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# Experimental Investigation of Impact and Hardness Properties of Cotton Fabric – Garment Waste Polyester Matrix Composite Materials

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**Abstract**

This study focuses on the characterization and evaluation of the impact and hardness properties of composite materials developed using fabric waste. The primary objective was to explore the potential of fabric waste as a reinforcing material for sustainable composite development, aligning with the waste-to-resource concept. Specimens were fabricated by reinforcing fabric waste in various weight ratios and arranged in different sandwich configurations: CCCC, CGCG, CGGC, GGGG, and GCCG. Among these, the GGGG arrangement demonstrated the best surface finish and uniform mixing structure. Experimental results revealed that the newly formed composite exhibited favorable mechanical properties, with the GGGG configuration achieving the highest impact strength of 78.20 Joules and the greatest hardness value of 101.02. In contrast, the CCCC arrangement recorded the lowest values, with 8.75 Joules for impact strength and 40.03 for hardness. These findings highlight the feasibility of converting fabric waste into high-performance materials suitable for structural applications. With further investigation, this composite material holds promise for use in components such as car hoods and other structural elements, offering both environmental and economic benefits through waste reduction and value-added recycling.

**Keywords:** Cotton rag, Hardness Property, Impact strength, Textile Waste Recycling.

## 1. Introduction

In recent years, the need for polyemer matrix composites has arisen due to their various advantages over metallic materials, such as lighter weight, easier processing methods, lower cost, and longer durability (Pervez *et al.*,2023). Today, many scientists and researchers show great interest in creating eco-friendly products that make the use of natural fibers to replace depleting petroleum sources more attractive in the fuel consumption area by reducing the weight of vehicles. Among all reinforcing fibers, natural fibers are noteworthy as reinforcements in polymer matrix composites. Studies have been conducted on natural fibers such as banana, coconut, bamboo, sisal, wood, and jute fibers that have been reinforced with cement and plastic (Wang *et al.*, 2020). Natural fiber-reinforced polymer composites are widely used in various industrial fields. Processing natural fibers can effectively improve their mechanical properties and durability, broadening the range of applications (Basker *et al.,* 2020). The consumption of materials is increasing significantly every day. The supply of traditional materials such as metals is very inadequate to meet these requirements. On the other hand, there is a demand for materials that are stronger and lighter than conventional materials. As such, researchers are inventing new materials to meet this need. Composite materials provide this property, Low-strength lightweight applications are very broad (Singh, *et al.,* 2019). With the aim of sustainable development, eco-friendly composites (made of biodegradable polymers and natural fibers) are a hot topic among researchers. Green Composite is so-called free pollution because it can be easily decomposed without harming the environment due to its sustainable and biodegradable properties (Uppal, Pappu, Patidar & Gowri, 2019). The other researcher also explains composite materials; Composites are generally made of glass, carbon, and other synthetic fibers and are neither environmentally friendly nor biodegradable. Growing environmental concerns have led to the use of renewable natural materials in the design and development of new components/products. Today, the use of natural fibers is creating a new paradigm in the production of composite materials (Dissanayake & Weerasinghe, 2021). From those recourses of composite fabrication materials, advances in the textile sector have given rise to many new and advanced materials. These led to the development of composite materials (Baloyi, Ncube, Moyo, Nkiwane, & Dzingai, 2021).

### 1.1 Textile Solid Waste and Its Impacts

Rapid population growth rising incomes, and living standards worldwide have led to a steady increase in the production and consumption of textiles and fibers in recent decades. The textile industry is an energy-intensive and natural resource-demanding practice that contributes to the rapid generation of post-consumer waste streams. According to a recent industry report, $400 billion worth of clothing is wasted (Shirvanimoghaddam, Motamed, Ramakrishna & Naebe, 2020) The global production of textiles is increasing rapidly. As a result, industrial waste management is becoming increasingly difficult. Without proper waste disposal facilities, post-industrial textile waste is mostly landfilled or incinerated, posing a hazard to both the environment and society (Özen, Demircan, Kisa & Ilik, 2020). As indicated in **Fig. 1**, textile and garment wastes are today's dangerous causes of environmental pollution mostly in developing countries that import second-hand clothes and outdated fashion products.


**Fig. 1** Solid waste problem in African countries: a = waste problem in Addis Ababa, b = Textile wastes in Kenya sent from Europe and China (Textile and plastic waste at Dandora dump site in Nairobi).
*https://texfash.com/special/africa-unbound-40-of-pre-loved-clothing-is-actually-textile-waste.*

According to the explanation of the research, with essential uses such as nutrition, protection, and health, and also covering important areas such as clothing, decoration, defense, industry, ~~and~~ automobiles and textiles, occupy an important position in people's daily lives. Plant-based products (such as cotton and linen) are used in a wide variety of applications, from medical applications to building materials, from aerospace technology to sporting goods, from furniture to automobiles (Guo, Eriksson, de la Motte & Adolfsson, 2021). As stated, a huge amount of polyester clothes fiber waste is discarded every year, causing serious problems to the environment (Senanayake & Gunasekara, 2020). With the rapid expansion of fashion consumption, fabric waste generated in the production process harms the environment. On the other hand, rapid fashion cycles are rapidly declining ancient crafts that have been passed down from generation to generation and have sustained artisans for centuries. Lack of knowledge of and lack of design skills to meet customer demands to achieve adequate value can be identified as the main problems leading to the decline of the craft (Kim, Kwon, Bai, & Jeong, 2022). Generally, different research review and outputs indicate the waste of textile and garment production is a hazard and contributes to environmental pollution. It indicated that there is much amount of waste before and after the end of the life of textile products.

- As many researchers stated more than 75% of textile waste materials are released into the environment. If thes waste materials are well studied, they can used as a reinforcing material for different applications as a composite material.
- The review indicates these limitations and gaps that should be studied and converted into economic resources. Besides, making textile and garment industries zero-waste production systems and zero-waste factories for the environment. It will also help in implementing the circle economy of the manufacturing system.
- Based on the perspective we highlighted, the textile and apparel industry should be in a new, demanding, and imminent cycle that demands maximum use of resources, little to no waste, zero emissions, and pollution-free.
- we briefly explained the current state of the textile and apparel industry and waste. The effects of fast fashion, textile production, and water consumption in addition to environmental pollution.
- Finally, this experimental study tries to investigate the impact and hardness properties of these wastes for the reduction mechanisms of wastes and develop them into composite material for usable products.

## 2. Materials and Methods

### 2.1 Materials

The material used in this research includes general-purpose polyester resin, hardener, wax, fly ash, cotton fabric, and wool garment waste. The polyester resin was cured by adding a hardener and fly ash. Wax was used as a purpose of mold releaser due to its collapsibility properties.

### 2.2 Equipment and Tools

The Equipment and tools used for sample fabrication are a brush, gripper roller, digital balance, caliper, caliper, and smart table

### 2.3 Method and Procedures for the Sample Fabrications

Hand lay-up is a molding process where a manually placed fiber strand or woven fiber mat is combined with various resin formulations and applied to an open mold. Manual rolling of the open mold is then used to ensure the even distribution of resin and to eliminate trapped air pockets (Meola, Boccardi, &. maria 2017: Raji, et al, 2018) . According to the explanation, manual hand layup of woven materials still dominates the composites manufacturing industry, requiring human labor skill, and experience to form flat layers into complex shapes (Elkington et al., 2015: Jamir et al., 2018).

Generally, based on the different works of literature the method of sample fabrication for this experimental research was the hand layup technique. Each step and procedure of the fabrication are listed in **Fig. 2** below.

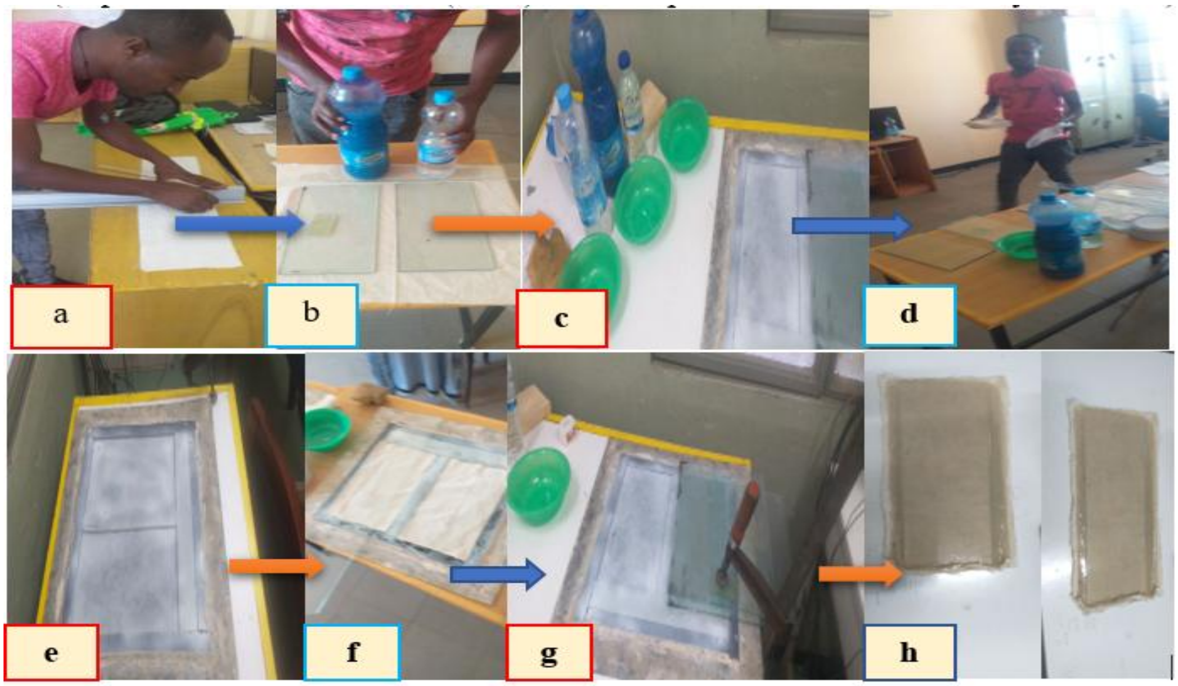



**Fig. 2** The hand layup technique procedures of the composite sample fabrication; **a** = cutting of the cotton fabric, **b** = preparing of matrix polyester and covering glass, **c** = preparing of mixing cup and mold, **d** = measuring of each of the component's matrix, fiber and hardener, **e** = painting & polishing of the mold by wax, **f** = smoothly laminating the layer and resin, **g** = covering and gripping for applying load, and **h** = opening the mold and taking out the sample composite plate.

The procedures and the parameters used for this finding were weight concentration and reinforcement alignment orientation of the cotton fabric wool garment waste.

### 2.3.1 Weight Concentration

The weight concentration of the reinforcing, the catalyst, and the matrix material was formulated based on different research papers and works of literature (Andrew et al., 2019: Batu & Lemu, 2020 ) To see each effect the reinforcing and the matrix material were used in the following (

Table 1) four categories of classifications.

**Table 1** Weight concentration of the reinforcing and the matrix materials.

| No | Polyester resin in (%) | Cotton Rag In (%) | Hardener and Fly ash in (%) |
|---|---|---|---|
| 1 | 79 | 19 | 2 |
| 2 | 59 | 39 | 2 |
| 3 | 39 | 59 | 2 |
| 4 | 19 | 79 | 2 |

The four-weight concentration of the matrix and the reinforcing effect are indicated in **Fig. 3.** The effects of the mass difference between the matrix and the reinforcing show different bonding strengths. For this study of all lamination orientation types 59 %, 39%, and 2% (polyester – cotton rag–hardener) weight concentration combination was used. Fig. 3 shows the four weight-different results of the composite plate.

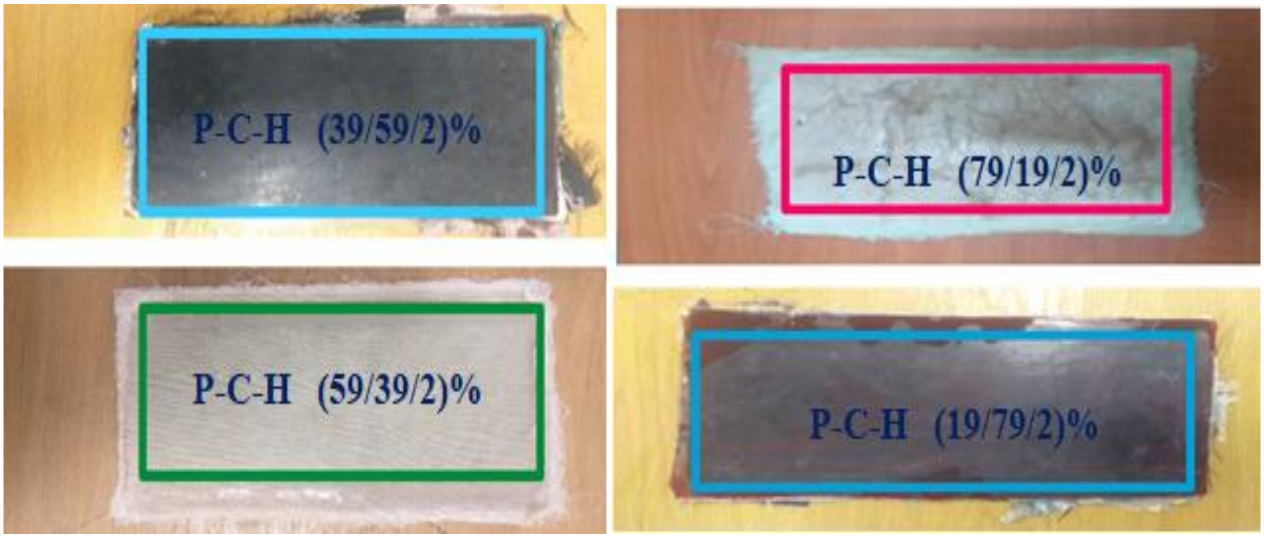



**Fig. 3** Effects of the weight difference between the matrix and the cotton rag. Where P = Polyester, C = cotton rag and H = hardener.

### 2.3.2 Effects of Orientation (Cotton fabric – garment waste lamination)

Cotton$_{fabric}$ – Garment$_{waste}$ - Cotton$_{fabric}$ – Garment$_{waste}$, this is a combination of the four layers is a matted structure and for the specimen, four layers with a total thickness of 4mm. Totally for this work, five types of orientation have been used. Fig. 4 indicated the laye arrangement and lamination of the reinforcing materials.

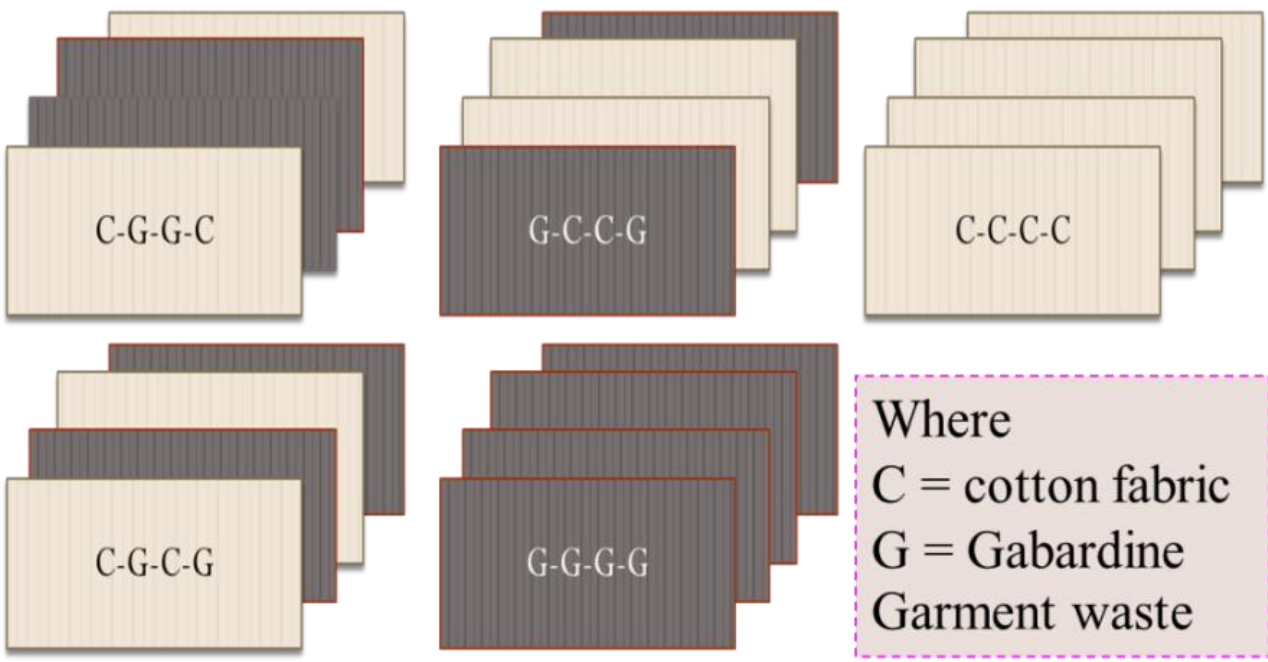



**Fig. 4** The cotton rag reinforcing orientation type of each specimen; where C = cotton fabric and G = garment waste (gabardine garment waste.

## 2.4 Experimental Test

### 2.4.1 Impact test

The impact test is a method for evaluating the toughness, impact strength, and notch sensitivity of engineering materials. An impact test is a technique for determining the behavior of material subjected to shock loading in:

- Bending
- Tension
- Torsion

This test is designed to determine how a specimen of a known material will respond to a suddenly applied stress. The test ascertains whether the material is tough or brittle. It is mostly used to test the toughness of metals, but similar tests are used for polymers, ceramics, and composites. **Fig. 5** shows the diagrammatical representation of the Charpy impact testing mechanism.

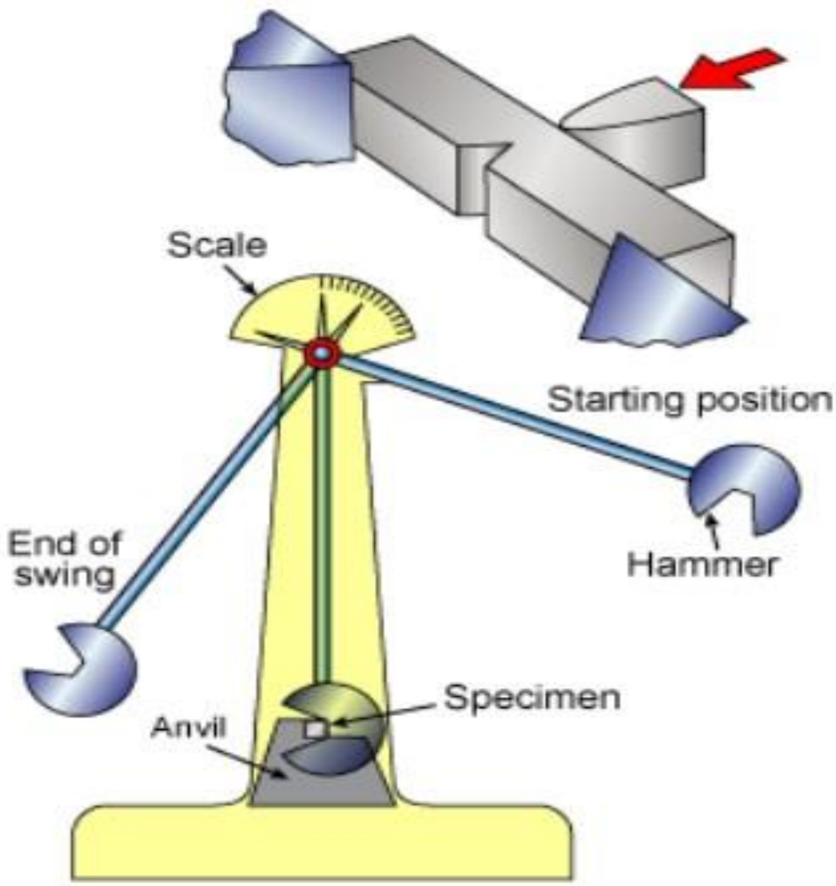



**Fig. 5** Diagram of the Charpy Impact testing machine
(Nagai & Miyairi, 1994; Yalcin-Enis, 2023; Yalcin-Enis, 2023).

For this experimental test, the Charpy impact test was used and the setup needed for Charpy testing consists of a rectangular beam of composite to be tested, which is placed between two anvils. A swinging pendulum then breaks the composite beam and the total energy absorbed as well as the toughness of the composite is determined by comparing the height to which the pendulum rises after impact and the height from which it was dropped. The dimension of the sample specimen was selected based on the different works of literature. Table 3 indicates refernces of each standard test sample specimen dimenstions.

**Table 2:** ASTM standard Impact test specimen dimension of the composite material.

| ASTM | Dimension in mm | Reference |
|---|---|---|
| ASTM D256 | 127 *13*3 | Balachandar et al., 2019 |
| ASTM D256 | 55*10*2 | Ramakrishnan et al., 2019 |
| ASTM D4812 | 80*10*4 | Khan et al., 2021 |
| ASTM D4812 | 64*12.7*3.2 | Prabhu et al., 2022 |

For this work, the Charpy type of impact test machine was used and its procedure and parameters are discussed in the Table 3.

**Table 3** The specification between the Izod and Charphy Impact tester (Navaranjan & Neitzert, 2017: Sathishkumar et al., 2022)

| Procedure | Izod Impact testing machine | Charpy Impact testing machine |
|---|---|---|
| Common standards | ASTM D256 or ISO 180 for notched specimens ASTM D4812 ISO 180 unnotched specimens. | ASTM A370, ISO 148, or EN 10045-1 |
| Test sample | Placed in a vertical position. | Placed in a horizontal position. |
| Test hammer striking | At the upper tip of the Specimen. | At the point of the notch but in the opposite direction. |
| Notch face | Facing the striker, fastened in a pendulum. | The face is positioned away from the striker. |
| Notch type | V-notch | V and U notches |
| Spec. Dim. | 75 x 10 x 10mm | 55 x 10 x 10mm |
| Hammer type | Farming hammer as a striker | Ball Pin hammer as a striker |

The machine used for this investigation is discussed in **Fig. 6**. This machine is a digital system and it displays the amount of energy that the material cracked or broke out.

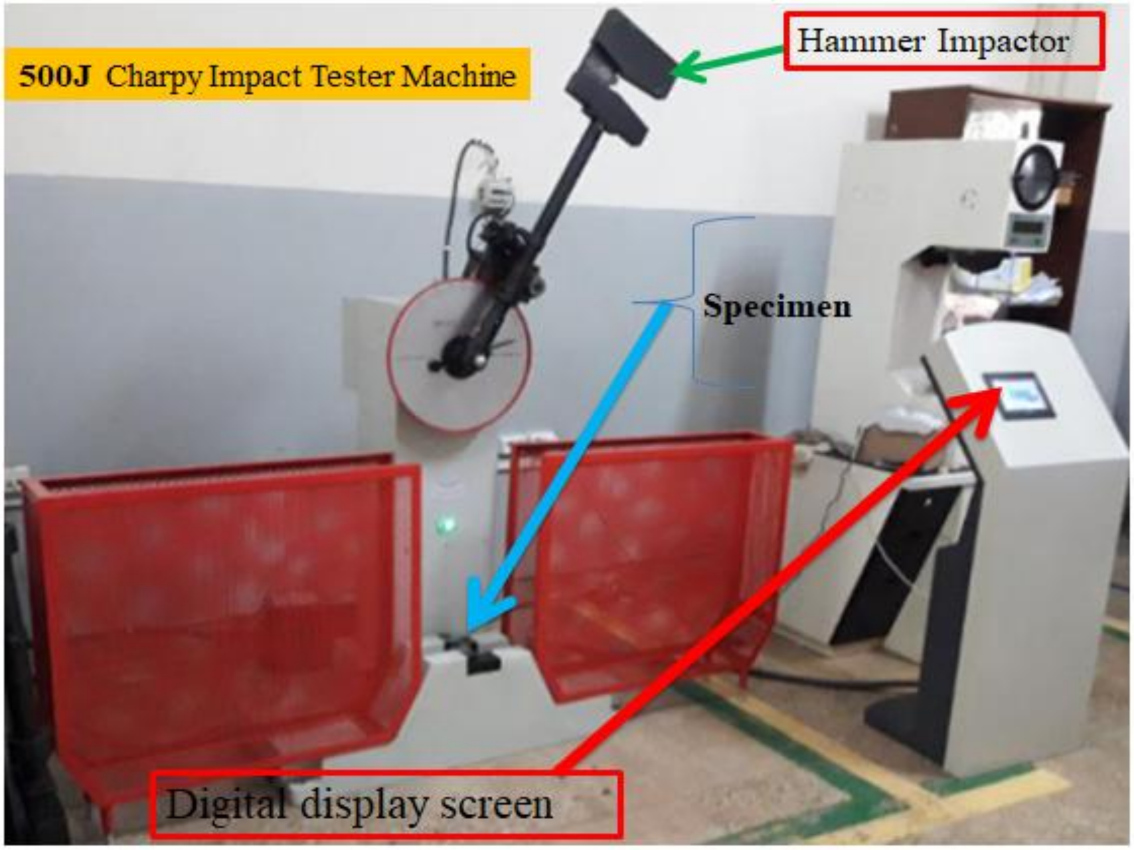



**Fig. 6** Experimental setup of the Charpy impact testing machine(S-500 J Impact Tester Machine, Made in China).

### 2.4.2 Hardness Test

Hardness is generally considered as resistance to penetration. The harder the materials, the greater the resistance to penetration. Hardness is directly related to the mechanical properties of the material. Factors influencing hardness include microstructure, grain size, strain hardening, etc. Principally, the importance of hardness testing has to do with the relationship between hardness and other properties of the material. For example, both the hardness test and the bending test measure the resistance of a material to plastic flow. ASTM D785 was adopted to conduct hardness testing in tropical locations (Amuthakkannan et al., 2013:Harati Khalilabad et al., 2023). Each specimen was given three hardness ratings, with the average being computed. The ASTM D785 standard sample is done in the size of (30×30×6) mm (Belagavi et al., 2019; Tirupathi et al., 2022). **Fig. 7** shows the experimental setup of the hardness test. For this work, the Rockwell hardness tester was used.

In the Rockwell test, a diamond cone or a hard steel ball is employed as the indenter depending on the hardness of the materials. Diamond cone or Brale indenter with a cone angle of 1200 is used to test hard materials and balls of sizes between 1.6 mm (1/16") and 12.7 mm (1/2") are used in testing softer materials. Rockwell tests differ from other indentation hardness tests in that the depth of indentation determines the hardness rather than the indentation size. All the specifications of the Rockwell hardness test are listed here in

Table 4.

| Scale | Indenter Type | Major Load (kg) | Typical Applications |
|---|---|---|---|
| A | Diamond Brale | 60 | Tool Materials |
| D | Diamond Brale | 100 | Cast Irons, Sheet Steel |
| C | Diamond Brale | 150 | Hardened steels and cast irons, Ti |
| B | 1/16" Dia. Ball | 100 | Annealed steels, Cu and Al alloys |
| E | 1/8" Dia. Ball | 100 | Al and Mg, reinforced polymers |
| F | 1/16" Dia. Ball | 60 | Soft sintered products |
| M | 1/4" Di.Ball | 100 | Very soft metals, polymers |
| R | 1/2" Dia. Ball | 60 | Very soft metals, polymers |

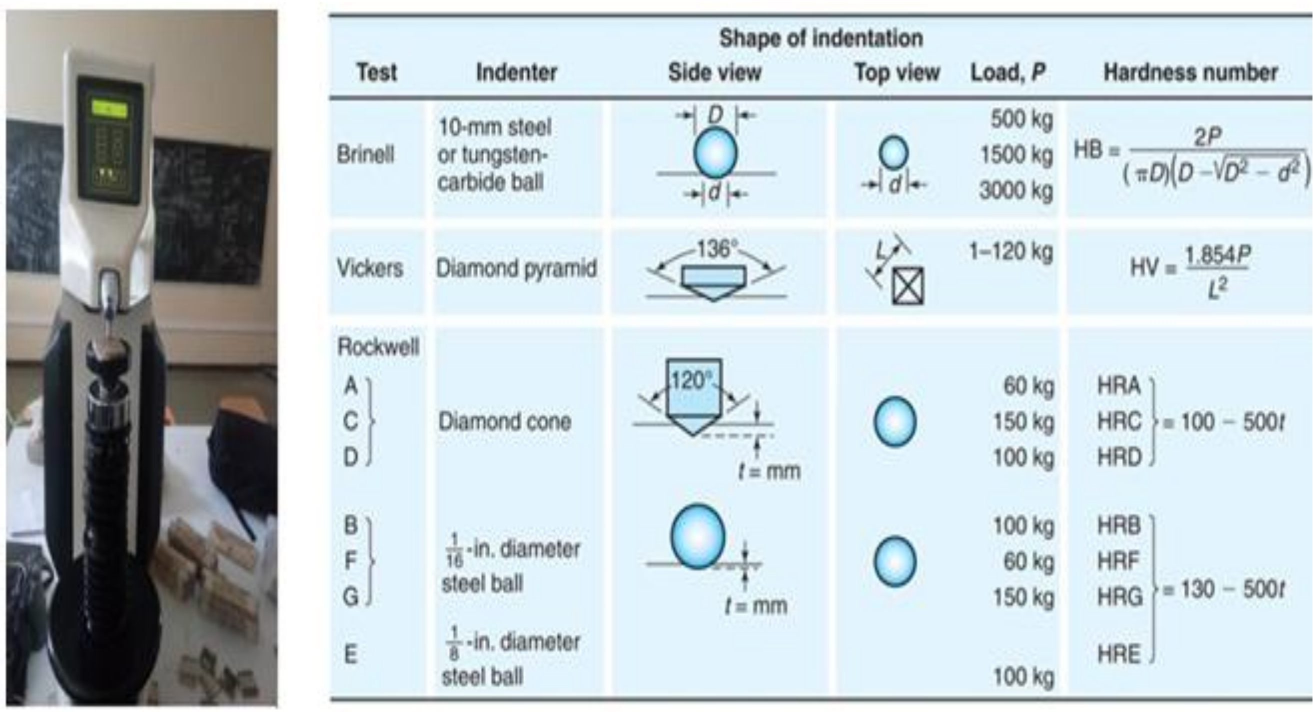
**Table 4**: Commonly used Rockwell hardness scales[32].

| Scale | Indenter Type | Major Load (kg) | Typical Applications |
|---|---|---|---|
| A | Diamond Brale | 60 | Tool Materials |
| D | Diamond Brale | 100 | Cast Irons, Sheet Steel |
| C | Diamond Brale | 150 | Hardened steels and cast irons, Ti |
| B | 1/16" Dia. Ball | 100 | Annealed steels, Cu and Al alloys |
| E | 1/8" Dia. Ball | 100 | Al and Mg, reinforced polymers |
| F | 1/16" Dia. Ball | 60 | Soft sintered products |
| M | 1/4" Di.Ball | 100 | Very soft metals, polymers |
| R | 1/2" Dia. Ball | 60 | Very soft metals, polymers |

So as indicated in

Table 4 above, for this experimental work the “E” scale, 1/8" Diameter Ball indenter type with a major load of 100 kg had been used. The reseaon why that for composite materials test recommended this scale of test.

| Scale | Indenter Type | Major Load (kg) | Typical Applications |
|---|---|---|---|
| A | Diamond Brale | 60 | Tool Materials |
| D | Diamond Brale | 100 | Cast Irons, Sheet Steel |
| C | Diamond Brale | 150 | Hardened steels and cast irons, Ti |
| B | 1/16" Dia. Ball | 100 | Annealed steels, Cu and Al alloys |
| E | 1/8" Dia. Ball | 100 | Al and Mg, reinforced polymers |
| F | 1/16" Dia. Ball | 60 | Soft sintered products |
| M | 1/4" Di.Ball | 100 | Very soft metals, polymers |
| R | 1/2" Dia. Ball | 60 | Very soft metals, polymers |



| Test | Indenter | Shape of indentation: Side view | Shape of indentation: Top view | Load, P | Hardness number |
|---|---|---|---|---|---|
| Brinell | 10-mm steel or tungsten-carbide ball | D, d | d | 500 kg<br>1500 kg<br>3000 kg | $HB = \frac{2P}{(\pi D)(D - \sqrt{D^2 - d^2})}$ |
| Vickers | Diamond pyramid | 136° | L | 1–120 kg | $HV = \frac{1.854P}{L^2}$ |
| Rockwell A, C, D | Diamond cone | 120°, t = mm | | 60 kg<br>150 kg<br>100 kg | HRA, HRC, HRD = 100 − 500t |
| B, F, G | $\frac{1}{16}$-in. diameter steel ball | t = mm | | 100 kg<br>60 kg<br>150 kg | HRB, HRF, HRG = 130 − 500t |
| E | $\frac{1}{8}$-in. diameter steel ball | | | 100 kg | HRE = 130 − 500t |

**Fig. 7.** Experimental setup of hardness test and the general characteristics of hardness testing methods and calculating hardness (Digital Hardness tester Machine, made in China).

## 3. Results and Discussion

### 3.1 Impact Test Result

The test was performed using the Charpy impact testing machine JB S-500B with the capacity of a 500J model at the Bahir Dar Institute of Technology lab. The maximum and the minimum average values of energy observation and toughness properties of the sample specimen are shown in the Fig.8.

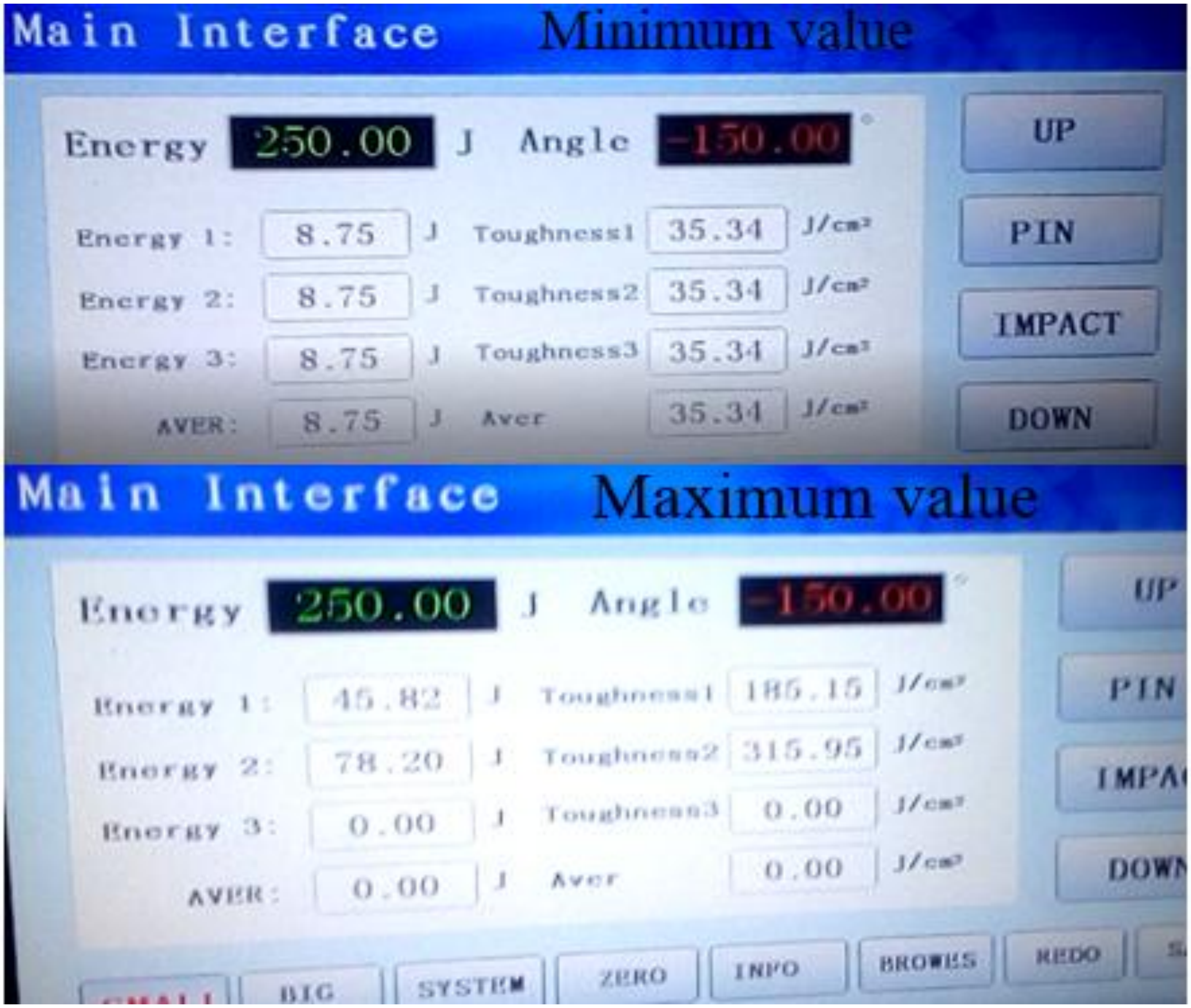


**Fig. 8** Digital display of the tester machine

The maximum toughness value of the sample specimen was 315.95 J/cm$^2$ and its minimum value recorded was about 35.34 J/cm$^2$. Also, the maximum value of the material's energy observation or external load resistance is about 78.20 J/cm$^2$ and the minimum energy observation value is 8.75 J/cm$^2$. Each test value of the experiment is listed in Table 5.

**Table 5** Experimental test results of the Impact test(T1 = test 1, T2 = test 2, T3 = test 3).

| Reinforcing orientation | Impact test Results of observed energy and Toughness | | | | |
|---|---|---|---|---|---|
| | Maximum Observed Energy (J) | | | | Toughness (J/cm$^2$) |
| | T1 | T2 | T3 | Avg. | Avg. Toughness |
| CCCC | 8.82 | 8.76 | 8.67 | 8.75 | 35.34 |
| CGCG | 37.32 | 36.94 | 37.01 | 37.09 | 149.80 |
| CGGC | 58.00 | 57.8 | 57.95 | 57.92 | 233.92 |
| GCCG | 44.67 | 46.08 | 46.71 | 45.82 | 185.15 |
| GGGG | 78.03 | 79.98 | 79.81 | 78.20 | 315.95 |

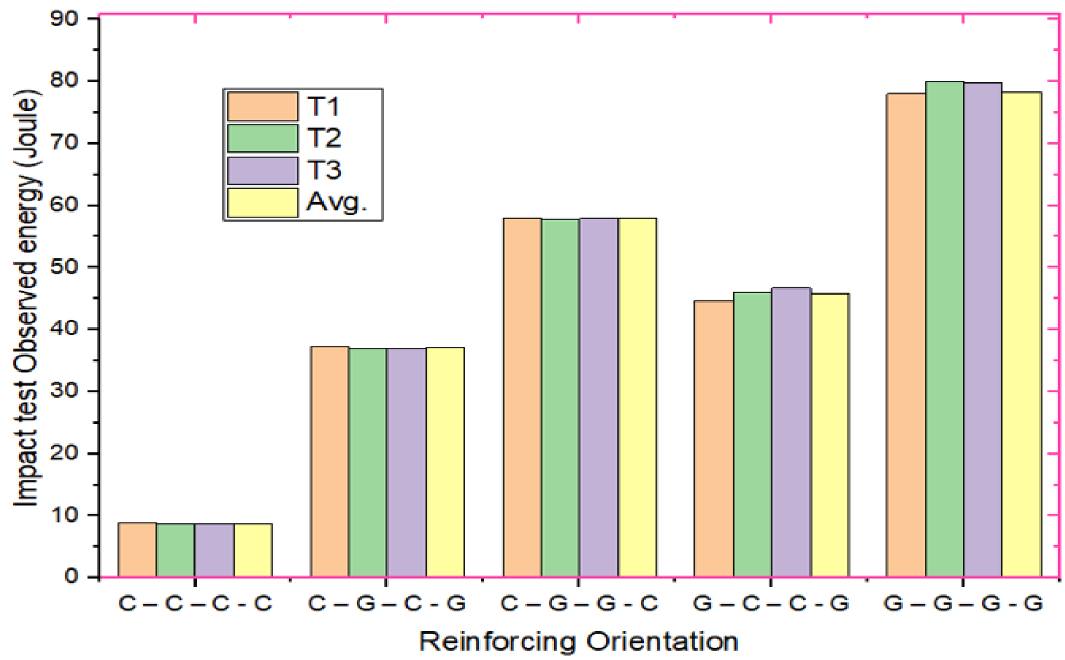



**Fig. 9** Impact test Maximum Energy observation of the composite material.

Fig. 9 shows the results of the impact test in terms of the observed energy absorbed by different reinforcing orientations of the composite specimens. The specimens were tested under Charpy impact loading, and the results are presented for three trials (T1, T2, T3) along with their average (Avg.). It can be observed that the reinforcing orientation significantly affects the impact resistance. The configuration with all garment waste fiber orientation (G–G–G–G) exhibited the highest energy absorption (around 80 J), indicating superior impact strength compared to the other orientations. In contrast, the all-cotton orientation (C–C–C–C) showed the lowest energy absorption (below 10 J), highlighting its weaker resistance to impact loads. The hybrid orientations, such as C–G–C–G and C–G–G–C, displayed intermediate performance, demonstrating that combining garment waste fibers with cotton fibers enhances toughness compared to pure cotton reinforcement. The consistency of results across T1, T2, and T3 (with minimal variation) further validates the reliability of the data. Overall, the figure illustrates that increasing the proportion of garment waste fiber reinforcement improves the energy absorption capacity of the composite.

### 3.2 Hardness Test Result

The hardness Test was conducted using a Rockwell Hardness tester digital machine under the E Scale of a 100kg load from the standard Rockwell value of 60kg, 100kg, and 150kg with diamond tip intender as discussed above.

**Table 6** Experimental test results of Rockwell hardness test HRA scale E (100 kg).

| Reinforcing orientation | Rockwell Hardness test result HRA scale(100 kg) | | | | | |
|---|---|---|---|---|---|---|
| | T1 | T2 | T3 | T4 | T5 | Avg. |
| CCCC | 36.78 | 41.00 | 40.50 | 41.00 | 40.89 | 40.03 |
| CGCG | 68.32 | 76.00 | 71.50 | 73.6 | 69.85 | 71.85 |
| CGGC | 98.00 | 96.80 | 102.35 | 93.9 | 98.50 | 97.91 |
| GCCG | 83.67 | 86.00 | 90.53 | 87.00 | 87.20 | 86.88 |
| GGGG | 96.00 | 103.2 | 106.00 | 104.3 | 96.50 | 101.2 |

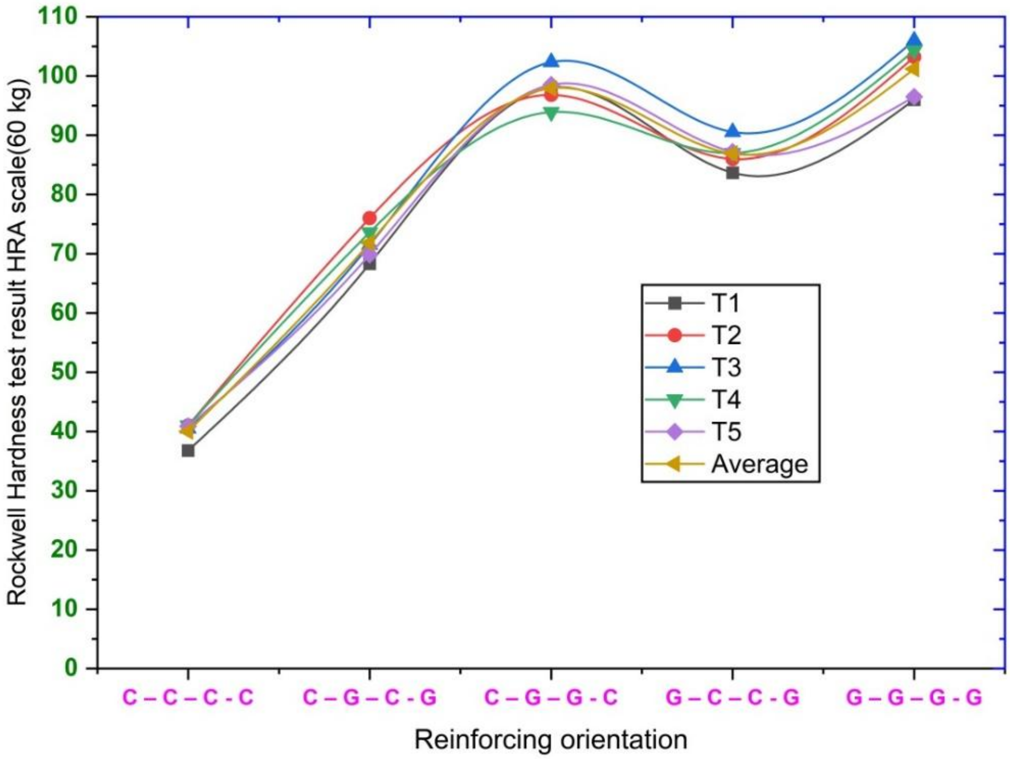



**Fig. 10** Experimental test result of hardness property of the composite sample ( where T1, T2, T3, T4, and T5 = trail test 1, 2, 3, 4, & 5).

According to the graph in Figure 10, the maximum energy observation ability of the composite was obtained at 59%P-39%C-2%H(P = polyester matrix, C = cotton rag, and H = hardener)wt. concentration with G-G-G-G orientation and minimum value of the energy observation property also obtained at the same weight concentration with C-C-C-C orientation. the hardness property also shows maximum values of the material's strength at G-G-G-G orientation with the same weight concentration of the impact test. This happened because the maximum value was obtained due to the better matrix formation between the fiber and the polyester resin, the strong internal microstructure, and bond strength. The minimum value obtained is due to the smallest bonding strength value of matrix content and fiber. During this time the composite showed lower surface smoothness, high surface scratch, internal porosity, and lower internal microstructure bond strength.

## 4. Conclusion

This study experimentally investigated the impact and hardness properties of polyester matrix composites reinforced with cotton fabric and garment waste fibers. The findings confirm that textile waste, when properly processed, can be transformed into high-performance composites with significant structural potential. Among the tested orientations, the GGGG configuration demonstrated the highest impact strength (78.20 J) and hardness value (101.2 HRA), whereas the CCCC orientation showed the lowest performance. This clearly indicates that garment waste fibers provide superior reinforcement compared to cotton rags, enhancing matrix bonding and improving overall mechanical properties.

Beyond the mechanical improvements, the study underscores the environmental and economic importance of valorizing textile waste. Converting discarded fabrics into functional composite materials not only reduces environmental pollution but also supports circular economy principles by generating value-added products from waste streams. Such composites show promising applicability in automotive, construction, and other structural fields, particularly in components that require energy absorption and durability.

For broader application and industrial adoption, future research should focus on exploring additional mechanical properties, such as tensile and flexural strength, as well as thermal and chemical resistance. Investigating surface treatments, hybrid reinforcements, and scalability of the fabrication process will also be critical in advancing these composites toward commercial viability. In conclusion, this work demonstrates that fabric waste is not merely an environmental burden but a valuable engineering resource. With continued innovation, waste-derived composites could play a pivotal role in sustainable materials engineering and eco-friendly product development.

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