applied impact load.

4. Conclusion

The experimental characterization of impact resistance behavior of 30°/60°, 30°/−45°, 0/90°, and 45°/−45° orientation woven sisal fiber reinforced polyester composite using 40% by weight of sisal fiber was studied. The result showed that the average absorbed energy and impact strength of 0/90° and 45°/−45° WSFRPC were greater compared to 30°/60° and 30°/−45° WSFRPC. Compared to all other orientation test specimens, the 30°/60° WSFRPC showed less absorbed energy (average absorbed energy is 0.72 J) and impact strength (average impact strength is 241.33 J/m). A 45°/−45° oriented woven sisal fiber reinforced polyester composite showed better toughness energy (0.02 J/mm²) and absorbed energy (average absorbed energy is 1.03 J). It has also better impact strength (average impact strength is 342.67 J/m) than the other orientation woven sisal fiber reinforced polyester composites. When compared to previous studies, the test specimens tested in this study showed greater impact energy than nonwoven sisal epoxy composite fabricated using hand layup process and tested using Izod impact testing setup. In addition, when compared to the impact strength of jute-banana hybrid 0/90° woven composite tested with Izod impact testing machine of unnotched specimen using ASTM D256 standard, the results of this experimental investigation for all types of orientation showed greater impact strength. Thus, the results of this experimental investigation showed that a 45°/−45° oriented woven sisal fiber reinforced polyester composite can be used as a semistructural material. Therefore, the importance of this study is to show the impact strength of WSFRUPC so that the user can select this composite in a structural application they need. In the future, woven sisal fiber can be hybridized with a filler natural fiber such as bamboo powder in order to fill the opening area between warp and weft fiber bundles and increase impact strength of the composite.

Data Availability

All the data used to support the findings of this study are available in the manuscript.

Disclosure

The authors declare that this paper is their own work and the information provided in this manuscript is correct up to
their knowledge. They bear the responsibility for the correctness of the information contained in this manuscript and comply with the accepted standards with respect to originality and quality.

**Conflicts of Interest**

The authors declare that there are no conflicts of interest.

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