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Research Article

Recycling of 100% Cotton Fabric Waste to Produce Unsaturated Polyester-Based Composite for False Ceiling Board Application

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In recent years, the garment and textile industries generate millions of tons of textile waste every year around the world. Textile wastes are one of the disposed of materials and the sum of disposed of material squander materials expanded from year to year. For this reason, regenerating and utilizing the textile waste item as resources and decreasing environmental pollution may be an extraordinary opportunity. This research is aimed at manufacturing unsaturated polyester composite reinforced with 100% cotton fabric waste for ceiling board application using a manual mixing process followed by the compression molding method. The statistical results showed that mechanical properties of the produced composite samples such as tensile, compressive, flexural, and impact strength are affected by fiber mixed ratio and matrix loading at $\alpha = 0.05$. The composite ceiling reinforced with 33 weight % cotton fabric waste and a matrix of 67 weight % unsaturated polyester had a maximum tensile strength of 198 MPa, the flexural strength of 30.1 MPa, and compressive strength of 1105.3 MPa. On the contrary, the false ceiling board made from 10% cotton fabric waste and matrix of 90% unsaturated polyester had a lower tensile strength of 112.6 MPa, flexural strength of 21.5 MPa, and compressive strength of 867.5 MPa. Generally, the manufactured composites' mechanical behaviors were comparable to existing commercial ceiling boards and the output of this research work can protect the environmental pollution by reducing textile waste disposed to landfills.

1. Introduction

The textile industry is the world's second largest polluting industry, accounting for 10% of total worldwide greenhouse gas emissions [1]. Many developing countries are experiencing a scarcity of postconsumer waste disposal sites, posing serious environmental concerns. The usage of textile waste will be helpful for its value addition and solving waste disposal problems [2]. As a result, it is much more important to recycle and use waste items as resources to avoid pollution. From this, various researchers are attempting to recover and utilize postconsumer wastes to avoid landfills [3–5].Textile wastes are divided into two categories, preconsumer and postconsumer. Preconsumer waste is estimated 75% of textile waste diverted from landfills [6]. Any clothing or home textile item that is no longer useful to its original user is classified as postconsumer trash [7]. According to the Recycling Council of Ontario, the average person throws away 37 kilograms of textiles annually [8]. In 2018, 17 million tons of textile waste ended up in landfills, according to data from the Environmental Protection Agency, making up 5.8 percent of the total municipal solid waste (MSW) generation that year. The volume of clothing Americans throw away each year has doubled in the last 20 years, from 7 million to 14 million tons [3].

Agricultural waste can be effectively used to develop a value-added product with enhanced performance properties [9]. Mechanical properties of composite reinforced with fibers enhances strength at the microlevel, to reduce cracks and to make it lighter in weight [10, 11].

Recycled fiber currently is in greater demand in industries because of its advantages such as low cost, biodegradability, and acceptable mechanical and physical properties [12]. Recycling also helps in greening our infrastructures by conserving natural resources, making our infrastructures more durable due to high-performance mixtures, reducing greenhouse gas emissions and air pollution and groundwater contamination [13]. Many researchers researched composite materials reinforced with different textile materials such as textile microfibers waste [14], cotton fibers waste [15], polyester fiber waste [16], woven bamboo fiber [17], rice husk, wheat husk, wood fibers and textile waste fibers [18], Maize Cob and Jute Fiber [19], polyester-cotton fabric [12], cotton, jute, and glass fabric, banana woven fabric, paper/jute fabric [20], low-density polyethylene (LDPE) [21], and biodegradable textile waste [22].

Rubino et al. investigated on environmental friendly composite materials for sound-absorbing application. Composite panels made of 100% wool waste fibers and bound by chitosan solution were evaluated and characterized for acoustic and nonacoustic properties. The thermal conductivity of the samples was found to be between 0.049 and 0.060 W/(m K), which was equivalent to that of standard construction materials [23]. Santhanam et al. studied the sound absorption properties of nonwoven fabric manufactured from recycled cotton and polyester fibers. The acoustical properties of these recycled nonwoven materials are useful for proper application in products such as sound barriers, road surfaces, walls, and interior lining materials for auditoriums, apartments, halls, aircraft, automotive, and ducts and encloses for noise equipment and machinery insulations, according to the findings [12].

Sadrolodabaee et al. examined the cement reinforced with textile waste fibers in the textile waste-reinforcement system and composite short random fibers at 6–10% by weight of nonwoven fabrics in 3–7 laminate sheets. The potential of using this textile waste composite as a prospective construction material in nonstructural concrete constructions such as raised floors, facade cladding, and pavements was proven by the results of an experimental study [24, 25]. Mishra et al. investigated 3D woven green composites made from textile waste and polypropylene in a 60/40 ratio. The mechanical behavior of 3D woven fabric reinforced composites made with waste fiber yarn and regular cotton OE yarn is similar. This work shows that waste material could be effectively employed as a reinforcing structure in the production of green composites [26].

Isolation of textile waste cellulose nanofibrillated fiber reinforced in polylactic acid-chitin degradable composite for green packaging application was explored by Samsul et al. When chitin and CNF were used instead of plain PLA, the tensile strength, elongation, tensile modulus, and impact strength all improved greatly [27]. Raghu et al. suggest that silk-sisal fiber-reinforced unsaturated polyester-based hybrid composites can be used to make water and chemical holding tanks [28]. Sadrolodabaee et al. investigated the mechanical and stability of a reinforced cement composite made of kraft pulp pine fiber (KPF) and textile waste fiber (TWF) (30.7 percent polyester and 69.3 percent cotton) for building applications. The TWF composite does have lower flexural resistance and toughness than the KPF control by nearly 9%, while the compressive strength is higher [24, 25].

Tigabe et al. developed polyvinyl acetate composite reinforced with jute fibers filled with rice husk and sawdust for particleboard (PB) in the furniture industry. When the amount of jute fiber in the composite is increased, the mechanical properties of the composite improve significantly. Because of its hydrophilic qualities, jute fiber content exhibited an inversely proportional relation with water absorption and thickness swelling [29]. Ancuța-Elena et al. develop sound absorption composite materials out of polyurethane foam and textile waste, and they discovered that the noise reduction coefficient (NRC) of the composite material with 40% textile waste and 60% rigid polyurethane foam is twice as high as the noise reduction coefficient (NRC) of the composite material with 100% rigid polyurethane foam [30]. Venkata Reddy et al. investigated unsaturated polyester hybrid composites reinforced with glass, kapok, and sisal textiles, finding that as the unsaturated polyester matrix increased, the mechanical characteristics of the composites improved [31]. Eariler, researchers reported that the mechanical properties of the composite improve significantly with the addition of natural fibers like jute [32], hemp [33] sisal [34], coir [35], flax/cotton waste [11], and cotton fiber [36].

Textile wastes are abundantly available all over the world and the second largest polluting accounting for 10% of total global environmental pollution. Numerous developing countries are experiencing a lack of postconsumer waste disposal sites, posing serious environmental concerns. It is much more important to recycle and use waste items as resources in order to avoid pollution and avoid landfills. However, textile waste fabric was not utilized as reinforcement of composite for ceiling boards and other application extensively. Some researchers tried to develop textile waste-based composites. The main problem was compatibility and adhesiveness between the resin and fibers. This is because the textile waste properties were composed of different fibers such as polyester, cotton, wool, and acrylic. To improve the mechanical properties of composite, 100% cotton fiber is proposed as reinforcement and it is expected that the compatibility and adhesivity between reinforcement and matrix will be good then it could provide good mechanical strength. The primary goals of this research were to manufacture and characterized composite materials made from 100% cotton waste fabric reinforced with unsaturated polyester. The mechanical properties such as tensile, compressive, flexural, and impact manufactured composite material were investigated and reported.

Table 1: The proportion of the mixtures using mixture optimal design of expert software.

Run	Component 1 R: reinforcement (textile waste %)	Component 2 M: matrix (unsaturated polyester %)
1	10	90
2	18	82
3	25	75
4	33	67
5	40	60

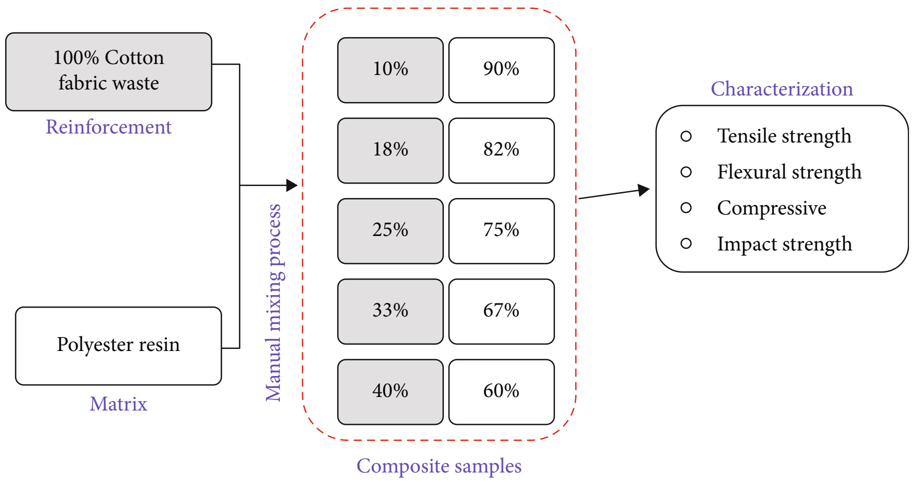

Figure 1: The general experimental procedure for this study. Experimental procedure.

2. Experiment

2.1. Materials. To develop composite ceiling boards, 100% cotton fabric waste (reclaimed) was used as reinforcement, unsaturated polyester P9509 was used as a matrix, and methyl ethyl ketone peroxide (55%) used as a hardener, soap, and water was used to clean the impurities of waste fabrics. The metal mold was prepared with a 200 × 200 × 10 mm dimension.

2.2. Sample Preparation. The 100% cotton fabric waste (weight of 160 g/m^2, warp yarn density of 16/cm, and weft yarn of 24/cm) was collected from local garment industries and cleaned and dried. The fabric is cut into size between 10 and 20 mm for better random orientation. After initialization, the fabric was added at the required proportion and mixed until a homogeneous mixture was achieved (see Table 1) before mixing hardener (methyl ethyl ketone peroxide) to the resin. The mold was coated with aluminum to prevent unsaturated polyester from sticking to the mold. The material to be molded was placed in the open tool, cavity was closed, and pressure/dead weight of 120 kg was applied to press the mixture to the required thickness and to reduce voids in the composite. Finally, after cured for 24 hr at room temperature and applied constant dead weight, demolding was carried out. Figure 1 shows the general experimental design of the study.

2.3. Test Methods. Before each type of testing, the samples were conditioned at 23°C ± 2°C and 50 ± 5% relative humidity for 24 hrs and the tests were also conducted in the same controlled condition.

2.4. Composite Thickness. Thickness is one of the basic physical testings of materials, and the thickness value of most materials will vary considerably depending on the pressure to apply to the specimen at the time. In this research, the load applied during ceiling board composite preparation was the same for all samples. However, to determine the effect of the ratio of textile waste and unsaturated polyester, the thickness of the developed composite was measured using a digital thickness tester (Mesdan Lab, model D-200) according to ASTM D1777 standard. 100 KPa was used for the testing, and 5 tests were performed in each sample.

2.5. Tensile Strength. For the tensile strength test, a rectangular shape specimen was prepared as per ASTM D 3039 test method. The testing was conducted at controlled atmospheric conditions of 23°*C* ± 2°C and 50 ± 5% relative humidity, and a universal testing machine (model WAW-600D) was used for the tensile strength test. Five tests were measured for each ceiling composite sample.

2.6. Compression Strength. Compressive strength test was carried out using a universal tensile machine (model WAW-600D) as per the ASTM D6641 standard, and the composite specimen size was a cube of 140 × 12 × 10 mm. Five measurements have been done in each type of ceiling board composite.

2.7. Flexural Strength. A flexural strength test was carried out in a three-point loading system applied on a supported beam. The tests were performed using a universal tensile machine (WAW-600D) as per the test standard of ASTM D7264 procedure [37]. The specimen size was the cube of 125 × 12 × 10 mm. Five trials were measured in each sample.

2.8. Impact Strength. The Charpy Impact (model JBS-500B) tester was used to determine the impact strength of materials. The method is also used to investigate the behavior of composites under impact conditions for estimating the relative brittleness or toughness of specimens especially for comparison (ASTM D256). The unnotched specimens were prepared according to the ASTM standard [38]. The specimen size is a cube of 55 × 12 × 10 mm. Five test specimens were evaluated in each type of ceiling board composite sample.

2.9. Data Analysis. Traditional experimental design methodologies are complicated to use. When the number of parameters increases, a large number of experiments must be performed. The Design-Expert statistical software application

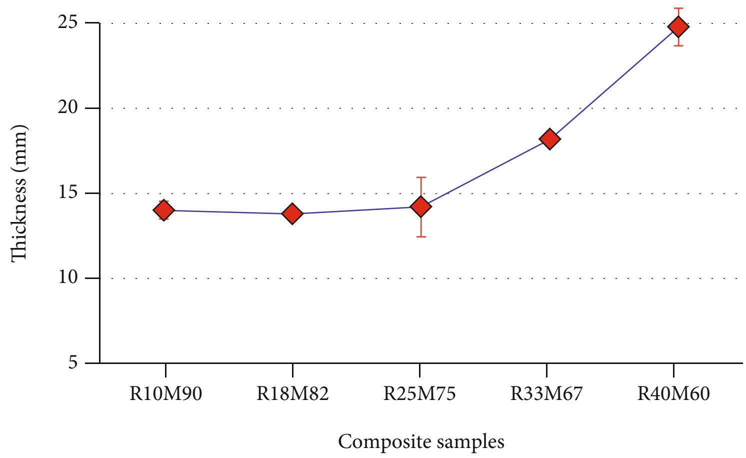

FIGURE 2: Composite thickness.

TABLE 2: ANOVA quadratic model for tensile strength.

Source	Sum of squares	*df*	Mean square	*F* value	*P* value	
Model	4323.47	2	2161.73	158.82	0.0063	Significant
[(1)]Linear mixture	2547.89	1	2547.89	187.20	0.0053	
AB	1775.57	1	1775.57	130.45	0.0076	
Residual	27.22	2	13.61			
Cor total	4350.69	4				

was used to determine the relationship between independent variables (fabric loading and matrix loading) and response variables (tensile characteristics, compression, flexural, and impact strength). A mixed optimum analysis approach was employed in this study since it is a better model for response variables.

3. Results and Discussion

Ceiling boards are essential in homes to reduce noise and heat, as well as to offer aesthetic value. In different areas, a ceiling with a highly reflecting upper surface, good compressive strength, higher impact strength, flexural strength, and tensile strength is preferred [39–41]. In this research, the following parameters were measured and analyzed. R donated as reinforcement or 100% cotton fabric waste, and M represents matric or unsaturated polyester.

3.1. Composite Thickness. Figure 2 shows the thickness of composite has increased as the content of reinforcement (textile waste) increases. This is because when the ratio of textile fabric is high, it will not easily be compressed by pressure load and result in higher thickness. Due to this ceiling composite made from R10%/M90% (reinforcement fabric 10% and matrix of unsaturated polyester 90%), it had the least thickness of 14 mm and the ceiling board made from *R*40%/*M*60% had the higher thickness of 24.8 mm than all others.

3.2. Tensile Strength. As evident in Table 2, the ANOVA table analysis for tensile strength shows that *P* values are less

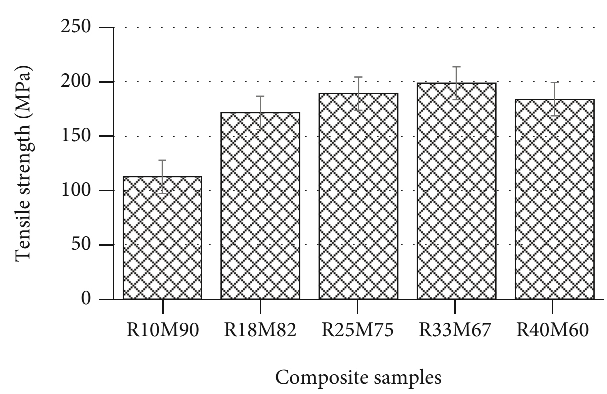

FIGURE 3: Tensile strength.

than 0.0500 indicating the model terms are significant. In this case, the *P* value for reinforcement, matrix, and proportions (mixture) are less than 0.0500 which means both of them had a significant effect on the tensile strength of the composite material.

3.3. Effect of Reinforcement and Matrix Loading on Tensile Strength. As shown in Figure 3, the tensile strength of the composite increased drastically with the increase in the fiber weight proportion from 10% to 33% and 114.6 to 198 MPa, respectively. It can be deduced that the initial linear portion of the graph shows the elastic behavior of the composite specimen, which is consistent as observed in the sharp

Table 3: Compressive strength.

Source	Sum of squares	df	Mean square	F value	P value	
Model	34841.29	3	11613.76	7504.37	0.0085	Significant
[(1)]Linear mixture	17711.85	1	17711.85	11444.72	0.0060	
AB	10976.23	1	10976.23	7092.42	0.0076	
AB (A-B)	6839.72	1	6839.72	4419.56	0.0096	
Residual	1.55	1	1.55			
Cor Total	34842.84	4				

increments from 10 to 25 weight percentage of fiber loading. This linear increment indicates that there is a better interfacial distribution between matrix and reinforcements [42]. Besides, the composite becomes stiff and could withstand higher stress at the same strain portion. This means that, according to Hook's law, Young's modulus of the composite is increased. The elastic modulus showed a linear increase with glass fiber content in the composites [38]. It can be seen that when the proportions of the reinforcements increased, the tensile strength of the composite increased.

For 40 wt. % of reinforcement, there was a drop in strength. This is because, at a higher volume fraction of reinforcement, the fiber acted as flaws and crazing occurred, thus creating a stress concentration area that lowers the stiffness of the composite. Besides, >33 wt. % of reinforcement was a bit excessive that the unsaturated polyester matrix was hard enough to flow through every reinforcement reclaimed fabric thus leaving voids and reinforcement reclaimed fabric were more easily exposed to environmental degradation. These ultimate stresses before break decreased because the interfacial adhesion between reclaimed fabric reinforcement and unsaturated polyester matrix was not good; fiber to fiber interaction was preferred by the system [43].

3.4. Compressive Strength. The ANOVA quadratic model was chosen for the compressive strength property. The ANOVA table analysis for compressive measures demonstrates that P values are less than 0.0500, indicating that the model terms are significant, as shown in Table 3. In this case, the P values for reinforcement, matrix, and proportions (mixing) are all less than 0.0500, indicating that they all had a substantial impact on the composite material's tensile strength.

3.5. Effect of Reinforcement and Matrix Loading on Compressive Strength. Figure 4 shows the compressive strength test results. The maximum and minimum compressive strengths of the composite are 1105.3 MPa and 867.5 MPa, when the weight % of fiber and matrix 33 and 67 and 10 and 90, respectively. The compressive strength increased with fiber loading increased and decreased with increased the weight % of the matrix. However, when the content of the textile waste is increased, i.e., greater than 33 wt.% of reinforcement in the composite, the adhesion between the fiber and the matrix is decreased because the matrix was hard enough to flow through every fiber thus leaving voids due to this the compressive strength becomes

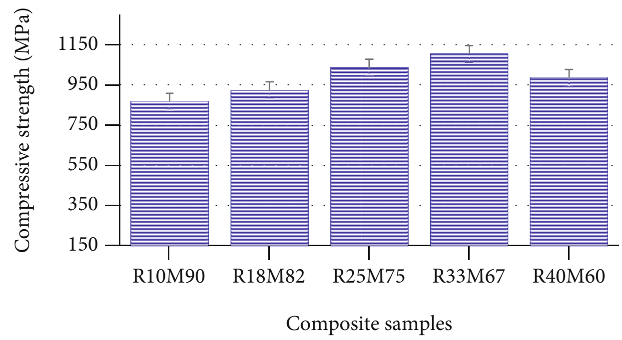

Figure 4: Compressive strength.

decreased. In addition, textile agglomerations happened thus causing dispersion problems in the matrix, which lead to a decrement in compressive strength. A similar concept was reported by previous researchers [44].

The weight % of the matrix is increased; it creates voids, and then, the interfacial adhesion matrix and reinforcement were not good, which leads to a decrement in compressive strength [44]. In general, the compressive strength is maximum when the weight % of the fiber is increased and the matrix weight % is decreased.

3.6. Flexural Strength. For this flexural strength test, ANOVA for the quadratic model was used and the reinforcement and matrix ratio of them had been significant model terms.

As shown in Table 4, the ANOVA table analysis for flexural strength shows that P values are less than 0.0500 indicating the model terms are significant. In this case, the P value for reinforcement, matrix, and proportions (mixture) are less than 0.0500 which means both of them had a significant effect on the tensile strength of the composite material.

Figure 5 shows that the flexural strength increased with fiber loading increased and decreased with the wt.% of the matrix increased. The flexural strength of the composite increased linearly with fiber composition from 10 to 33 wt.%. However, further increase in fiber content above this value, there is a lowering of flexural strength. The decrease in flexural strength at higher wt.% of fiber loading may be due to the increased agglomeration or fiber-to-fiber overlapping and dispersion problems. Defect and fail when the stress initiates the defective cells as a result of stress concentration. Consequently, the fiber can withstand bending forces which comprise compressive forces and tensile stress.

Table 4: Flexural Strength.

Source	Sum of squares	*df*	Mean square	*F*-value	*P* value	
Model	51.66	2	25.83	194.73	0.0051	Significant
(1)Linear mixture	39.89	1	39.89	300.76	0.0033	
AB	11.77	1	11.77	88.70	0.0111	
Residual	0.2653	2	0.1326			
Cor total	51.92	4				

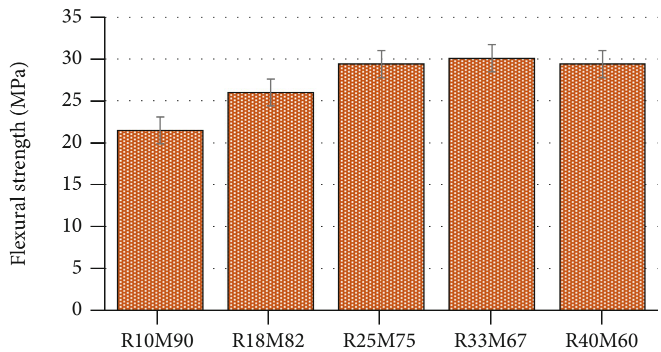

Figure 5: Flexural strength.

Table 5: Impact strength.

Source	Sum of squares	*df*	Mean square	*F* value	*P* value	
Model	129.17	1	129.17	499.10	0.0002	Significant
Linear mixture	129.17	1	129.17	499.10	0.0002	
Residual	0.7764	3	0.2588			
Cor Total	129.95	4				

3.7. Impact Strength. As shown in Table 5, the ANOVA table analysis for tensile strength shows that *P* values are less than 0.0500 indicating the model terms are significant. In this case, the *P* value for reinforcement and matrix are less than 0.0500 which means both of them had a significant effect on the tensile strength of the composite material.

As illustrated in Figure 6, composite impact strength decreased as textile loading (reinforcement) decreased. Earlier researchers like Piah et al. reported that [45] the energy-absorbing mechanism of composites during fracture includes the utilization of energy required to deboned the textile and pull them completely out of the matrix due to weak interface strength between the fiber and matrix. In practical interest, a significant part of energy absorption during impact takes place through the textile pull-out, matrix crack, and textile waste breakage. For polymer-based composite materials when subjected to impact type of loading conditions, energy is absorbed in the process of plastic deformation of the matrix material, debonding at matrix/reinforcement interface, and in the fracture of reinforcing material. The phenomenon that absorbs the least amount of energy for its occurrence becomes prominent (protruding) and leads to fracture [46].

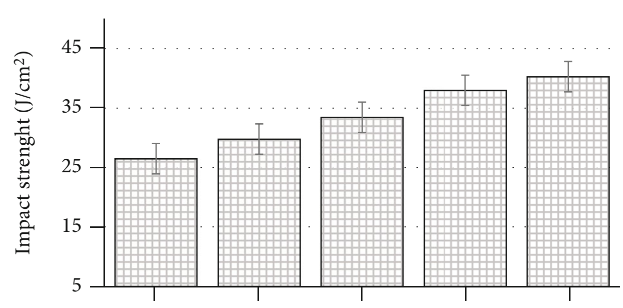

Figure 6: Impact strength.

In most fiber-filled composites, a significant part of the energy absorption during impact takes place through the fiber pull-out process. The fracture energy will be a combination of the work necessary to debone the fibers out of

Table 6: Comparison of different ceiling board composites.

Composites made from	Tensile strength (N/mm^2)	Flexural strength (N/mm^2)	Compressive strength (N/mm^2)	Reference
Sawdust, resin, and false Banana fiber	3.96-12.54	3.52-5.13	1.52-7.03	[48]
Maize husk, rice husk, and saw-dust	—	0.05-0.1	1250-1315	[49]
Rice husk and waste paper	—	0.03-0.1	1250-1320	[50]
Rice husk, sawdust, resin, and methyl ketone peroxide	13.4-20.4	3.2-6.20	7.05-9.52	[51]
Rice husk, sawdust, corncobs, and, resin	—	4.86-14.78	—	[52]
Sawdust, corncobs	2.79-7.21	0.26-3.43	1627.96-9351	[51]
Cotton waste and resin	112.6-198.75	21.5-30.1	867.5-1105.3	This research work

the matrix and the work done against friction in pulling the fibers out of the matrix. The weak surface adhesion between the fiber and the matrix initiated the crack upon the energy transferred to the composite. The impact strength decreases due to poor interfacial bonding between the fiber and the matrix [44, 46, 47].

3.8. Comparison of Composite Samples. The developed composite properties have been compared with the existing reference ceiling boards made from natural fiber composite. Table 6 shows the comparison of mechanical properties of composite ceiling boards. As seen from Table 6, the tensile and flexural strengths of these research composite results are better than the reference composite false ceiling boards. Besides, the compressive strength of cotton waste and resin had comparable property as demonstrated in Table 6.

4. Conclusion

Composite materials were developed using 100% cotton fabric waste reinforcement with an unsaturated polyester matrix with different ratios of R10%/M90%, R18%/M82%, R25%/M75%, R33%/M67%, and R40%/M60% textile waste (R) and unsaturated polyester matric (M), respectively, and their tensile, flexural, compressive, and impact strengths had measured and analyzed. The statistical results showed that all studied mechanical properties of the composite were affected by textile waste loading and matrix ratio at α value of 0.05. From developed ceiling board composites, the highest tensile strength of 198 MPa, flexural strength of 30.1 MPa, and compressive strength of 1105.3 MPa had recorded at sample R33%/M67% (33% cotton fabric waste and a matrix of 67% unsaturated polyester). On the other hand, the composite ceiling board made from 10% cotton fabric waste and matrix of 90% unsaturated polyester had a lower tensile strength of 112.6 MPa, flexural strength of 21.5 MPa, and compressive strength of 867.5 MPa. The highest impact strength of 40.31 J/cm^2 was observed at 40% cotton fabric waste and a matrix of 60% unsaturated polyester (R40-M60) composite sample. Finally, using 100 percent cotton fabric waste as reinforcement for ceiling board application, an effective ceiling composite with good qualities has been successfully produced.

Data Availability

All relevant data to the manuscript have been included.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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