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Investigating Tensile and Flexural Strength Properties of Grey Cotton Fabric with Textile Solid Waste Composite Materials

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Abstract

Currently, in Ethiopia and around the world, large amounts of ante and post-mortem waste, such as clothing waste, plastic waste, and cotton waste, contribute to air pollution. This waste is simply discarded and thrown into the environment. Studying and characterizing this waste has many advantages. This work focused on the characterization and study of the tensile and flexural strength properties of these wastes for lightweight automotive body applications such as hoods. For the experiment, the specimen was fabricated using cotton fabric and garment waste reinforcing layer with a weight ratio of polyester–cotton rag-hardener (79%-19%-2%, 59%-39%-2%, 39%-59%-2%, 19%-79%-2%), and the better surface bonding obtained at 59%-39%-2% combination respectively. The reinforcing layer is arranged as a sandwiching form; C_f C_f C_f C_f (cotton fabric-cotton fabric-cotton fabric-cotton fabric), C_f G_w C_fG_w, $C_fG_wG_wC_f$, $G_wG_wG_wG_w$, and $G_wC_fC_fG_w$. From those sandwiching forms, $C_fG_wG_wC_f$ has shown a better surface finish and maxing structure. The test results indicated the newly formed composite material has the best properties. The maximum tensile strength of 115.918 MPa was obtained on the $C_fG_wG_wC_f$ combination and the minimum value of 64.894 MPa was obtained in C_f C_f C_f C_f lamination. Also, the maximum and minimum flexural strength of 107.95 MPa and 52.71 MPa were obtained on Chopped and C_f C_f C_f C_f lamination of the reinforcing respectively. Finally, as indicated in the result that it will apply to many structural applications like car hoods with additional studies.

Keywords: Cotton fabric • Garment waste • Mechanical properties • Waste recycling

Introduction

Composite materials are the results of two or more members of components that compiled each other for better properties than the individual element (Figure 1).

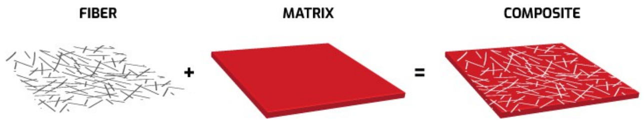

Figure 1. Composite materials forming components (the fiber and the matrix).

Composite materials performed a significant role in the production of automobiles, furniture, area and aircraft, naval ships, and lots of others. Composite materials are synthetic with the aid of using combining diverse substances into a brand new fabric that's higher perfect for a specific application than both of the authentic fabrics alone. At present, the current industry requires materials with an unusual combination of residences that can't be met with the aid of using traditional substances and provides better results than the previous. Composite substances are green and reasonable to be used in numerous engineering applications [1,2]. Composites were first thought of as structural materials more than three-quarters of a century ago. Since that time, it has attracted attention in all aspects of material science, manufacturing technology, and theoretical analysis. The term composites, taken at face value, can mean almost anything. Because if you look closely enough, all materials are composites of different subunits. However, in modern materials technology, the term usually refers to fiber-reinforced matrix materials. Many composites in use today are at the forefront of materials technology, with performance and cost suitable for highly demanding applications such as spacecraft. In the explanation, composite materials generally consist of relatively strong fibers within a tough resin matrix. The past decade has seen a significant increase in the use of bio composites. Materials from renewable resources are expected to replace not only

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the reinforcement elements but also the matrix level of composites to overcome the sustainability issues associated with the use of synthetic materials in composites [3]. Natural fibers replace synthetic fibers in major areas, gradually with most daily applications environmental impact. In addition to the environmental benefits of low Technology prices and steadily improving performance and the use of standard plastics, natural fibers became more pronounced [4,5]. According to the description, from those composite materials, consumer goods made from cotton can be found anywhere including textile and garment cotton fabric wastes. As research data indicated, global cotton consumption has increased in recent years, reaching about 110 million bales and 115 million bales in 2016 and 2017, respectively. Cotton consumption has outstripped production for the past two years, and they expect this trend to continue. As a result, the amount of cotton waste generated also increases. This includes both pre-consumer waste generated during the production of yarns, fabrics, and clothing, and post-consumer waste discarded at the end of the product's life (Figure 2) [6,7].

- Figure 2 shows, according to the green peace report in Ghana and Uganda, it is a serious problem next to plastic products. This is a common problem for other African countries mostly imported old clothes from European countries. The following Figure 3 also shows the other African countries Ethiopia and Kenya which are addicted to this waste problem.

Figure 2. Different wastes in African countries and their environmental impact.

Figure 3. Wasted textile products and their environmental impact in Kenya and Ethiopia.

- According to the reports of the Guardian as indicated in Figure 3 above. There is an open landfill (Qoshee also known as Koshe) waste textile products that cause environmental pollution in Ethiopia. The site is located in the southeastern part of Addis Ababa. It has been in operation for about 50 years with a total area of about 36 hectares.

- In Figure 3 Kenya city also shows an investigation into the hidden waste of fashion has revealed that European dumped more than 37 million items of plastic clothing in Kenya in 2021, exposing the ugly truth of how the Global South bears the brunt of Europe's addiction to fast fashion.

As a study mentioned, cotton-based waste fibers are mainly derived from cotton, and cellulose fibers can be viewed as an alternative renewable biomass source for finishing bio-based products through various pretreatments and subsequent biological processes [8-10]. According to the discussion, modern lifestyles and technological advances have increased the amount and types of waste we generate in danger of disposal. The amount of energy required, and manufacturing costs are lower than fiberglass [11,12]. In the current apparel manufacturing process, conventional sewing patterns waste fabric, and waste in cutting and sewing has become a problem. About half of the total cost of clothing is fabric, leading to unsustainable and wasteful fashion development. Fabric is therefore the most valuable material in the fashion production process. In addition to the unforeseen economic impact of waste, pre-consumer waste has serious environmental impacts. In recent years, the clothing and textile industry produces millions of tons of textile waste worldwide every year. One type of waste is textile waste, and the amount of waste is increasing year by year. Therefore, there is a unique opportunity to recycle and utilize textile waste as a resource and reduce pollution [13]. The other researcher also explained that fiber-reinforced composites made from textile fiber waste are environmentally friendly and economically advantageous. However, fiber waste-reinforced composites have not received the attention of composite manufacturers due to the limited reported studies on the variation of physical and mechanical properties of waste fibers that affect composite properties [14,15]. On the other side, Polymer composites have been part of the automotive industry for decades. Due to their beneficial properties (e.g. high tensile and compressive strength, controllable electrical conductivity, low coefficient of thermal expansion, excellent fatigue resistance, and suitability for manufacturing complex-shaped materials), reinforced composites are Very widely used [16,17]. A recent interest of automakers is to develop components that can enhance the safety features associated with lightweight materials such as the use of aluminum and composites. Aluminum metal matrix composites and composites improve the performance of automotive crash boxes due to their lightweight. An automotive crash box is a component that is installed on the front end of a vehicle and is one of the most important crash energy absorbers [18-20]. The other green peace reports also state in Kenya, and Tanzania, "Global fashion brands are promoting circularity, but reality shows that this is still a myth. Nowhere is the failure of the fast fashion linear business model more visible than in the countries where many of these cheap clothes end up once their short lives are over: On huge dump sites, burnt on open fires, along riverbeds, and washed out into the sea, with severe consequences for people and the planet. Greenpeace Germany went to Kenya and Tanzania to witness the problem of imported textile waste in these countries and to find out about some of the many local initiatives trying to counter it through their means."

- Generally from the different research literature, we observed that during the decomposition process, textiles generate greenhouse methane gas and leach toxic chemicals and dyes into the groundwater and our soil.
- So that recycling and changing this waste material into useable products has many advantages like sources of income such as circle economy, waste reduction and making zero waste production, free greenhouse gases, and other waste prevention systems.
- Also can able to produce lightweight automotive parts and bodies by recycling these waste materials.

Materials and Methods

Materials

The material used for this work was:

Cotton fabric and gabardine garment waste: Used as a reinforcing material for the composite materials in different orientations and lamination between the cotton fabric and Gabardine garment waste. Also, the chopped forms of the reinforcing materials have been used to fabricate and prepare the specimens (Figure 4 and Table 1).

Figure 4. Cotton fabric waste materials.

Property	Value
Density, g/cm^3	1.5–1.6
Elongation, %	7.0–8.0
Tensile strength, MPa	287–597
Young's modulus, GPa	5.5–12.6

Table 1. Mechanical properties of the cotton fabric.

Polyester resin (unsaturated general purpose): The resin used for this study was GP resin 1003 Unsaturated Polyester (UP) GP resin of density 1.14 g/cm^3 at 25°C mixed with a hardener of density 0.97 to 0.99 g/cm^3 based on the standards.

Hardener: Polyester resin is cured by adding a catalyst, which causes a chemical reaction without changing resin is cured by adding a catalyst, which causes a chemical reaction without changing its composition. The catalyst initiates the chemical reaction of the resin and monomer ingredient from liquid to a solid state (Figure 5).

Figure 5. Polyester and hardener used in the study.

Fly ash: used to fasten the curing time during composite fabrication in addition to that of the hardener material. Fly ash is one of the most inexpensive and low-density reinforcements available in large quantities as a solid waste byproduct during the combustion of wood and coal in thermal power plants.

Wax: It is a chemical agent used to stop the bonding of the molding material with the mold. Mold-release wax, in particular, was used in laminating and prevented the part from attaching to the surface of the mold (Figure 6).

Figure 6. Determination of particle density of the new forming composite based on the principles of Archimedes.

Theoretical analysis and density determination

$V_c = V_f + V_m$ (1)

Where,

V_c: The volume of composite material V_f:

A volume of fiber

V_m: A volume of matrix

Particle density=(g/cm^3)=

$=((W_b - W_a)/V_O)$ (2)

The experimental data obtained:

W_b=total weight of the cotton fabric and flask water (g)=1059 g

W_a=weight of empty flask and pure water (g)=677 g

V_o=volume of flask (ml)=400 ml

The initial flask volume of water V_O=400 ml;

Particle density=(g/cm^3)=

$$=((W_b-W_a)/V_O) \quad (3)$$

$$=((1059\ g-677\ g)/400\ ml)$$

Methods

The different experimental sample test was used to determine the best combination of the reinforcing and matrix material. For this experimental work, the five-combination orientation and the weight concentration have been effectively checked. Also, the chopped form of the reinforcing has been done (Figure 7).

- C_F–C_F–C_F–C_F (cotton fabric–cotton fabric–cotton fabric–cotton fabric).
- C_F–G_W–C_F–G_W (cotton fabric–gabardine waste–cotton fabric–gabardine waste).
- C_F–G_W–G_W–C_F (cotton fabric–gabardine waste–gabardine waste–cotton fabric).
- G_W–C_F–C_F–G_W (gabardine waste–cotton fabric–cotton fabric–gabardine waste).
- G_W–G_W–G_W–G_W (gabardine waste–gabardine waste–gabardine waste–gabardine waste

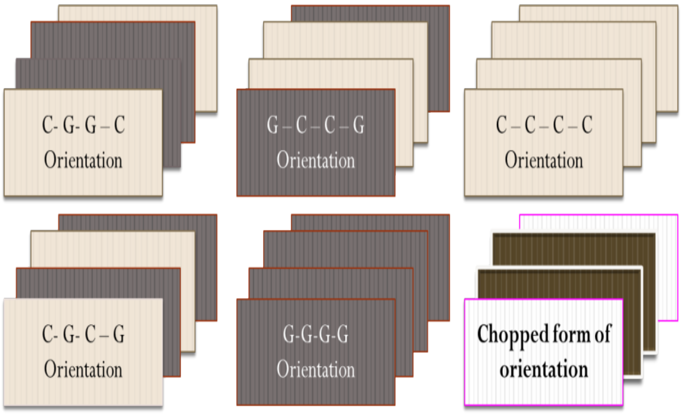

Figure 7. Different orientations of the cotton fabric textile waste and garment waste, and also, the chopped forms of the waste reinforcing which was used to sample fabrication.

The weight concentration was also used to see the effects during the composite fabrication and testing. The four types of weight-concentration combinations of composite fabrication have been checked. The result as shown below the figure, the cotton rag–polyester resin–hardener (19%, 79%, 2% and 39%, 59%, 2% and 59%, 39%, 2% and 79%, 19%, 2%) combination respectively.

From the first combination C–P–H (19%, 79%, 2%): The brittleness and low strength of the composite result happened due to the amount of the polyester resin being 79%and the reinforcing material being 19% content (Figure 8).

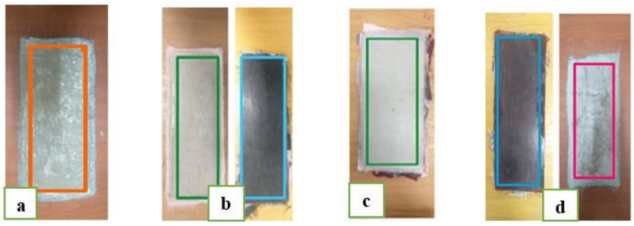

Figure 8. The composite sample was fabricated using the combination of the weight concentration between the reinforcing, matrix, and hardener components; a) represents C–P–H (19%, 79%, 2%), b) represents C–P–H (39%, 59%, 2%), c) represents C–P–H (59%, 39%, 2%), and d) represents C–P–H (79%, 19%, 2%).

From the second nomination, C–P–H (39%, 59%, 2%): The best result was recorded and the mixing–bonding strength is also very nice in this combination when we compared it to the other. The mixing ratio is also better than the other combination. The void and cavity of the surface are minima than the other nomination. Surfaces and bonding structure of the composite plate also better bonding.

The third combination C–P–H (59%, 39%, 2%): The result shows that the void and cavity in the composite specimen were very high compared to the other but better than the first combination. The mixing and bond structure, surface quality, and porosity were shown in the specimen.

The fourth combination is C–P ss–H (79%, 19%, 2%): The result shows the matrix material is not enough to compile the reinforcing materials. The porosity void content is also very high. So, this combination is not used for further study and testing due to that the specimen is of very poor quality and unable to test.

From the all-over result observed, for this research work the second combination C–Pl–H (39%, 59%, 2%), has been used for the fabrication and testing of the composite sample specimen. It shows better finishing and bonding structure.

Experimental setup for each test

Tensile strength: Tensile properties consist of the reaction of a material when a force is applied under tension. Determining tensile properties is very important as it provides information on Young's modulus, yield strength, elongation, proportionality limit, area reduction, tensile strength, yield point, yield point, and other tensile properties.

Tensile properties vary by materials and are determined by tensile tests. This is usually described by ASTM standard tests. Suitable standards for tensile testing are ASTM D638 and ASTM D3039, depending on the type of polymer composite. ASTM D638 is recommended for randomly oriented, discontinuous, moldable, or low-volume reinforced composites. Instead, ASTM D3039 is used for highly oriented and/or high tensile modulus fiber-reinforced polymer composites (Figures 9 and 10). Tensile specimens are typically dumbbell or dog bone shaped and rectangular bar shaped as shown in Figure 3.

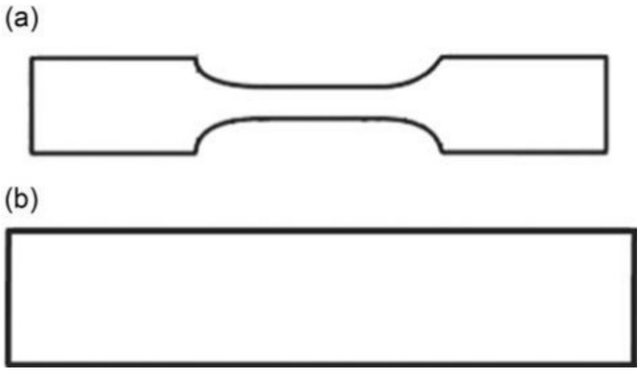

Figure 9. Specimens shape for the tensile strength test; (a) dumbbell or dog bone shape (b) rectangular shape.

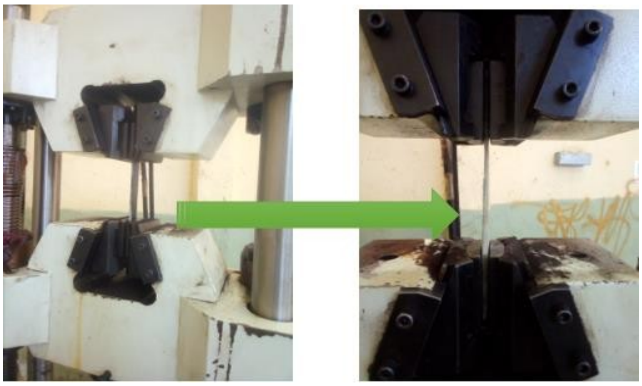

Figure 10. Experimental setup of tensile strength test on UTM machine.

According to the different literature recommendations for composite materials, the mold used for specimen fabrication was rectangular wood according to ASTM D-3039-76 and the specimen size for the tensile test length was 250 mm, width 30 mm, and thickness 4 mm (Figure 11).

$\sigma t=P/bh$ (4)

Young's modulus=Tensile stress/Tensile strain

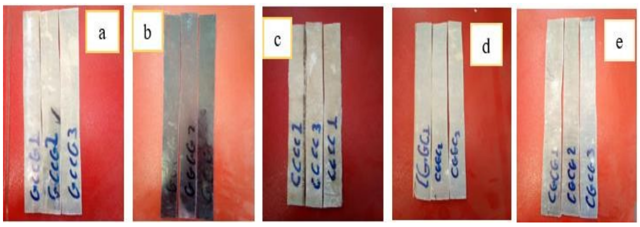

Figure 11. Sample specimen of the tensile strength test for each lamination (250 × 30 × 4) mm. a) G-C-C-G combination, b) G-G-G-G, c) C-C-C-C, d) C-G-G-C, and e) C-G-C-G combination of the cotton fabric with gabardine garment waste.

Flexural strength

The flexural test measures the force required to bend the specimen under three-point loading situations. This test is used to select specimens for vehicle body parts that support loads without breaking. The flexural strength test specimens were prepared as per the ASTM D790-76 standards. The flexural specimens were 150 mm by 30 mm and 4 mm thick. The loading fixture was adjusted to an mm span which resulted in a span-to-thickness ratio of about 27:1 which is shown in the Figure 12.

Figure 12. Experimental setup of flexural strength test on UTM machine.

$\sigma_{max=3PL/2}bt^2$ when $L/t \le 16$ (5)

$EF=mL^3/4wt^3$

$\varepsilon_F=6dt/L^2$

Where σ_{max}=flexural strength, P=load at yield (max. load), L=support span (mm), b=width (mm), t=thickness (mm), m is the slope of the initial portion of load versus displacement curve d is the maximum bending before failure. From the different literature for this test (150 × 30 × 4) mm specimen dimension had been used for the flexural strength.

Results and Discussion

Tensile strength test result

The experimental test results of the tensile strength has been done using the five lamination of reinforcing orientation and the chopped forms of the cotton rag. This cotton rag contains both gabardine garment waste and cotton fabrics. The outputs of the experimental results have been listed below Table 2 and Figure 13.

Orientation of the reinforcing materials	Tensile strength (MPa)					
	T1	T2	T3	T4	T5	Average
C-C–C-C	65	65.85	65	64.5	64.12	64.894
C–G–C-G	89	90.6	90	91	90.86	90.292

C–G–G-C	116.8	117	115.9	114.89	115	115.918
G–C–C-G	78.5	82	79	78.96	80	79.692
G–G–G-G	98.45	97.55	98	98.12	101	98.624
Chopped form	71.23	70	69.96	72.2	70	70.678
Where T_{12345}=levels of sample size.						

Table 2. Experimental test results of tensile strength test.

The result shows in the Table 3, the maximum tensile strength is 115.918 MPa, and the minimum value of the tensile strength observed is 64.894 MPa.

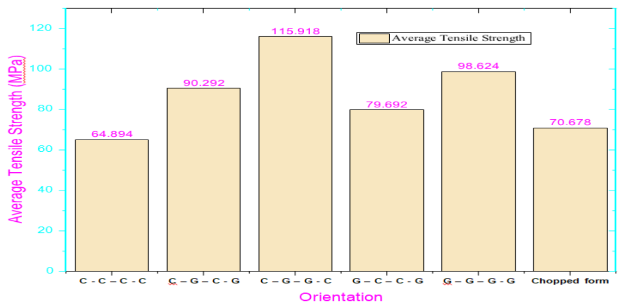

Figure 13. Experimental test results of the tensile strength test.

Orientation of the reinforcing materials	Average tensile strength in (MPa)	Strain rate E (%)	Average strain in %	E=(δ/ε) In (GPa)
C - C – C - C	64.89	2.05-2.87	2.46	2.64
C – G – C - G	90.29	2.00-3.86	2.93	3.08
C – G – G - C	115.92	4.19-5.78	4.98	2.33
G – C – C - G	79.69	3.15-3.38	3.27	2.43
G – G – G - G	98.62	2.13-3.12	2.62	3.76
Chopped form	70.68	1.02-2.13	1.57	4.5

Table 3. The experimental test results of elastic modulus properties of the newly formed composite materials.

Flexural strength test result

It is presented in Table 4, Figures 14 and 15.

Orientation of the reinforcing materials	Flexural strength (MPa)					
	T1	T2	T3	T4	T5	Average
C-C–C-C	53	52.5	57	49.05	52	52.71
C–G–C-G	83.2	78	81.5	83	80.65	81.27
C–G–G-C	94.82	93.27	90.75	92.56	94.5	93.18
G–C–C-G	68	71.89	69.86	70.22	71.8	70.354
G–G–G-G	102	101.78	104	102.8	104.58	103.032
Chopped form	109.4	106	107.85	109	107.5	107.95

Table 4. Experimental test results of flexural strength.

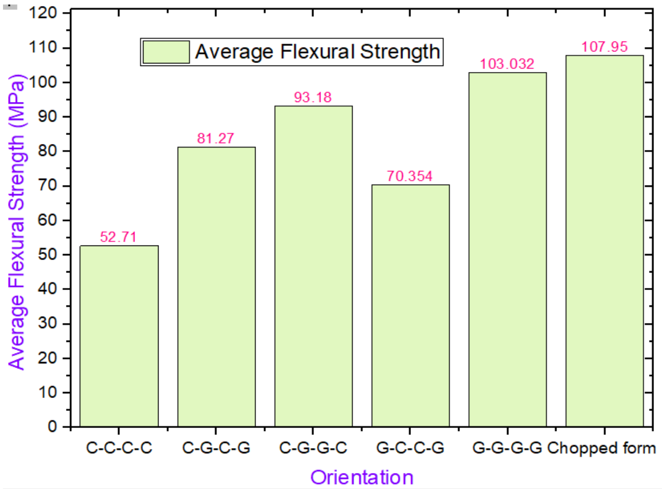

Figure 14. Experimental test results of the flexural strength properties.

Figure 15. Effects of the reinforcing arrangement and lamination on the delamination properties.

Conclusions

- From the tensile strength test result, we observed that better strength was obtained on C-G-G-C combination with 59% polyester, 39% Reinforcing, and 2% additive catalysts (Hardener and fly ash). The maximum average value of the tensile strength was 115.918 MPa.
- The minimum values of the tensile strength obtained in the C-C-C-C combination of the reinforcing materials The minimum average tensile strength was 64.894 MPa.
- From the flexural strength the maximum value obtained in the chopped layer lamination. Its maximum value is 107.95 MPa. The minimum value of the flexural strength is 52.71 MPa C-C-C-C lamination. But there is no maximum significance difference between the G-G-G-G and chopped form of the reinforcing materials. The value of the G-G-G-G is 103.032 MPa. So, the difference between them is minimal.
- But during the experimental test of the flexural strength, the sample shows delamination types of bending properties. Without the chopped forms of the reinforcing, all the other lamination of type of reinforcing materials shows this property. In the Figure 15 the delamination of the flexural test was located.
- As indicated in Figure 15 almost all samples show the delamination property of the reinforcing materials.
- Figure 15 above shows the reinforcing materials delaminated between the cotton fabric and the gabardine garment waste material.
- The delamination properties never occurred in the cotton fabric and the chopped forms of the reinforcing materials.
- The chopped forms of the reinforcing material have shown very hard properties than the other types of combination. But it had very low plasticity properties.
- The recycled composite materials can able to the car hood application with some additional studies.
- Finally, we conclude that recycling and reusing of such waste materials has many advantages; prevention of pollution, recycling and making zero waste manufacturing, production of low-cost lightweight materials, and other important.

Recommendation

Generally from this experiment, we suggest that:

- This newly formed composite material can apply in the automotive sector with some additional research and studies.
- The other mechanical properties like impact, hardness, vibration, and compression should be studied to apply the different structural application areas.
- The delamination properties also should be studied and the laminating properties of the different garment wastes should be also considered for the next study.

Credit Authorship Contribution Statement

Melese Shiferaw: Conceptualization, methodology, and compressive review, writing-review and editing, visualization, experimental test and data analysis, conclusion, and recommendation.

Asmamaw Tegegne and Assefa Asmare: Formal analysis, resources, data curation, writing original draft, and also commenting on the overall work.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests.

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