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From Waste to Innovation: A Review on Textile Waste-Based Composite Materials

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ABSTRACT

The continuous acceleration of the textile industry, fueled by fast fashion and global demand, has led to the generation of millions of tons of textile waste throughout the world. Eventually, these textile wastes are dumped into the landfill or incinerated, which causes air, water, and soil pollution. Due to this issue, serious consequences for public health and the environment are arising. Considering this global environmental crisis, this review dives into the possibility of using textile waste in order to produce composite materials. This paper highlights various types and sources of textile wastes, followed by a detailed overview of several manufacturing methods such as compression molding, vacuum bag molding, and injection molding. The developed materials were further characterized for their mechanical, thermal, and acoustic behaviors. Results from different studies report that waste-based composites can exhibit high strength, good ductility, thermal insulation, and sound absorption properties. The alternative materials presented showcase tremendous potential across multiple industries, including automotive, construction, furniture, and electronics. Producing quality alternative materials from textile waste is an approach that supports the principles of the circular economy and promotes sustainable development. The review accentuates the significance of continuous research and innovation in the process of transforming textile waste into useful resources through eco-friendly and cost-effective solutions.

Keywords: Textile Waste, Composite Materials, Sustainable Development.

1 Introduction

Textiles play a key part of our everyday life. Starting from clothing, which is one of the basic needs of any human being besides food and shelter. It covers our body, provides protection from dusts and rough environment, and helps us to survive in different weather. As its necessity is unavoidable, the demand for textile-based products has sky-rocketed over the decades because of the increasing population rate and socio-economic changes [1]. To keep up with this massive demand the textile industry has expanded significantly and it provides a major impact in the global economy. In 2002, the global market for commercial textiles was valued at $400 billion, or 6% of global trade [2], [3]. Among other countries China, Bangladesh and India produces and exports the highest amount of apparel in all over the world. In terms of production capacity, quality, and growth [4], Bangladesh is the world's second-largest supplier of ready-made clothing, after China [5], [6]. Beyond meeting global demand, this industry plays a crucial role in boosting the economy of developing countries like Bangladesh by creating a vast number of direct and indirect jobs, significantly contributing to national poverty reduction [7].

Despite these economic successes, the textile sector still faces a significant obstacle which is the growing amount of waste produced. Due to rapid growth of globalization, new fashion trends are appearing regularly and dresses are becoming old quicker than ever before. Consumer preferences continue to shift towards rapidly changing fashion trends and this 'fast fashion' culture increased the overall textile consumption rate leading to massive rise in textile waste generation [8], [9]. Every year countries like USA, UK, Brazil and many European nations generate millions of tons of textile wastes. Around 21 billion tons of municipal solid textile waste are being produced annually by the USA and almost 0.3 million tons of used textile go to the landfill in the UK. The European textile industry generates approximately 16 million tons of fabric wastes per year and this amount for Brazil is 0.175 million tons per year [10], [11]. It is predicted that by 2030 the total amount textile waste will be 148 million tons globally or 17.5 kg per person annually. Moreover, in 2050 more than 150 million tons of waste fabric textiles would be landfilled or burned [12].

These numbers will keep growing until practical and economical methods to reduce waste generation or close the loop that converts waste into new products are found [13]. Material waste management is becoming a major challenge because of its direct effects on the environment [14], [15]. Because of the consequences for both the environment and human health, open dumping and landfilling of waste have grown more serious [16]. Resource recovery and environmental protection have received little to no attention, and waste management in developing countries is usually restricted to collection and removal services [17]. Shifting from landfill-based disposal to resource recovery-based solutions requires a clear understanding of waste composition and the implementation of effective waste collection and characterization processes [18], [19]. However, there remains a significant knowledge gap regarding the volume of waste generated by the textiles and apparel manufacturing industry, which must be addressed to enable sustainable waste utilization within the circular economy [20].

The idea of the circular economy is viewed as a crucial first step in enhancing sustainability in the textile sector [21]. Optimizing resource flows and repeatedly circulating them in a closed loop reduces the need for virgin materials and resources, which is the core of a circular economy [22], [23]. However, from an economic standpoint, recycling fabric waste is still not recognized as the most practical way for circulating materials because landfilling and waste-to-energy have been shown to be significantly more economical solutions. Because synthetic materials are highly flammable and emit a lot of heat when burned, they are ideal for incineration [24]. However, achieving a true circular economy is not possible if textile waste is merely used for energy recovery [25]. Instead, it must be reintegrated into the manufacturing cycle through recycling or remanufacturing. Landfilling and incineration not only contribute to environmental pollution but also result in the loss of valuable resources [26].

To address this growing challenge, researchers are increasingly exploring ways to repurpose textile waste into valuable materials, particularly in the development of composite materials. By integrating textile waste fibers into composites, it is possible to create sustainable, high-performance materials for various industries. This review aims to explore the potential of textile waste in composite fabrication, examining its types, manufacturing techniques, and mechanical properties.

2 Methodology of Literature Review

This review employed a systematic approach to identify, select, and analyze relevant studies related to textile waste utilization in composite material fabrication. It was intended to ensure that information included is comprehensive, up-to-date, and scientifically relevant. The overall methodology consists of few sections.

2.1 Literature Search Strategy

An extensive search was conducted in peer-reviewed journals, conference proceedings, and reputable databases from January 2010 to March 2025. Besides, the following databases were consulted: ScienceDirect, Scopus, SpringerLink, Taylor & Francis Online, and Google Scholar. The search has been performed by combining the keywords and Boolean operators: "textile waste" AND "composite materials", "fiber recycling" AND "sustainable composites", "waste textile fibers" AND "mechanical properties", and "eco-friendly materials" AND "circular economy". Then, in order to ensure the completeness of this review, further studies were retrieved after examining the reference lists of the selected papers.

2.2 Inclusion and Exclusion Criteria

The studies for this review have been selected based on clearly defined inclusion and exclusion criteria for relevance and quality. Accordingly, the included studies focused on composites fabricated from either pre-consumer or post-consumer textile waste, reported the mechanical, thermal, acoustic, or physical properties of developed materials, and discussed manufacturing techniques such as compression molding, vacuum bag molding, injection molding, and hand lay-up. Further, the studies included were those published in English and that appeared in peer-reviewed journals or reputable conference proceedings. The non-English publications, review articles without any experimental or analytical data, and studies related exclusively to textile waste management without composite applications have been excluded.

2.3 Data Extraction and Organization

The publications selected were further analyzed and logically organized with respect to the type of textile waste used, namely, natural, synthetic, or hybrid fibers, the employed fabrication process, and the imparted material properties under study, such as mechanical strength, thermal insulation, and acoustic performance. The findings of each study were tabulated to outline trends, material combinations, and process–property relationships. These data were further synthesized in order to enable comparisons with conventional composite materials, emphasizing similarities and performance advantages of textile waste-based composites.

2.4 Quality Assessment and Synthesis

Preference was given to those with clear experimental procedures, validated testing standards such as ASTM/ISO, and quantitative results. Consideration was also given to research gaps, emerging technologies, and potential industrial scalability. Critical analysis of the literature will focus on extracting information not just at a descriptive level but also at a comparative level concerning fabrication efficiency, mechanical performance, and environmental impact. This approach ensures that the review offers both breadth and analytical depth necessary to underpin future research in sustainable composite materials.

3 Textile Waste

Textile waste can generate in many ways ranging from fiber producers to end-users but the main sources can be classified into two major categories, pre-consumer/ post-industrial waste (PCPIW) and post-consumer waste (PCW) [27], [28].

PCPIW is the type of waste that develops during the manufacturing processes in the textile industries, which includes short fibers, yarn waste, rejected fabric due to production error, garment cutting waste, scraps, and end lots from surplus production [29], [30]. In a woven and knit factory, the fabric checking department eliminates defective fabrics, those that fail chemical tests, and leftover samples from the development stage. In the cutting department fabrics thrown after cutting as per given pattern and clothing gets rejected while line inspection in the sewing department [31]. In this way various type of factory generates a significant number of textile waste from each department, as shown in In general, textile wastes consist of fibrous natural and synthetic polymeric materials like cotton, wool, silk, polyester, nylon, polypropylene etc. [11]. Some new materials, non-woven structures and composite materials, composed with textile wastes like cotton, leather, polyester, EVA, and wool features acoustics and/or thermal isolation capabilities.

Table 1. A study approximated that during the production processes, in a range from 10-12% to as high as 25-30% of textiles are wasted [32]. PCPIW is referred as virgin or clean waste because the material is thrown away before any use [33]. Thus, PCPIW can offer high quality fibers, but if they are collected near the end of material's life, they will exhibit lower fiber quality [34].

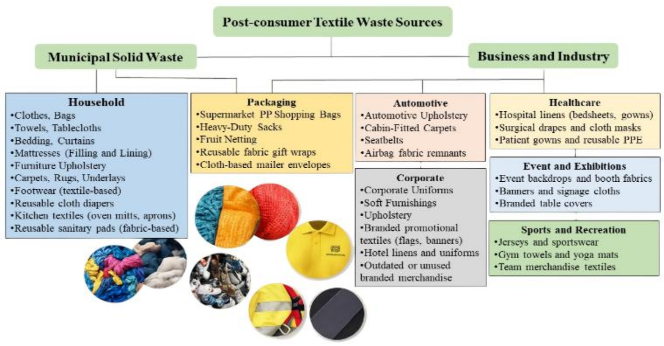

Fig. 1 Common post-consumer textile waste stream [36]

Majority of the post-consumer waste (PCW) comes from the household. Fibrous products that are thrown away after their service life are referred to as post-consumer waste. The amount of waste generated after consumption is significant and is similar to the rate of fiber consumption [11]. This includes the items that no longer in use due to wear, damage, out of fashion or any other issues in the product, which leads to discarding these products. At the time of discarding the clothes, it is estimated that over 70% of their usable life is still there [35].

In general, textile wastes consist of fibrous natural and synthetic polymeric materials like cotton, wool, silk, polyester, nylon, polypropylene etc. [11]. Some new materials, non-woven structures and composite materials, composed with textile wastes like cotton, leather, polyester, EVA, and wool features acoustics and/or thermal isolation capabilities.

Table 1 Sources of textile waste from production chain in a garments factory [29], [31], [37]

Factory/ Department	**Type of Waste**
Spinning	Cotton lint, damaged yarn, unfinished cones
Apparel	Fabric cut pieces (cutting waste), excess development samples, excess apparel
Knitting/ weaving	Fly fiber, scrap yarn, greige/unfinished fabric
Wet processing	Rejected colored fabric, excess finished fabric
Sweater	Damaged panels, Wastage Yarn from auto knitting and winding, rejected body
Carpet mill	Needle felt, tufted carpet, cut waste, coated, uncoated
Fabric Checking	Defected fabrics, fabrics not passed in chemical test, fabric leftover from sample development stage
Sewing	Garments rejected in line inspection.
Dyeing, Finishing and Warehouse	Old stock finished fabric, old stock gray fabric, Rejected colored fabric, excess finished fabric

4 Composite Manufacturing Processes

Textile wastes can be used as fibers and utilized to create composite materials by applying enough heat and pressure. One way is to convert the textile waste into non-woven or else, using it directly as it is. Several layers of fibers and mixtures are used during composite production and polymers are frequently used as binders [35]. In the past, composite materials were produced manually by hand [38], [39]. As the availability of advance technology increased with growing demand, semi-automated and automated techniques started taking its place gradually. In the current century, closed mold processes are getting popular due to their accuracy, higher precision and productivity [40], [41]. Compression Molding (CM), Vacuum Infusion (VI) or Vacuum Bag Molding (VBM) are common processes to manufacture composite materials from textile wastes. In some cases, Thermoforming (TF), custom made Single Screw Extruder (SSE) and hand lay-up method is also used [42] - [44]. In this section different ways of producing composite materials with waste textile fibers will be discussed.

4.1 Compression Molding

CM is one of the oldest and simplest approach for producing polymer composite materials. In this method, both thermosetting, thermoplastic or fibrous materials can be used as matrix [45]. The apparatus consists of heated dies and big tonnage press. There are two mold sections, upper and lower, and the charge (deformable fibers and matrix of the composite) is put in between these mold section. Then the upper section which is heated, used to press the charge with high pressure to acquire the desired shape of the mold cavity [46]. This process can be easily automated and waste free production of complicated geometries is possible [34]. CM process is better than vacuum assisted resin infusion technique for fabricating composite panels using multilayer fiber waste as it is difficult to assure proper fiber orientation during resin infusion. Any modification in fiber orientation will lead to change in mechanical properties of the composite [47]. A schematic setup for CM technique is shown in Fig. 2.

In a study, Kamble et al. converted the cotton shoddy, obtained from textile waste, into multilayer carded fiber web on a roller carding machine. Since the fiber orientation is dependent on the cylinder speed of roller carding machine, multiple samples were prepared by varying the speed. Epoxy resin along with hardener and curing agent were used as matrix. By changing the fiber volume fractions (0.1, 0.2, 0.3 and 0.4) composite samples were produced [48]. Further study by Kamble et al. incorporates graphite oxide nano fillers into the epoxy resin matrix and generate composite specimens by compression molding method. Here the optimized cylindrical speed (200 rpm) of roller carding machine was used to produce the fiber carded web [9]. In another study Kamble et al. investigated the effect of reduced graphene oxide (rGO) nanoparticles and enzyme-treated hemp fiber (HF) fillers on the properties of green composites formed by CM method [49]. Kamble et al. developed a hybrid composite where multilayer carded web cotton fibers, jute nonwoven fabric and unidirectional glass fiber were used as reinforcement. Epoxy resin was used as matrix and by varying the weight percentage of the fibers several sustainable composite specimens were prepared [50].

Mishra et al. utilized CM process to form green composites using different percentage of polypropylene (PP) fiber and waste cotton fiber along with polypropylene resin matrix. The effect of moisture and different areal mass on the tensile properties of the sample were measured besides other mechanical properties [51]. Muthuraj et al. used textile waste fibers along with other industrial wastes such as, rice husks, wheat husks, and wood fibers to develop sustainable bio-composites [52]. Gómez et al. utilized scrap denim and polypropylene (PP) to develop composite specimens of different configurations. A hydraulic hot press machine was used to perform the CM process [53]. Ramamoorthy et al. developed three types of composite structure using cotton/polyester fabric blend. Soybean oil based thermoset resin and thermoplastic bicomponent fiber were used as matrix. The variation in properties with change in the processing parameters were recorded in all three cases [54]. Al Mahmud et al. incorporated coconut shell powder with epoxy resin and hardener. Upcycled fabrics were utilized and the specimens were prepared by CM technique [55].

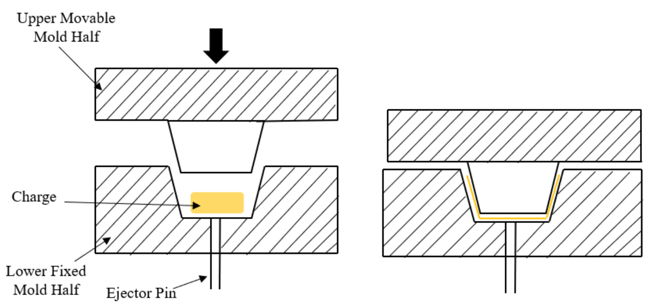

Fig. 2 Compression molding process

Barbanera et al. reported the potential of composite boards made out of finished leather scrap and polyvinylacetate binder (PVA). A hydraulic press was used to fabricate the boards. Thermal and acoustic performance, thermal stability, hygrothermal, wettability and ignitability properties were tested [56]. Juciene et al. fabricated composite panels using ecofriendly, corn starch, binder and denim fabric waste. A 1:1 waste fiber to binder ratio was maintained. By varying the preparation method of raw materials two sample were made [57]. Rubino et al. reported about the development of a sound absorbing, eco-friendly composite material which is fabricated by utilizing 100% wool fiber extracted from textile waste. Gum Arabic (from vegetable resources) and chitosan (from animal resources) were used as two different binders [58]

Rajkumar et al. transformed silk selvedge waste into silk fiber and developed a silk/wool hybrid fiber polypropylene composite by compression molding technique. Several samples were fabricated by varying the silk/wool/polypropylene proportion in the composite [59]. In another study, Dissanayake et al. produced composite panels by utilizing cotton/polyester mixed waste fibers and natural rubber as a bonding agent. A variety of samples were developed by altering the compression molding processing parameters (temperature, pressure and panel thickness) [60]. Kim et al. developed PP/cotton fiber and PP/wood fiber composites by CM process and compared their mechanical properties. Additionally, the impact of the melt index (MI) of PP on the composites mechanical characteristics was examined [61]

4.2 Vacuum Bag Molding

Vacuum bag molding, also commonly known as vacuum infusion molding and vacuum assisted resin transfer molding (VARTM), is another common technique of fabricating composite materials. It uses vacuum pressure to ensure resin flow into a laminate [62]. Dried materials are laid into the gel-coated mold surface and a perforated release film is used to cover the dry reinforcement. The dry materials compacted by the influence of vacuum pressure. After generating a full vacuum condition, the resin is guided into the dry materials through carefully placed tubing. Vacuum bag molding (see Fig. 3) enables significant emission reduction and provides excellent mechanical properties to the manufactured material [63].

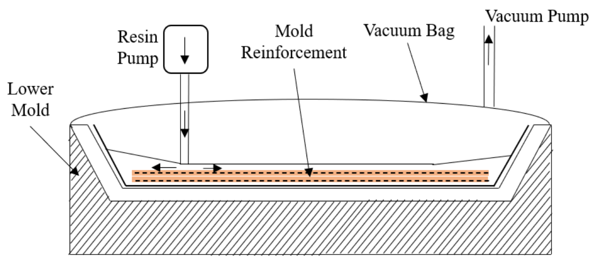

Fig. 3 Vacuum Bag Molding Process

Baccouch et al. used 100% post-industrial cotton waste as reinforcement and epoxy resin with hardener was utilized as a matrix system. The cotton wastes were shredded into fibers and by carding and needle punching process they were converted into non-woven mats. After pretreatment the panels were fabricated by VARTM method. Vacuum pump is utilized to ensure proper elimination of air gaps and a uniform distribution of resin matrix. Multiple samples were prepared varying the soaking time during pre-treatment [64]. Xu et al. prepared ramie fabric fiber/ epoxy resin composite panels through hot compaction and vacuum pressure infusion molding processes. Several samples were prepared by modifying ramie fabric fiber through different surface treatment. More than 0.095KPa vacuum pressure was applied and compacted the panel for 15min. Instead of vacuum infusion molding process, hot compaction process was more effective with increasing fiber content [65]

In another study, 100% cotton fibers extracted from denim, ~60/40% cotton/ polyester fibers and ~90% polyester fibers were used as reinforcement to form three groups of samples. Vacuum bag molding process was used to ensure the epoxy resin matrices flow and manufacture the composite laminates. The entire procedure is carried out at room temperature with 1 bar of pressure, and the created panel is allowed to cure for 24 hours mechanical, thermal and acoustic behavior of these samples were investigated later on [8].

Karahan et al. developed hybrid green composites using different percentage of waste cotton, jute and glass fabric as reinforcement with an areal density of 200, 270, 250 g/m^2 respectively. Thermosetting unsaturated polyester resin was used as matrix along with, cobalt naphthalene (hardener) and poly-ethyl-ether ketone (accelerator). Total seven samples were prepared having different fraction of cotton, jute, and glass using the vacuum bag molding technique and 30% fiber volume fraction was maintained [66]. In another investigation, Meng et al. produced high-performance composite panels by VARTM using denim fabric waste with epoxy resin matrix. The epoxy resin, improved methyl tetrahydro phthalic anhydride (hardener) and tertiary amine (accelerator) were combined into a mix by weight ratio of 100:85:1. A vacuum pressure of 0.3 MPa was maintained and a three-step cure cycle, first step (2 h at 90°C), second step (1 h at 110°C) and final step (6 h at 135°C), was followed [67]. Umar et al. fabricated total eight composite samples using cotton fiber sourced from comber noil waste from spinning and the knitting waste. As a matrix, mixture of unsaturated polyester resin, hardener (0.1%) and accelerator (1%) were used. During the vacuum bag molding process a vacuum pressure of -1bar was maintained. There were eight reinforcement layers in the laminated composites placed in the following order: $[+45/90/0/-45]_s$ [68].

Özen et al. collected different types of fibers from fabric wastes such as, Tencel, hemp, modal, micro-modal and viscose. These fibers were used as reinforcement and epoxy resin matrix were used for the fabrication of composite panels. Multiple set samples were produced using the VARTM technique and their mechanical properties were determined [69]. Further study by Masood et al. illustrates the variation in mechanical properties of hybrid composite panels with the change in the fraction of jute, glass and cotton fiber (extracted from textile wastes). Total seven numbers of samples were prepared using vacuum bag molding process, each having six layers of the reinforcement. A vacuum pressure of -1bar was applied and a constant volume fraction of 30% was maintained [70]

4.3 Injection Molding

In injection molding (IM) process, a predetermined amount of fiber and molten polymer are combined and pushed through a mold cavity. Both thermoplastics and thermoset polymers can be utilized in the injection molding process, although the thermoset procedure is challenging to carry out [71], [72]. Deringer er al. reported the process parameters (curing time, curing temperature, injection pressure, and injection torque) for thermosets [73]. On the other hand, it is simpler to fabricate thermoplastic polymer-based composite using IM technique [74]. Chopped fiber and tiny pellets of thermoplastic polymer are combined and fed into a hopper. A revolving screw (single screw extruder or twin-screw extruder) moves the material through a melting section at high temperatures and high pressures. The high temperature melts the materials, turning into a viscous fluid. Finally, due to high pressure it passes through a sprue nozzle into the mold cavity. The product gets removed from the mold cavities once it has solidified. The necessary shear force is produced by the screw-type extruder [46].

Dobircau et al. used waste cotton fiber reinforcement and wheat flour based thermoplastic matrix to develop new, completely eco-friendly composite materials. A single screw extrusion machine was use during the production of the specimen and the fiber composition of the composite was ranged from 0% to 15% w/w. The influence of fiber content on the mechanical and thermal characteristics of the composite was investigated [76].

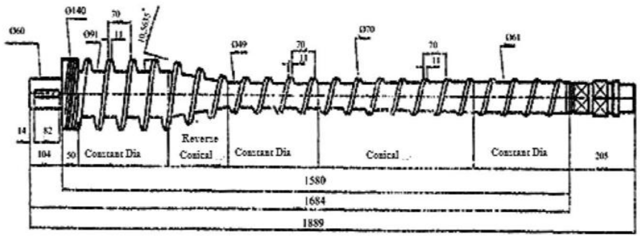

Fig. 4 Single screw extruder [75]

Bodur et al. developed a glass fiber/waste cotton fabric reinforced hybrid composite using a custom-made single screw extruder (see Fig. 4). Low density polyethylene (LDPE) was used as matrix and several samples were prepared by altering the wt.% of glass fiber, cotton fiber and LDPE. The sample preparation process consists of numerous rounds of extrusion and grinding. The sample preparation process flow is shown in Fig. 5 [77].

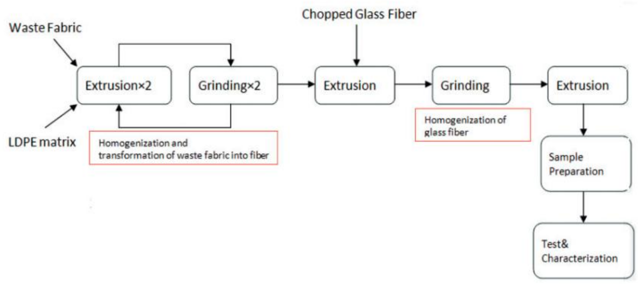

Fig. 5 Schematic diagram of manufacturing process of hybrid composites [77]

Petrucci et al. studied the morphological, tensile and fatigue characteristics of cotton/polypropylene composite laminates which were produced by injection molding technique. A twin-screw extruder was used during this process [78]. Bateman and Wu, used a single screw bench top extruder and utilized carpet fibers to LDPE. Four types of compatibilizers were used during the processing of polymer blends to enhance the performance of the final product. The change in mechanical property with alteration of carpet fiber percentage has been recorded in this study [79]. Bakkal et al. fabricated cotton waste/LDPE composite panels using a custom-made single screw extruder. To investigate the consequences of processing repetition on the mechanical and rheological characteristics of plates, two distinct waste fabric reinforced composite plates with 12.5 wt.% and 25 wt.% fibers were created and reprocessed six times. Tensile and impact tests, in addition to SEM, DSC, XRD, and MFI rheological and characterization analysis, were used to assess the effects of reprocessing [80].

4.4 Hand Lay-up

Hand lay-up is one of the simplest open mold manufacturing techniques available which is also older compared to other methods [81]. This technique offers a wide range of size of products. Long and continuous natural, glass or carbon fiber composite materials can be derived easily by this method [38]. The fiber orientation can be varied in different directions like, unidirectional, inclined or woven. This method for creating hybrid composites has gained a lot of interest in the composites sector due to their tolerance to various stressors and lack of directional dependency [82]. During fabrication the first step is to apply an antiadhesive agent layer at the mold surface to avoid polymer sticking and to make it easier to remove [83] A plastic sheet is positioned at the top and bottom section of the mold plate to create a smooth surface [84]. The bottom mold surface is then covered with a gel coat of matrix material, and the fiber, which has been chemically treated and oriented in different directions, is immediately placed on the coat. A roller is used to apply pressure and remove trapped air bubbles. In order to guarantee a stronger interfacial bond, fiber, matrix, or both must be mixed with other substances [85]. The hardened product is taken out of the mold cavity once the base material has completely dried [86]. A schematic diagram for hand lay-up method is shown in Fig. 6.

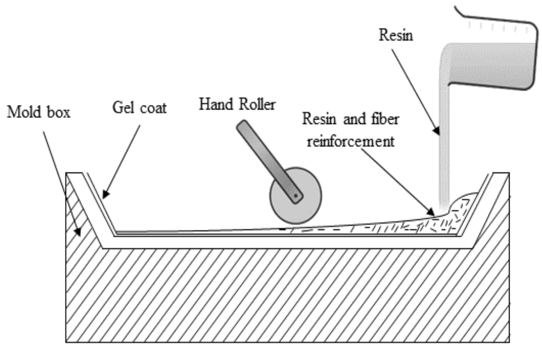

Fig. 6 Hand lay-up method

Yadav et al. utilized the All-Cellulose Composites (ACCs) approach and manufactured textile waste based cellulosic composites (TWCCs). For comparative study three different type of samples (TWCCs, TWCC laminate, and cotton/epoxy TWCC composite laminate) were prepared. Sodium alginate $(C_6H_7O_6Na)_n$ were used to bond TWCC laminates and the specimens were fabricated via hand lay-up method [87]. Taye Wondmagegnehu et al. manufactured textile waste/glass fiber hybrid composite material and studied the variation in mechanical properties. Five distinct samples were prepared by varying the stacking sequence of unsaturated polyester resin, textile waste layer and glass fiber layer [44].

5 Characteristics of Textile Waste Reinforced Composites

To characterize textile waste reinforced composites most of the studies prioritized the mechanical, acoustic and thermal properties of the specimens. Tensile, flexural and impact tests are commonly done to determine the mechanical properties.

5.1 Thermal and Acoustic properties

In building application, thermal isolation materials play a crucial role to minimize energy consumption as it reduces the heat loss/gain during heating/cooling process in the building [34], [92]. Around 60% of energy consumption can be reduced by using thermal isolations in domestic households [93]. Thus, proper utilization of waste can generate such sustainable materials which have appropriate thermal properties and can be useful for saving a significant amount of energy. On the other side, noise pollution is rising at a progressive rate because of urbanization, industrialization, availability of vehicles, electrical and mechanical machineries in households and industries which leads to major health and environmental effects [94]. Health issues like sensorial stress, high blood pressure, coronary heart disease, and stroke are arising as a result of this noise pollution [95]. Along with these health effects it impacts on the people's work life, as noise pollution diverts the concentration from work and reduces working efficiency [96]. One method for minimizing the negative impacts of noise is sound insulation. A number of European nations have laws requiring buildings to use soundproof materials in order to mitigate the detrimental effects of noise pollution [97]. As a result of these rules, the need for effective and affordable sound insulation materials have grown.

5.2 Mechanical Properties

Table 2 Mechanical properties of textile waste reinforced composites

Matrices/ Binder	**Fiber**	**Fabrication Method**	**Characterization Technique**	**Key Findings**	**Ref**
Epoxy	Cotton	Compression Molding	Tensile, flexural (3-point bending), and Izod impact (ISO 180:2000); TGA, water absorption, and SEM	-GO nanoparticles enhanced mechanical strength -Composites remained thermally stable and showed lower water diffusion than common woods.	[9]
Epoxy	Cotton, Cotton/Glass Cotton/ Jute Non-woven	Compression Molding	-Mechanical properties: tensile, flexural, izod impact strength, and bearing strength of composite in a pinned joint -Estimation of void volume within the composite -SEM, TGA and Water absorption characteristics	-Glass UD preform boosted tensile, flexural, and impact strength -Jute content above 10.76% reduced mechanical properties. -Higher glass fiber reduced water absorption.	[50]
Polypropylene	Cotton, Polypropylene fiber	Compression Molding	-SEM images -Tensile test on instron 5582 using 50 kN load-cell according to ASTM 3039. -Free fall drop impact test and dynamic mechanical analysis	-Higher PP fiber content increased breaking strength, tensile, impact strength, and storage modulus. -Mechanical performance remained stable under high humidity.	[51]
Ecovio	Textile Fiber	Hot Pressing	Density, thermal conductivity, flexural and compression tests, DSC, TGA, water absorption, and SEM analysis.	-Compressive strength of textile fiber/Ecovio composites is lower than wood, wheat husk, and rice husk/Ecovio composites. -Flexural strength and water absorption of textile fiber/Ecovio composites are higher than others.	[52]
Soybean oi based thermoset resin	Cotton and Polyester	Compression molding	-Tensile and Charpy impact tests (ISO 179), -Water absorption -Thermal analysis, DSC, TGA, and SEM analysis.	-Cotton in 50/50 cotton/PET fabric improved strength without separation. -External matrix reduced cotton degradation, raising tensile strength (up to 88 MPa).	[54]
Upcycled Fabric	Upcycled Fabric	Compression molding	-Tensile test, three point bending test and Charpy impact test - TGA and SEM	-Tensile tests show improved strength and ductility. -Improved heat resistance, suitable for high-temperature applications. -Remarkable average impact energy absorption of 3.33 J	[55]
-	Polyester/ cotton blend	Compression molding	-MTS QTest/10 (flexural, tensile), QC-639 (impact), Mettler Toledo DSC822e (thermal behavior) -Thermal degradation, and statistical analysis.	-PET/cotton composites: +153% modulus elasticity, +36% Young's modulus, but –17% flexural and –44% tensile strength vs. CMPET -Plasticizers reduces melting point and mechanical properties.	[88]
BOPP waste, PP nonwoven (TNT) waste, 50/50 BOPP/TNT blend, and virgin PP fibers	Polyester woven fabric scraps	Thermoforming	-Mechanical properties: Tensile stress, bending strength	-Composite materials with 50/50 matrix/reinforcement ratio show the best mechanical properties -Recommended percent of matrix is 30–40 %	[89]
-	Denim fabrics	Vacuum infusion technique	-Tensile and flexural test was performed in a universal 10KT testing machine	-No significant differences in mechanical strength and modulus were observed among ACCs made from different cellulose sources and fresh/recycled IL.	[90]

Matrices/ Binder	Fiber	Fabrication Method	Characterization Technique	Key Findings	Ref
			- Impact testing was performed Zwick test instrument -TGA and SEM	-The low cellulose matrix content (~17 wt%) suggests that denim reinforcement largely determines the mechanical properties of ACCs	
Polyester resin	Cotton, Jute, Glass fiber	Vacuum bag molding	-Tensile and flexural properties of the samples were tested on an Instron 4411 Universal Tensile Testing machine -Dynamic mechanical properties analysis and SEM images	-Regression models developed and predicted hybrid composite mechanical properties. -Waste-based composites had lower tensile/flexural strength than glass fiber composites; hybrids showed comparable strength. -Mercerization and desizing enhanced textile waste reinforcement for composites.	[70]
Epoxy resin	Recycled waste fabrics	Vacuum-assisted resin transfer molding	-Tensile, compressive and flexural properties -Density of the samples were measured by using Archimedes' principle. -Specific strength and thermal conductivity	Waste fabric composites showed lower tensile strength than non-waste; hemp and viscose had notably reduced strength. Tencel and micromodal had lower compressive strength; hemp showed higher flexural strength vs. some epoxy composites. No significant change in thermal conductivity.	[69]
Unsaturated polyester resin	Knitting waste and Noil waste	Vacuum bag molding technique	-The tensile strength was tested according to ASTM D3039 -The flexural properties were tested by three-point bending test -Impact test performed on Monsanto Tensometer	-The impact strength of these composites is comparable to glass fiber-reinforced composites, but their flexural and tensile strengths are lower -Composites are biodegradable and environmentally friendly	[68]
Epoxy resin	Cotton and polyester fiber	Vacuum infusion method	-SEM images: to analyze the fiber–matrix interactions -Tensile tester (Instron 5980); Charpy impact tester (Instron CEAST 9050 -Thermogravimetric analyzer (Mettler Toledo) -The sound absorption properties by impedance tube.	-The composites show anisotropic behavior, with higher elongation in the 90° direction -Specific Young's modulus (3500 MPa/g cm^3) and tensile strength (38 MPa/g cm^3) are comparable to or higher than pure epoxy -The composites follow the thermal behavior of epoxy resin.	[8]
Epoxy resin	Denim fabric waste	Vacuum assisted resin transfer molding	-Tensile, three-point bending, compressive and peel properties were tested with a universal testing machine -DMA, SEM images	-2#3DWECs show superior static and dynamic mechanical properties than other samples -Strength rises with planar fiber web density but drops if too high -The composites exceed the peel strength limits set by the Chinese National Standard for particle boards	[67]
Unsaturated polyester resin	Cotton, jute, glass fiber	Vacuum bag molding	-SEM images -The tensile properties were determined by a Testomeric tensile strength machine -Flexural properties were tested according to the ASTM D7264 standard	-Waste-based composites had lower tensile/flexural strength than glass fiber ones; hybrids showed comparable performance. -Mercerization and desizing enhanced textile waste compatibility with virgin materials. -Regression models developed and predicted hybrid properties	[66]
Epoxy resin	Ramie fabric	Vacuum assisted resin infusion molding	-SEM images -DMA (T101423D instrument) -Tensile and flexural tests (Instron 3382)	-Hot compaction improved mechanical properties more than vacuum pressure compaction; compaction temperature of 100°C was optimal for treated fibers.	[65]

Matrices/ Binder	Fiber	Fabrication Method	Characterization Technique	Key Findings	Ref
Epoxy resin	Cotton waste	Vacuum-assisted resin transfer molding	-To measure cotton fiber diameter: optical microscopy -FTIR, tensile test (Shimadzu AG-IS test machine) -SEM analysis.	-Alkaline treatment enhanced cotton waste/epoxy composite properties -1.5M NaOH (3hours of soaking) gave highest tensile strength. -1.5M (1hour of soaking) gave best Young's modulus. -SEM showed improved fiber-matrix adhesion.	[64]
Unsaturated polyester resin	Cotton waste, chopped e-glass fiber	Hand lay-up method	-Tensile and flexural tests (Amsler UTM), -Izod impact test (Pendulum-type hammers testing machine) -Water absorption in tap, saline, and distilled water.	-Mechanical performance improved compared to pure resin -Tensile strength increased by 31.1% and elasticity modulus increased by 38.3% -G/T/G composite had highest flexural strength (173.1 MPa) and water absorption. -G/G/G had lowest absorption but highest thickness swelling in salt solution.	[44]
Low-Density Polyethylene (LDPE)	Carpet fiber	Single screw bench top extruder	-Tensile testing on Instron tensile-testing apparatus (5565) -Scanning Electron Microscopy (SEM) -High temperature Gel Permeation Chromatography HTGPC)	-MAh-modified PE copolymer compatibilizer (1 wt%) improved mechanical properties and tensile strength by enhancing interfacial adhesion through chemical bonding with carpet fibers.	[79]
Epoxy resin	Recycled cotton fiber	Hand Lay-up method	-Tensile, compression tests, FTIR (single-reflection) -UL-94 flammability -Biodegradability, and SEM analysis.	-Compressive strength 196% higher than EPS foam -Fully biodegradable within 120 days -Hydrophilic and sensitive to moisture -NaOH/urea solvent system improved flexibility and energy absorption of the composites.	[87]
Low-Density Polyethylene (LDPE)	Waste cotton fibers, glass fiber	Single screw extruder	-Tensile (ASTM D638–08), flexural (3-point), Izod impact (A-notch), SEM, and rheological analysis (Haake Polylab torque rheometer).	-Cotton fibers improved mechanical properties via fiber entanglement and matrix interaction. -Maleic anhydride boosted mechanical properties rapidly up to 7 wt%. -Glass fibers impacted rheology more than cotton; -Maleic anhydride raised torque values.	[77]
Low-density polyethylene (LDPE)	Waste cotton fabric	Single screw extruder	-SEM images -DSC (rheology) -FT-IR spectroscopy (to evaluate surface chemistry) -Tensile (Shimadzu AG-IS) -Flexural (3-point), and Charpy impact tests.	-Tensile and flexural strength improved up to 70% and 45% with treatments; -Maleic anhydride was most effective. -Alkali + maleic anhydride reduced strength (~40%). -Impact strength decreased due to brittleness.	[91]

Currently, synthetic materials like glass fiber, mineral wool, and polymers are employed to make a variety of building insulation materials [98]. There is a tremendous potential of textile waste fibers to be utilized as soundproofing materials due to the acoustic and sound absorption properties of the composites.

Juciene et al. developed composite panels utilizing commercial denim waste and evaluated their acoustic performance. Two types of panels were formed, one with scrap, tiny square-cut denim fabrics and another with threads that was obtained by tearing down the waste fabric. The panel made of disassembled treads exhibited two to three times better acoustic performance compared to sound absorbing panels made of wood or wood-based materials. The acoustic performance of the two panels were measured by a special test stand showed in Fig. 7, which is a non-standard method [57].

In another study, Rubino et al. used 100% wool waste fiber to develop nonwoven material that exhibits compatible sound absorption and hygrothermal properties compared to products available in the market for building application.

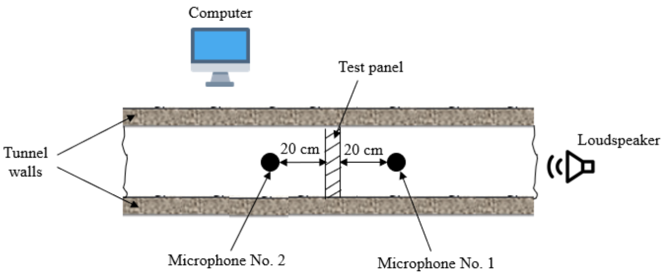

Fig. 7 Top view of the special test stand setup [57]

By the method of compression molding the materials were fabricated and polyester/ copolyester bi-component fibers were used to form bonds with the wool waste. Using samples that were 50 mm thick, absorption coefficients ranged from 0.7 to almost 1, and thermal conductivity values between 0.044 and 0.057 W/(m·K) were found [99]. Barbanera et al. utilized leather scraps from cutting waste of leather goods industry to develop thermally stable, noise absorbing composite boards. For the 45 °C and 50 °C set-up hot temperatures, the calculated thermal conductivity was 0.104 W/(mK) and 0.108 W/(mK), respectively. Regarding the acoustic performance, two panels of 18 mm and 28 mm in thickness were fabricated, they were distinguished by transmission loss values ranging from 25 to 33 dB and 25 to 42 dB, respectively, and noise reduction coefficients of 0.46 and 0.20 [56]. Lin et al. developed composite nonwovens by hot pressing method using recycled Kevlar, nylon and polypropylene-salvages. Effects of piled orientation and hot pressing on puncture resisting, thermal and noise insulation were tested on the specimens and the results were satisfactory enough to use these composites as wall coverings on building compartments [100].

In another study, Ricciardi et al. evaluated the thermal performance and determined the coefficient of acoustic absorption of two panels reinforced with textile fiber and waste paper [101]. Dissanayake et al. reports a method for producing thermal insulation materials using post-industry waste materials including Nylon/Spandex (NS) fabrics and Polyurethane (PU) offcuts, in a tri-layered configuration (NS/PU/NS). Thermal insulation with a 60:40 (by weight) mixture of NS and PU exhibited a thermal conductance of 0.0953 W/mK. It requires less preprocessing and no additional binders, with a bind function performed by NS, and is thus cost-effective and environmentally friendly. It is a feasible alternative for post-industry textile waste, which is otherwise disposed in landfills, and can have future application in developing countries as a manufacturing hub [33]. Del Rey et al. illustrated that recycled textile materials used as core elements have sound absorption and airflow resistivity coefficients equivalent to commercial sound absorption materials, and therefore, can serve as a viable alternative to conventional materials. Prototypes were measured in a small custom-made reverberation chamber, providing sound absorption values with high accuracy for sound waves with a frequency over 500 Hz, and full-scale ISO standard tests confirmed them [102]. Tuic et al. reported that incorporation of 10-50% of textile waste in rigid polyurethane foam (RPF) significantly increases sound absorption. 60-RPF composite, consisting of 60% RPF and 40% textile waste, shows the best sound absorption property with a noise reduction coefficient (NRC) twice as high as 100% RPF. It attains a sound absorption value of at least 0.4 for all measured frequencies. All such composite materials are cost-effective and contribute towards environmentally friendly building initiatives through reuse of textile waste. The materials produced are flexible and can be used in both indoors and outdoors, providing enhanced acoustic, physical, mechanical, and thermal performance over conventional RPF [103].

Table 3 Thermal and acoustic properties of textile waste reinforced composites

Matrices/ Binder	**Fiber**	**Fabrication method**	**Characterization Technique**	**Key findings**	**Ref**
Corn Starch	Denim waste	Compression Molding	-SEM images -Acoustic properties: A custom made test stand -Bending test: UTM -Surface hardness: EN 15283-1 standard	-The damping coefficient of panel made from threads is 0.04-0.07 -Two to three times better acoustic performance than wood or wood-based panels. -Panels made from threads had three times higher hardness than panels made from fabric scraps. -Panels made from threads have a more uniform structure	[57]
Polyester/ copolyester bi-component fibers	Wool waste	Compression molding	-SEM images -Acoustic properties: BSWA SW 260 two microphones impedance tube -Open porosity measured by Quantachrome Helium gas Pycnometer -Thermal insulation properties were examined by transient plane source device Isomet 2104	-Thermal conductivity ≤ 0.06 W/(m·K), suitable for thermal insulation panels - Absorption coefficients as high as 0.7 at frequencies from 500 Hz onward -Water vapour permeability around 2·10-11 kg/(m·s·Pa) -Compatible sound absorption and thermal insulation properties	[99]
Polyvinyl acetate	Leather cutting waste	Compression molding	-Acoustic performance measured by means of a Kundt's tube	-Thermal conductivity is about 0.10–0.11 W/ (mK) at 33–35 °C	[56]

Matrices/ Binder	**Fiber**	**Fabrication method**	**Characterization Technique**	**Key findings**	**Ref**
			-Thermal performance measured by means of a small hot–box system -Water contact angles were evaluated using the sessile drop method -Thermal stability was assessed by TGA analysis - Ignitability test	-Better thermal conductivity and noise reduction coefficient than glued wood fiber panels -Thermally stable panels up to about 250 °C -Hydrophobicity behavior and low water permeability	
-	Recycled kevlar, Nylon 6, Low melting polyester (PET)	Hot pressing	-Static and dynamic puncture test -Sound absorbing properties measured by twin-microphone tube -Measurement of thermal insulation property	-30% low-melting polyester fiber and 180°C hot-pressing temperature are optimal -Hot pressing increased puncture resistance and thermal insulation but reduced sound absorption. -Plied orientation significantly influenced sound absorption and thermal insulation but not puncture resistance.	[100]
-	Textile waste and waste paper	-	-Hot box apparatus used to evaluate thermal performance -To investigate the weak points of the assembled panels thermal infrared camera was used -Acoustic absorption coefficient was determined by a Kundt's tube	-Good thermal performance, with thermal conductivity (k-values) ranging between 0.034–0.039W/mK, comparable to traditional materials like rock wool. -Noise Reduction Coefficient (NRC) of the panels ranged from 0.23 to 0.38, depending on thickness, but was lower than rock wool	[101]
-	Nylon/Spandex, Polyurethane	Compression moulding	-Thermal Conductivity of the samples were tested by the Lee's Disc Method	-The optimal composition for thermal insulation was found to be 60% NS and 40% PU by weight. -Thermal conductivity of such composition 0.0953 W/mK -The thermal conductivity can be approximately described by the equation where "T" is the thickness of the panel (1367 * T 5.272 + 0.08799)	[33]
Recycled polyester (PET), Phenolic	Textile industry waste	-	-SEM images -Custom small scale reverberation chamber was used to determined acoustic characteristics -Air flow resistivity was measured by two different indirect methods	-Sound absorption coefficients and airflow resistivity values comparable to commercialized acoustic products -Reliable sound absorption measurements for frequencies above 500 Hz	[102]
Polyuretha-ne formulation	Textile waste	-	-SEM image -Density of the composite materials was measured according to ASTM D 1622-08 standard -Sound absorption coefficient measurement by two-microphone transfer-function method	-Composites reinforced with textile waste fibers have better sound absorption properties than 100% rigid polyurethane foam - 60-RPF exhibits the best result in terms of sound absorption	[103]

Matrices/ Binder	Fiber	Fabrication method	Characterization Technique	Key findings	Ref
-	Cork plate, Recovered textile fiber	-	-The Kundt tube method for acoustic testing. -Sound absorption coefficient and acoustic impedance of materials by Impedance tube method.	-The sound absorption coefficient increases with higher frequencies -The textile plate (85% recovered PNA) and composite materials exhibit good sound-absorbing properties, classified as Class D -The composite material performs best in the 2000–3200 Hz range, with an absorption coefficient around 0.47	[104]
Natural hydraulic lime	Textile wastes	-	-Bulk density and shrinkage -Optical stereomicroscopy observations -Mechanical strength and hardness -Water absorption by capillarity -Thermal conductivity -The absorption coefficient, measured by the impedance tube	-Lower lime content reduced thermal conductivity. -Sample C showed highest sound absorption at high frequencies. Higher water content increased pore size and allowing better sound wave penetration and improving absorption. -Fiber addition enhanced acoustic performance over plain lime plaster.	[105]
Polyester/ Polypropylene	Carpet waste	Compression molding	-Tensile/flexural (MTS QTest10), -Impact (Tinius Olsen 66), -DSC, DMA (Q800) -SEM images	-PA66/PP composites outperformed jute/PP in flexural strength (+37%), sound absorption (+45%), water stability (+10%), and improved damping properties. -Among carpet types, PA66/PP showed highest mechanical performance (up to +88% flexural modulus)	[106]

6 Potential Applications of Textile Waste-Based Composites

Apart from offering thermal and acoustic isolation, the utilization of composite materials derived from textile waste offers numerous possibilities across various industries. Since the demand for sustainable materials has skyrocketed, exploration of textile waste reinforced composite materials opened up the potential of such materials in many sectors. This section discusses their applications in different sectors, including automotive, construction and building industry, furniture industry and more.

6.1 Automotive Applications

In a study by Araujo et al. developed polypropylene (PP) composites reinforced with cotton fibers derived from textile waste. The resulting composites exhibited increased strength, stiffness, and durability. These enhanced properties make them suitable for applications in the automotive industry, where lightweight and strong materials are required. This approach also adds value to textile waste by repurposing it into high-performance polymer composites [107]. Another study by Baccouch et al. fabricates cotton waste-reinforced composites using NaOH treatment, improving fiber-matrix adhesion. The treated fibers had stronger adhesion with the matrix, leading to a 70% increase in Young's modulus for composites, making the composites suitable for automotive and building applications [64].

For an automotive dashboard panel, a composite material should have a density, Young's modulus, and tensile strength of at least 1180 kg/m^3, 2.3 GPa, and 25 MPa, respectively [108]. Kamble et al. developed epoxy composites by reinforcing cotton shoddy and graphite oxide nanoparticles as filler, which fulfills the criteria for automotive dashboard panel applications [9]. Additionally,

Table 4 displays and compares values derived from the produced composites as well as typical mechanical property values for automotive applications [109]. In a further investigation Kamble et al. confirmed the potential of thermoset composites reinforced with recycled textile fiber in some visible and non-visible automotive components [48]. Textile fiber reinforced aluminum metal matrix composites exhibit potential for lightweight and load-bearing applications. Numerous benefits, including a higher strength to weight ratio, high modulus, resistance to creep, wear, and fatigue qualities, are offered by metal matrix composites made of aluminum reinforced with textile fiber. These composites must have the capability to support primary and secondary loads in the automobile industry [110].

Table 4 Comparison of mechanical properties of composites for automotive applications [9]

Property	Typical Natural Fiber Composites used in the automobile industry	Cotton Shoddy Reinforced Epoxy	Cotton Shoddy Reinforced Epoxy + 0.3 wt.% Graphite Oxide
Fiber	Bast fiber	Extracted waste cotton fibers	Extracted waste cotton fibers
Processing Technique	Hot pressing	Hot pressing	Hot pressing
Natural Fiber Content (Mass %)	65	38	38
Polymer Content (Mass %)	35 (Epoxy)	62 (Epoxy)	62 (Epoxy)
Density (g/cm³)	0.80 – 0.85	1.23	1.23
Tensile Strength (MPa)	40 – 50	83.75	86
Flexural Strength (MPa)	50 – 70	83.58	106.54
Flexural Modulus (MPa)	4000 – 4500	5111.74	6836.52
Impact Strength (mJ/mm²)	14 – 20	6.69	6.94

6.2 Construction and Building Materials

Fiber reinforced mortars (FRM) are growing in popularity as construction materials in a variety of building technology areas, such as masonry buildings, raised floors, roofs, and façade panels. Textile waste generated from cloth waste is one of the most promising fiber types for these composite materials. In the building industry, using these kinds of wastes and recycled materials as cement reinforcement can be important from an environmental, economic, and social standpoint [111]. It is feasible to reduce CO_2 emissions by redesigning concrete materials using waste materials that would otherwise end up in landfills [112]. Concrete can be replaced with lightweight composite materials that are strong and have thermal insulation qualities to drastically cut CO_2 emissions [113]. In order to improve ductility and fracture control, Sadrolodabaee et al. investigated the use of textile waste as internal reinforcement agents for cementitious matrices. Initially, they used the needle-punching technique to create non-woven of polyester, cotton, and linen fabrics. These constructions were subsequently covered with mortar, which is a cement and water mixture. The final mold was developed by compressing and aspirating this mixture. Since these composites exhibited good performance in terms of tenacity and post-cracking stress capacity, the experimental study confirms their feasibility as a potential building material for nonstructural concrete applications such as pavements, raised floors, and facade cladding [114], [115].

In China two large-scale industrial wastes are flue gas desulfurization (FGD) gypsum and textile fibers. Liu et al. worked with these waste materials to develop foamed concrete which have the capability of increasing the energy efficiency of the buildings. The outcome from their study provides an effective way to recycle such large-scale industrial waste to reduce the environmental impact while simultaneously producing affordable and efficient building materials [116]. Considering the harmful impact of waste polymer textile bags a sustainable way of reusing them were urgent. To find solution of this issue Chen et al. developed a novel and sustainable way sustainable way to reuse waste polymer textile bags by incorporating them into soil improvement projects. The research tested the effectiveness of polypropylene fibers, including fibers extracted from waste bags, in reinforcing cement-treated soft clay for applications like pavement bases and subbases. Laboratory tests showed that adding fibers significantly enhanced the soil's strength and flexibility, with the best results at 0.5% fiber content. This approach offers an eco-friendly solution for waste management while improving soil stability in construction projects [117]. Another study explores the use of waste cotton fibers from discarded jeans in polyester concrete, with a novel treatment using gamma irradiation. The findings show that this treatment significantly enhances the concrete's strength, improving compressive strength by up to 40% and flexural strength by 7%. This innovative approach provides a sustainable way to repurpose textile waste, making it useful for construction applications that require stronger and more durable concrete materials [118].

Spadea et al. investigated the use of recycled nylon fibers from waste fishing nets to reinforce cementitious mortars. The research evaluates the fibers' resistance to chemical exposure, their impact on mortar workability, and potential environmental effects. Tests show that adding these fibers improves the mortar's tensile strength by up to 35% and toughness by up to 13 times. These findings highlight the potential of recycled nylon fibers for the reinforcement of sustainable cement mortar and enhancing construction materials [119]. Another study demonstrates that composite panels made from waste jute bag, Portland cement, and starch can be produced using heat and pressure, making them suitable for interior cladding and furniture. These panels have lower densities than those made with other plant fibers and offer good mechanical and thermal properties. Panels with 5–10% jute content are ideal for thermal insulation in buildings, while those with 15–20% jute can serve as effective thermal insulators. The manufacturing process is energy-efficient compared to conventional wood–cement panels. Recycling industrial waste jute fiber panels in particleboards promotes sustainability, offering both industrial and environmental benefits [120]. Aghaee et al. examined the bending behavior of lightweight concrete panels reinforced with textile waste fibers and glass fiber mesh. The results show that these panels have lower density than water, high energy absorption, and good ductility. Additionally, they offer effective thermal insulation, making them suitable for use as partition walls in buildings. Their solution promotes sustainability by utilizing textile waste while enhancing building materials [121]. Ozger et al. explores the use of recycled polyamide fibers from textile carpet waste in concrete applications for thermal energy storage systems. The fiber-reinforced concrete showed improved ductility and toughness, though with slightly reduced tensile strength and load-bearing capacity. It also exhibited lower drying shrinkage, making it more durable. The thermal properties indicate its potential for energy-efficient construction, as it offers enhanced heat storage and conductivity [122]. Another research investigates the use of waste polypropylene and polyacrylonitrile fibers to enhance recycled concrete beams. The addition of these hybrid fibers improved the concrete's strength and mechanical properties while reducing crack formation and growth. This makes the material more durable and resistant to cracking. This approach supports sustainable construction by repurposing industrial and textile waste for stronger, more durable concrete structures [123]. Rajput et al, reports the use of cotton waste (CW) and paper waste (PW) from Recycle Paper Mills in producing Waste Crete Bricks. The produced bricks weigh half of that of the conventional clay brick and these economical bricks can be used as internal partition walls. Bricks with a 1–5% CW addition and 10% cement to PCW have a compressive strength of 21–23 MPa (with 30% shrinkage), which is several times higher than that of traditional clay bricks and meets the specifications for a building material to be used in indoor structural applications, according to test observations [124].

6.3 Other Applications

M. Müller investigates the use of textile waste from tire recycling as a filler in polymer composites. The addition of recycled microfibers increased impact strength by 140.1% and improved adhesive bond strength, but it also reduced tensile strength by 54.81% and elongation by 49.84%. The results indicate that waste textile fibers can be effectively used in composite materials, particularly for applications requiring enhanced impact resistance, such as adhesives and protective coatings [125]. Another study explores the use of recycled textile fibers and rubber granules from tire waste in hybrid polymer composites. The composites, made with an epoxy adhesive matrix, were tested for tensile strength, elongation, and impact resistance. Results showed a decrease in tensile strength by up to 80.1%, but an increase in impact strength, especially in composites with a higher proportion of textile fibers. Some composites also exhibited improved tensile lap-shear strength. These findings suggest that waste textile fibers and rubber granules can be effectively used in polymeric composites for applications such as machine part repairs and roofing materials [126]. Serra et al. developed a potential eco-friendly alternative material to glass fiber composites by using waste cotton flocks from the textile industry to reinforce polypropylene [27]. El Hage et al. developed new fire-resistant and insulating biocomposites using miscanthus fibers (Mf) and recycled textile fibers (RTf), bonded with chitosan and reinforced with aluminum trihydroxide (ATH) as a flame retardant. The results showed that adding 33% or more ATH significantly improved the thermal stability of chitosan, though it slightly reduced mechanical strength. The final biocomposites, produced via thermocompression, had a high fiber content (up to 90%), low thermal conductivity (0.07–0.09 W/m·K), and lightweight density (270–299 kg/m³). These composites met fire safety standards (E rating, NF EN ISO 11925-2) and showed improved mechanical performance when combining both fiber types. Applications include eco-friendly insulation and fireproof materials for sustainable building construction [127] In another study Bodur et al. reported how water absorption affects the physical and mechanical properties of glass fiber/waste cotton fabric hybrid composites. Results showed that adding maleic anhydride (MA) as a coupling agent significantly reduced water absorption from 5% to 1.5%, while maintaining tensile strength even after prolonged exposure. These findings suggest that MA-treated composites offer better durability in moisture-prone environments, making them suitable as an alternative material in outdoor products [75]. Chen et al. developed wearable strain sensors using carbonized waste cotton fabrics combined with natural rubber latex. The sensors remained flexible and conductive, with resistance changing under strain, making them ideal for monitoring human motion. Cyclic stretching-releasing tests showed that the wearable strain sensors were sensitive to strain and stable under repeated loading, demonstrating their ability to monitor human finger and arm movements [128]. Rajkumar et al. fabricated silk/wool hybrid fiber polypropylene composites by compression molding technique which has a potential application as an electrical insulating material in printed circuit boards [59]. Another way to sustainably value textile waste is through the creation of energy. In order to generate thermal energy, Nunes et al. crushed cotton PCPIW into briquettes. A boiler that generated two tons of steam per hour at 10 bars could be heated by the briquettes. This substitute was less expensive than wood briquettes [129]. The use of textile waste as a thermal energy source for boilers in Bangladesh's ready-made clothing industry was reported by Roushan [31].

A completely bio degradable textile waste reinforced composite developed by Yadav et al. show case excellent impact protection. Thus, it can be used in the protective helmets used in sports and motorcycling [87]. Rizal et al. investigated the use of cellulose nanofibrillated fiber (CNF) from textile waste cotton fabrics to enhance polylactic acid (PLA)/chitin biocomposites. The addition of CNF significantly improved tensile strength, impact strength, and thermal properties compared to neat PLA. The PLA/chitin/CNF biocomposite showed better mechanical and wettability properties than the PLA/chitin blend, making it suitable for packaging applications [130]. The integration of waste is also beneficial in agriculture. When growing maize and sunflower, wool waste, post-consumer preindustrial waste, is used to the soil to boost its nitrogen content, negating the need for fertilizers [131]. As it is inexpensive, textile waste can also be utilized as feed for the synthesis of enzymes. The cellulase enzyme was obtained by fermenting Aspergillus niger CKB in a nitrogen atmosphere using cotton and polyester wastes in various ratios. Apart from acquiring cellulase, it was also feasible to partially recover glucose from cotton [132]. Kamble et al. confirms the potential of textile waste reinforced thermoset composites as furniture materials, specially it's possibility to successfully replace timber in furniture applications [48].

7 Challenges of using textile waste for composite fabrication

Sustainable composite development by utilizing textile waste is challenged by several technical, economical and logistical factors. Fiber collection and extraction from pre- and post-consumer textile wastes is one of the preconditions for developing the composites. This can be challenging since the lack of fiber uniformity is very common in textile wastes. Although widely discussed in recycling related literatures, this issue directly affects the composite fabrication by increasing the complexity in cases of fiber separation and standardization. The challenging factors that affect the textile waste based composite fabrication are discussed below.

Fiber Heterogeneity and Inconsistency: In order to improve the quality and properties of the fabric variety of fiber blends are used. Heterogenous mixture of natural and synthetic fibers to develop a product is frequently observed. These fiber blends and their structures vary from product to product [133]. Products that are produced by using mono materials like, 100% cotton, are suitable for recycling. Since textile and related products are generally composed of multi-materials, recycling and extracting fibers from such non-uniform materials is challenging. Currently, there is a major gap present in the fiber recycling sector, since the available technologies can only recycle up to two fiber blends and unable to decompose the synthetic blends like nylon/spandex. This type of mixture is commonly found in the sportswear and due to lack of technological advancement such large volume of waste ended up in landfilled or incinerated [33]. Fiber separation via chemicals is possible but its feasibility for mass fabrication is still under question since, this technique involves a high volume of chemical, specific temperature and pressure. Also, this process can be costly and time consuming [26]. Since the technologies to recycle and separate the fibers from heterogenous blends is still under development, it is challenging to fabricate textile waste-based composites in large scale. Also, fiber heterogeneity will lead to inconsistent mechanical properties in composites.

Contamination and Chemical Processing: In textile industry, a final product undergoes several chemical processes. According Echeverria et al. around 8000 chemicals are used in textile processing that includes dyes, mordants, softness, finishes, and coatings. These chemicals restrict the fiber recovery process of end-of life textile materials crucially [36]. In order to meet the market demands and improve the functionalities of the apparel like water repellence and hydrophobicity, different type of chemicals and coatings are used during the finishing process. These makes the fiber separation process more complicated [134]. Due to these chemical processing and contaminations the fibers characteristics reduces significantly. When these fibers used in composite fabrication, ensuring consistent level of mechanical and thermal characteristic for mass production will become extremely challenging.

Limited Standardization and Sorting Infrastructure: Post-consumer wastes usually have multiple components other than the fabric such as, buttons, zipper, labels and other accessories. Each item is different from other in terms of their age, type, fiber blend, chemical processing etc. Since these wastes has different histories associated with them, recycling post-consumer wastes become much challenging than pre-consumer waste [13]. Textile waste sorting based on their fiber type is an arduous job. It is generally a manual process, not time and cost effective which questions the economic feasibility of the fiber recycling process [135]. On the other hand, the quality of the recycled fiber is affected by the condition of the fabric waste, its structure and shredding parameters [136]. The properties of the fibers drop with the recycling processes. In case of cotton, the recycled cotton fibers are shorter and lower in tensile property than the virgin fibers [137]. Therefore, it will be difficult to produce composites with standardized characteristics using textile waste in a mass scale.

In order to overcome such challenges and ensure production of textile waste-based composites in commercial level, interdisciplinary research, advanced processing technologies, and infrastructure investment is necessary.

8 Conclusion

In this review paper a detailed overview on textile waste utilization in order to develop alternative materials has been compiled. Potential applications of such materials in various sectors and an overall positive impact of them on our health and environment also has been discussed. Millions of tons of textile wastes are produced and discarded annually but a proper universal solution for textile waste management is still missing. According to the outcomes of these literatures, fabricating new materials is necessary and by manufacturing new materials such as composites, non-woven or cementitious matrices using recovered fiber from textile waste can activate circular economy concept in textiles sector. The present studies usually characterize the textile waste-based composites for mechanical properties, thermal and acoustic insulation properties. Due to their reasonable mechanical properties, in building and construction structures sector they can play a significant role. Also, in some cases their acoustic and thermal isolation performance is far more superior than the currently available products in the market. Thus, these materials showcase the possibility to replace these conventional synthetic insulation materials. However, the research of utilizing textile waste as composite materials is still in its early stages. Most of the fabricated materials are not completely characterized thus, requires further investigation. Sufficient number of literatures are not present that covers the characteristics of such materials in terms of moisture sensitivity, biological degradation, and long-term durability under varying environmental conditions. Further research is required to address these issues and develop practical products for commercial application. Cost of the material is an important factor for commercialization. Many authors mentioned that the composites will be low in cost and can be manufactured commercially. However, specific information regarding cost is still not discussed in the literatures. Keeping the limitations and challenges aside it can be concluded that, textile waste based composite materials have the capability to shine as an alternative material in near future. By addressing these limitations, well-focused research can successfully commercialize these composite materials and become a novel eco-friendly alternative option for current available products in the market.

Author Contributions

M. M. Ahmmad: Methodology, Formal Analysis, Investigation, Data curation, Writing-Original Draft **M. S. Rabbi:** Conceptualization, Supervision, Writing-Review & Editing

Conflict of Interest Statement

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Data will be available on request.

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