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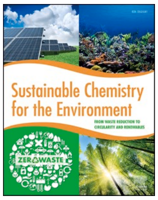

Waste-based composites using post-industrial textile waste and packaging waste from the textile manufacturing industry for non-structural applications

R.M.N. Sulochani [a,b,*], R.A. Jayasinghe [a], G. Priyadarshana [a], A.H.L.R. Nilmini [a], M. Ashokcline [c], P.D. Dharmaratne [d]

[a] *Faculty of Technology, University of Sri Jayewardenepura, Sri Lanka*
[b] *Faculty of Graduate Studies, University of Sri Jayewardenepura, Sri Lanka*
[c] *Faculty of Engineering, University of Jaffna, Sri Lanka*
[d] *Faculty of Engineering, Sri Lanka Institute of Information Technology, Sri Lanka*

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ABSTRACT

The textile industry significantly contributes to environmental pollution, generating substantial amounts of waste. The prevailing linear model exacerbates this issue, accumulating a significant portion of the waste in landfills. This research aimed to tackle these challenges by developing value-added composites from post-industrial textile waste and packaging materials, for non-structural building applications. To achieve this, shredded polyester textile waste fibers served as the reinforcement, while waste packaging was used as the matrix. Varying fiber-matrix weight percentages seven composite types were developed. The physical, mechanical, and thermal properties of the composites were evaluated. The findings indicated that these composites exhibited properties comparable to those of commercial partition boards. Notably, composites with fiber weight percentages of 7.5 % and 10 % demonstrated the most favorable performance among the tested variations. Emphasizing the application of sustainable chemistry, this study highlights the potential of these composites to develop substitute materials for non-structural building applications. Moreover, it presents a promising solution to address the textile waste management challenge and value-added materials for the construction industry in a developing context.

1. Introduction

The textile industry has garnered widespread attention for its negative impact on the environment and has been identified as the second most polluting industrial sector globally [50,60]. The production process is known for its high resource consumption and the generation of substantial waste at each stage [35]. The current operational model places an overwhelming burden on resources throughout the product's lifecycle, leading to environmental pollution and the degradation of ecosystems [47]. To address this issue, the Ellen MacArthur Foundation's report "A New Textile Economy" underscores the urgency of transitioning from the prevailing linear textile economy to a more sustainable circular textile economy [25].

The scale of textile waste generated on a global level is staggering, with millions of tons being produced annually [69,70]. This waste can be broadly classified into two categories: post-industrial/pre-consumer and post-consumer. Post-industrial waste arises during the various stages of textile manufacturing, including cutting, threading, and quality control. In contrast, post-consumer waste results from the disposal of textile products by consumers after their use [57]. Additionally, the textile industry generates a considerable amount of packaging materials, such as High-Density Polyethylene (HDPE), Low-Density Polyethylene (LDPE), Polypropylene (PP) materials, cardboard, and paper.

Directing research and development towards mitigating the adverse effects of textile manufacturing waste on the environment and promoting sustainable production and consumption practices is of utmost importance. Considering this, the main aim of this study is to add value to post-industrial polyester textile waste and plastic packaging waste by developing composite materials. The utilization of post-industrial textile and plastic packaging waste as a resource for creating composite

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* Corresponding author at: Faculty of Technology, University of Sri Jayewardenepura, Sri Lanka.
E-mail address: sulochanirathnayaka@sjp.ac.lk (R.M.N. Sulochani).

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materials not only addresses the issue of waste but also advances sustainable production and consumption practices, ultimately leading to a reduction in post-industrial waste.

1.1. Environmental impact of post-industrial textile waste

As the global population increases, the demand for synthetic textiles like polyester, nylon, and spandex has surged, outpacing that for natural alternatives [1,39]. The global market valuation of synthetic fibers was approximately USD 63.93 billion and forecasts indicate a substantial expansion in this sector, with projections suggesting a market capitalization of around USD 93.03 billion by 2023 [63]. This global issue of textile waste management is exaggerated by the extensive use of synthetic textiles, as approximately 60 % of all clothing is manufactured from synthetic materials like polyester, acrylic, and nylon [43]. This intensified demand for synthetic textiles has resulted in the generation of large quantities of synthetic textile waste.

The issue of solid waste management in the textile industry has been compounded by the presence of packaging materials. These materials, consisting of single-use plastics like polyethylene (PE) and PP, are generated in vast quantities by textile industries [36]. Once the textiles have served their purpose, these packaging materials become waste.

The improper disposal of textile and plastic packaging waste via open dumping leads to soil and water contamination and the generation of microplastics and microfibers. Therefore, utilizing the least preferred disposal methods, such as open dumping and burning, to manage textile waste has become a serious issue [48,61]. While incineration is widely used in handling textile waste as it significantly reduces waste volume, managing the formation of toxic compounds at high temperatures remains challenging [57]. These problematic situations have brought increased attention to the environmental concerns associated with textile waste management.

1.2. Post-industrial textile waste management in Sri Lanka

The textile industry in Sri Lanka is the largest manufacturing sector, contributing positively to the economy. However, a significant challenge faced by the sector is the generation of substantial amounts of textile waste [55]. Most of the generated waste comprises synthetic materials, creating a gap in the sustainability loop as the country lacks an effective textile waste management system [56,64]. The lack of adequate land for waste disposal sites further exacerbates the issue, with local authorities struggling to manage over 90 % of the generated waste [28].

The severity of the problem has increased due to the indiscriminate dumping of various types of waste, including industrial, hazardous, and hospital waste, alongside municipal waste in the same dumpsite [38]. In Sri Lanka, a small fraction of the generated textile waste is utilized as an alternative fuel and co-processed in cement kilns by INSEE Ecocycle [30]. However, the growing quantity of industrial waste has exceeded its capacity, leading to competition for the use of textile waste in co-processing [55]. As a result, a large volume of textile waste is either disposed of in open dumpsites or burned in the open [37].

In the pursuit of presenting the Sri Lankan textile industry as a sustainable business, companies are actively exploring alternative waste management methods [55]. Therefore, addressing the textile waste crisis has become an urgent need, requiring the adoption of innovative technologies. To this end, it is essential to devise novel approaches for repurposing waste, with a focus on simple technologies that can upcycle waste or convert it into high-value-added products.

1.3. Composite materials from post-industrial textile waste

In recent years, considerable attention has been directed toward the development of new materials from industrial waste products as a means of reducing waste and safeguarding the environment [12,68]. A recent trend in textile waste management is the use of textile fiber waste in composite technology, particularly in fiber-reinforced composites [24]. Previous studies have investigated the potential of using textile waste fibers to reinforce polymer composites for various applications such as automotive, structural, and non-structural construction materials [33,42,51].

A literature review conducted by the authors revealed that the physical, mechanical, and thermal properties of textile waste-reinforced polymer composites have significant potential for use in the construction industry [65]. Therefore, exploring new approaches to repurpose textile waste into high-value-added products, focusing on simple technologies that allow for upcycling waste, is essential to address the textile waste crisis and promote a sustainable textile industry.

The utilization of textile waste in composite technology has been extensively studied in the literature, with various studies exploring the use of different types of waste textiles to provide alternative solutions to the growing amounts of textile waste [2,15,24,67]. Most of these studies have focused on investigating the physical and mechanical properties of waste textile fiber-reinforced composites and evaluating the impact of different parameters on their properties. The findings of these studies suggest that advanced composites with properties comparable to existing materials can be developed by varying production parameters, leading to a broad range of properties and performance.

To determine the viability and appropriateness of replacing existing materials with newly developed composites, a comparative analysis of the mechanical, physical, and thermal properties of the composites and commercially available materials is necessary. Successful evaluation of the potential application of upcycled textile waste in composite materials can significantly contribute to sustainable waste management practices within the textile industry, along with facilitate their substitution in various non-structural building applications, interior fitments, and automobile interiors. Structural building materials deliver the crucial foundation and support for a building, while non-structural materials play a vital role in enhancing its functionality, appearance, and overall user experience [31]. A few examples of these types of materials are Interior Partitions (dividers within a building that are used to separate spaces), Ceilings, Floor Finishes, Interior Doors, Cladding, Interior Fitments, and Fixtures (e.g., countertops) that enhance functionality and usability within a building. While these materials do not any loads from the structure, they are essential for creating a comfortable and visually appealing environment for people who live in a building [31]. Thus, this study has the potential to advance the development of sustainable non-structural building materials and promote their diversified usage across different industries.

2. Materials and methods

2.1. Materials

Post-industrial polyester textile waste and packaging materials were collected from a local textile company in Sri Lanka. Polyester textile waste is selected because it is the highest-consuming textile type in the world [56] and in Sri Lanka. Due to its widespread availability in textile companies as a secondary waste, waste thermoplastic packaging materials were chosen as the matrix. The size reduction of the waste was achieved through shredding.

2.2. Methods

2.2.1. Sample preparation

Seven different types of composites were manufactured with varying weight percentages of reinforcement, which is the waste textile fiber (0 %, 2.5 %, 5 %, 7.5 %, 10 %, 15 %, and 20 % fiber) with the same fiber length. First, the polyester textile waste was shredded into roughly 1 cm pieces (diameter: 0.39 – 0.42 mm) using a mechanical shredder. Labels and stickers on packaging materials were removed manually. The shredded waste polyester and the packaging materials were weighed according to the required compositions and manually layered between two Teflon sheets before pre-pressing. Then the shredded waste polyester and the waste packaging were pre-pressed to create a thin sheet using a pneumatic double-heated press at 140 ℃ for 10 minutes per sheet.

The above process was repeated to create sheets with varied weight ratios of packaging materials and fabric waste. The pre-pressed panel was cooled for 10–15 minutes in a cold press under constant pressure. Then the sheet was re-shredded in a mechanical shredder for the excellent dispersion of the matrix with the fibers, making the material more comfortable to handle and insert into the final mold.

The shredded particles were then pressed in a heat press to create the final tile using a mold at 140 ℃ at a pressure of 5.5 MPa for 10 minutes. The processing temperature was chosen to exceed the melting temperature of the matrix, as determined by the DSC analysis. The panel was then left to cool to room temperature within the mold under constant pressure in a cold press to facilitate a slow cooling rate of the polymer matrix. After the panel was removed from the mold, the excess plastic that flowed out (flashing) was cut. The dimensions of the composite panel are 15 cm × 15 cm × 3.2 mm (length × width × thickness). Developed waste polyester textile fiber-reinforced composite panels are presented in Fig. 1.

2.2.2. Differential scanning calorimetry

DSC analysis was conducted to determine the polymeric composition and melting point of the packaging material waste using a Q200 Differential Scanning Calorimeter (T.A. Instruments). The test was conducted by applying a heating-cooling-heating thermal cycle within a temperature range of −60 ℃ to 250 ℃ with a heating rate of 10 ℃min^{-1} in a nitrogen atmosphere using samples with approximately 10 mg.

2.2.3. Fourier transform infrared spectroscopy

FTIR analysis of the textile waste and waste packaging material was conducted using a Burker Vertex 80 FTIR spectrophotometer. The samples were analyzed using the ATR mode from 400 cm^{-1} to 4000 cm^{-1} with a resolution set at 4 cm^{-1} and an accumulation of 128 consecutive scans.

2.2.4. Scanning electron microscopy

Scanning electron microscopy (SEM) was used to analyze the tensile fracture surface of the composites. The tensile fractured test specimens were scanned using a Hitachi SU6600 Scanning Electron Microscope. The sample was sputtered with gold to overcome the charging effect.

2.2.5. Tensile test

Tensile tests were conducted to determine tensile strength and Young's modulus using a Testometric M500–50CT tensile testing machine with a standard load cell of 5 kN at a constant crosshead speed of 50 mm/min with a gauge length of 50 mm. The test specimens were shaped following ASTM D 638 [9,16,17]. Five specimens were tested for each batch, and the results were arithmetically averaged.

2.2.6. Flexural test

Flexural testing was performed using the three-point mode following ASTM D 790 [8,16,17]. Rectangular specimens (127 mm×12.7 mm×3.2 mm) were tested using a Testomeric M500–50CT testing device. Five specimens were tested for each batch, and the results were arithmetically averaged.

2.2.7. Izod impact test

The Izod impact test was conducted by following ASTM D 256 [3,11]. To test the impact strength required to fracture the composites, v-notched rectangular specimens (63.5 mm×12.7 mm) were used. Five samples were tested in each batch, and the results were arithmetically averaged.

2.2.8. Hardness test

The hardness was measured using the Shore Durometer (MonTech HT 3000) following ASTM 2240, with the Shore D scale which is the scale for harder plastics [10,46]. The specimen size for the hardness test was 10 cm×5 cm x 3.2 mm. Ten readings were taken for each composite and results were arithmetically averaged.

2.2.9. Water absorption properties

Water absorption of composites was tested following ASTM D 570 [7,41]. Samples (50 mm×20 mm x 3.2 mm) were dried in an oven for 24 h at 60 ℃ to remove the remaining moisture. After drying, the samples

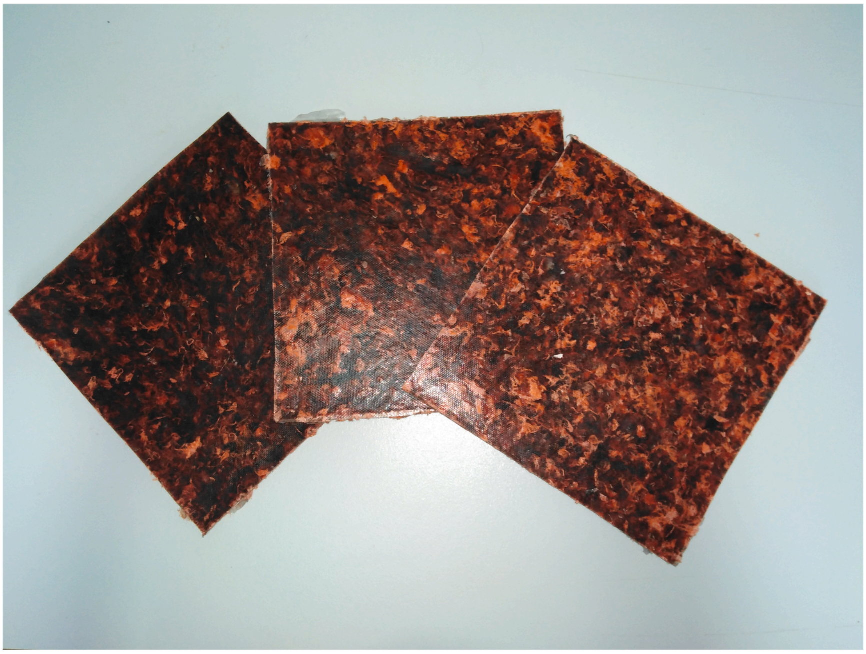

Fig. 1. Developed waste polyester textile fiber-reinforced composites.

were allowed to cool to room temperature, and the initial weight was recorded. Then the samples were immersed in distilled water at room temperature. After 24 hours, the samples were removed from the water and wiped with tissue paper to remove surface water and reweighed within a minute to prevent evaporation. The samples were returned to the distilled water to continue the sorption and were reweighed at regular 24-hour intervals until reaching equilibrium.

The percentage weight gain (W %) of the composite was calculated using Eq. 1 [20].

$$W\% = \frac{W_t - W_0}{W_0} \times 100 \quad \% \tag{1}$$

Where W_t is the weight of the specimen at a given immersion time, and W_0 is the initial weight of the specimen after oven drying.

2.2.10. Flammability test

The flammability of the composites was determined following UL-94 Horizontal Flame Propagation Test Method [24], in a flammability chamber. Three specimens (120 mm × 10 mm × 3.2 mm) for each composite were tested. Each sample was marked with two lines at 25 mm and 100 mm from one end and placed horizontally in the flammability chamber's sample holder. A controlled Bunsen burner flame (up to 1200 ℃) was applied to the sample for 30 s at a 45° angle. If the specimen continues to burn after removing the test flame, the time taken for the flame front to travel between two lines was measured, and the burning rate was calculated in mm/min. The ranking was determined by observing the speed of flame propagation. The samples were classified as HB rating only if:

- The burning rate did not exceed 40 mm/min over a 75 mm span, or
- The samples ceased burning before the flame reached the 100 mm mark

3. Results and discussion

The FTIR-ATR spectra of collected pre-consumer polyester textile waste (a), one of the composites prepared in this research using a blend of polyester textile waste and waste packaging materials (b), and waste packaging material (c) are presented in Fig. 2.

The FTIR-ATR spectrum of waste packaging material (Fig. 2-c) is typical for PE [5]. The FTIR-ATR spectrum can be used to distinguish the different types of PE, including HDPE, LDPE, and linear low-density polyethylene (LLDPE) which consist of repeating methylene groups (-CH_2) made with the elements carbon (C) and hydrogen (H).

These three types of PE indicate characteristic doublets of CH_2 asymmetric stretching at 2915 cm^{-1} and 2848 cm^{-1} [5]. The wavenumbers 1471 cm^{-1} and 1463 cm^{-1} characterize CH_2 bending deformation doublet [40]. The other doublets, around 729 cm^{-1} and 719 cm^{-1} characterize the rocking deformation of CH_2 [18]. The presence of these indications is strictly associated with the chemical structure of PE.

The wavenumbers range from 1340 cm^{-1} to 1400 cm^{-1}, and the three weaker peaks at around 1377 cm^{-1}, 1366 cm^{-1}, and 1351 cm^{-1} can be used to identify the particular type of PE material from the three types HDPE, LDPE, and LLDPE [40]. As reported in the literature [32], if the peak at 1377 cm^{-1} is more significant than the minor but visible peak at 1366 cm^{-1}, the type of PE is LDPE. If the peak at 1366 cm^{-1} is more significant than the minor but visible peak at 1377 cm^{-1}, the type of PE is LLDPE. If the peak at 1377 cm^{-1} is absent, the type of PE is HDPE. The peak at 1351 cm^{-1} is essentially present in every type of PE. The FTIR-ATR spectrum shows more significant peaks with nearly the same intensity around 1377 cm^{-1} and 1366 cm^{-1}. This observation confirms that the packaging material comprises a blend of LDPE/LLDPE which was also further confirmed by the DSC analysis.

The DSC cooling (upper-blue) curve and the second heating (lower-red) curve of the waste packaging material are presented in Fig. 3.

The second heating curve of the material displays two melting peaks, at around 110 ℃, and 121 ℃. These endothermic peaks were identified as corresponding temperatures for the melting points of LDPE and LLDPE, respectively [23]. Furthermore, two crystallization peaks were visible in the cooling curve, at around 98 ℃ and 108 ℃. These two exothermic peaks were identified as the corresponding temperatures for the crystallization of LDPE and LLDPE, respectively [45]. The presence

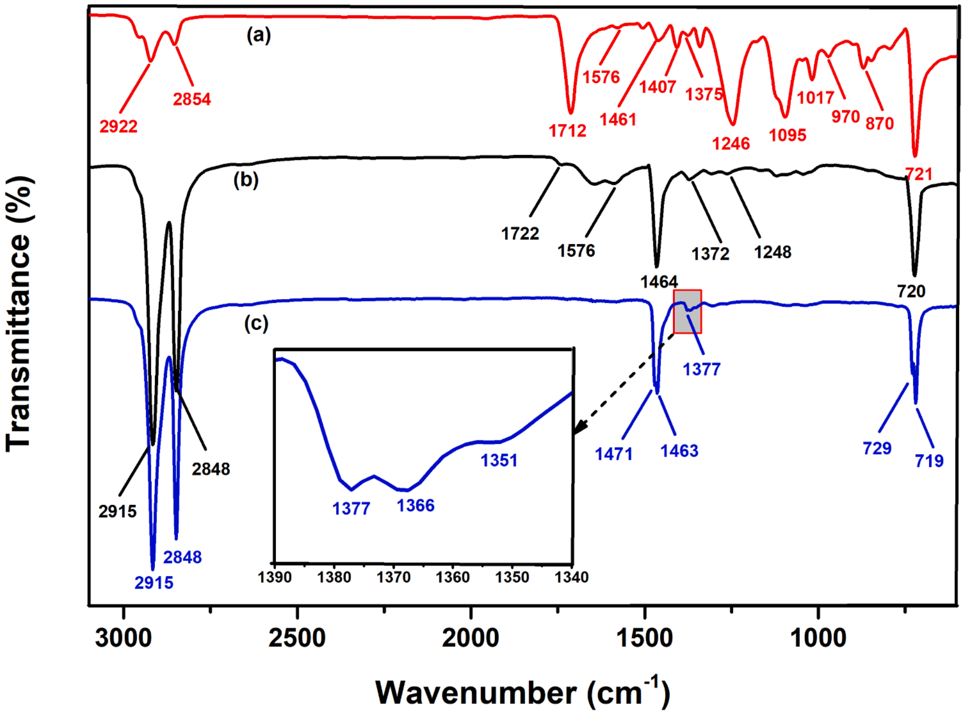

Fig. 2. : FTIR-ATR spectra of (a) polyester textile waste, (b) 15 wt% fiber-reinforced composite, (c) waste packaging material.

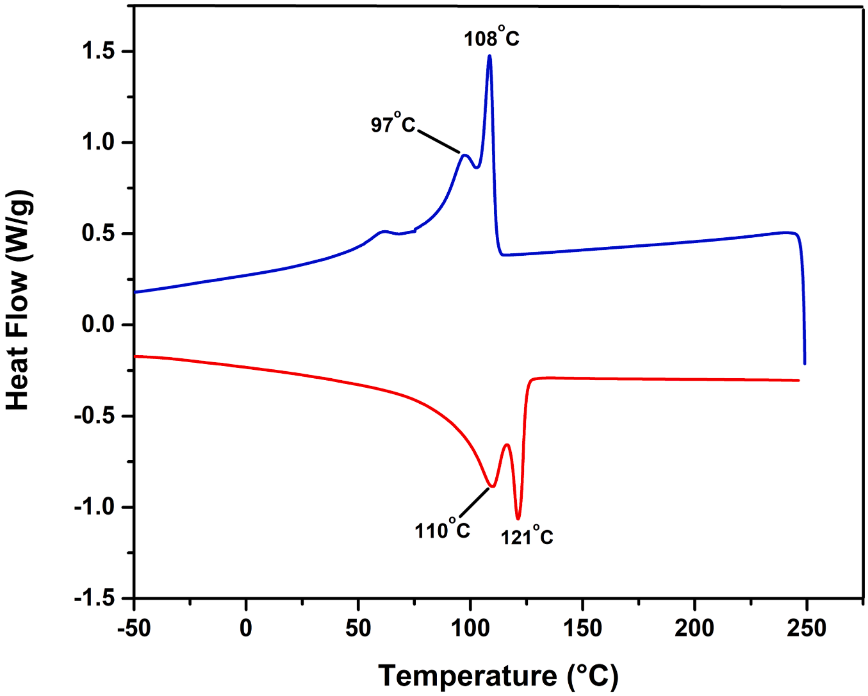

Fig. 3. : Cooling (upper-blue) and second heating (lower-red) curves of waste packaging material.

of two melting peaks and two crystallization peaks corresponding to LDPE and LLDPE confirms that the waste packaging material consists of a blend of LDPE and LLDPE, which was also confirmed by FTIR analysis. The waste packaging material completely melted at 131.8 ℃. Accordingly, 140 ℃ was chosen as the processing temperature to ensure the complete melting of the polymer matrix.

The FTIR-ATR analysis was conducted for a more precise characterization of the textile waste material and the spectrum is presented in Fig. 2-a. The most characteristic bands for polyester fibers are at around 1712 cm^{-1}, 1246 cm^{-1}, 1095 cm^{-1}, and 721 cm^{-1}, corresponding to ester linkages [14]. The peak at 2854 cm^{-1} is attributed to -CH2- stretching, while the peak at 1712 cm^{-1} indicates C═O (carbonyl) stretching vibration, 1017 cm^{-1} indicates secondary alcohol, 1246 $cm^{-1,}$ and 1095 cm^{-1} peaks indicate C–O vibrations. The characteristic peak at 721 cm^{-1} is attributed to the benzene rings [19]. The peaks at 1576 cm^{-1} and 1407 cm^{-1}, respectively, indicate the aromatic ring and methylene groups of polyester. The peak at 970 cm^{-1} indicates C═C stretching, and the 870 cm^{-1} peak indicates five substituted H in benzene. Similar results have been acquired in previous studies [14].

The tensile strength and Young's Modulus of developed composites are presented in Fig. 4. According to the experimental results, first, the tensile strength and Young's modulus values have increased with

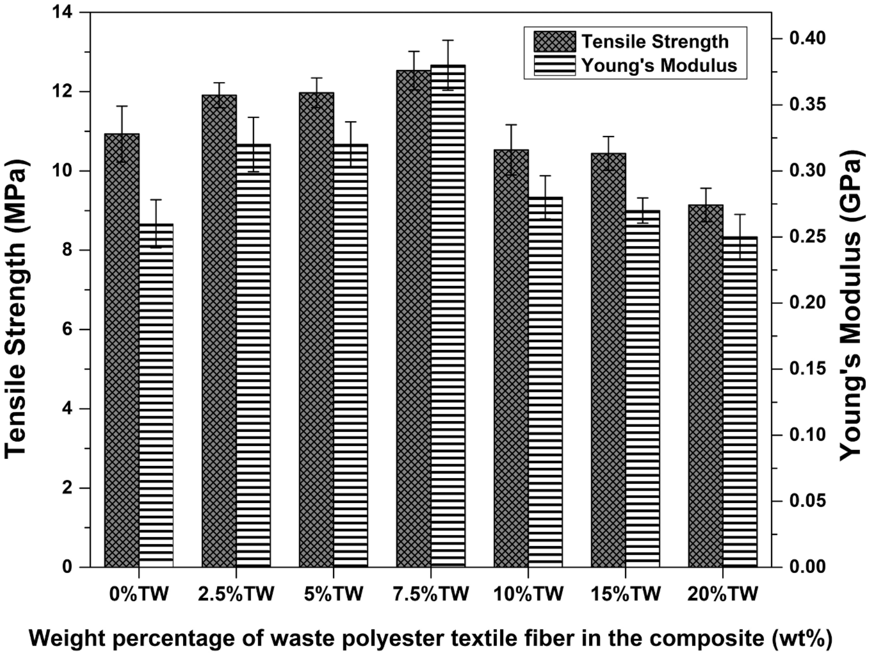

Fig. 4. : Tensile properties of waste polyester textile fiber-reinforced composites with different compositions of textile waste (TW).

increasing fiber loading in the composites. However, both tensile strength and Young's modulus have decreased with increasing reinforcement fiber loading, further. Out of the weight loadings tested, 7.5 wt% fiber-reinforced composite exhibited the highest tensile strength and Young's modulus of 12.53 MPa and 0.38 GPa, respectively. Increasing the fiber reinforcement to 10 wt% decreased the tensile strength and Young's modulus to 10.53 MPa and 0.28 GPa.

Usually, the weight loading of reinforcement added to the composites contributes to the variation of tensile strength and Young's modulus. However, for a significant increase in tensile properties, there should be good interfacial adhesion between fibers and matrix facilitating efficient stress transfer from the matrix to the fibers under the load [13]. The reduction in tensile properties of the developed composites after 7.5 wt % fiber loading can also be attributed to the increment of insufficient interaction between fibers and matrix, resulting from the increased fiber loading in the composites [58]. The quantity of reinforcement present in a fiber-reinforced composite plays a noteworthy role in guaranteeing a uniform distribution of stress [54]. As such, at lower levels of matrix loadings, since the fiber loading is higher, the stress transfer turn out to be more challenging due to inadequate wetting of the fibers by the matrix. At the increased fiber loadings, the stress transfer becomes more challenging because of the insufficient wetting of the increased population of fibers by the matrix. This leads to lower values of tensile properties [6,54].

The polyester textile fiber-reinforced composites developed in this study have exhibited a higher tensile strength compared to the wood particleboards used in structural applications (6–10 MPa). However, they have a low Young's modulus [33]. Moreover, Young's modulus of these composites is lower than commercial furniture-grade wood particleboard [59]. Moreover, the tensile properties of the developed composites were comparatively lower than the waste cotton textile shoddy web-reinforced epoxy composites which are comparable to commercial wood [41]. Furthermore, the tensile strength of the developed composites in this study is lower than the waste cotton-reinforced unsaturated polyester composites that can be used in areas where mechanical stresses are low, such as automobile interiors, and door panels [67].

The micrographs of tensile fractured specimens (Fig. 5) were taken to understand the failure modes of the composites during tensile testing. Analysis of the tensile fractured specimen surface shows that the thermoplastic composite failed in the tensile test by typical failure mechanisms of fiber-matrix de-bonding (Fig. 5-B) and fiber breakage (Fig. 5-A). Generally, fiber breakage is an indication of better interfacial bonding [6]. When a load is applied, the polymer matrix transfers the load to the reinforcement fibers. Under excessive tensile stress, the interfacial adhesion between the reinforcement fibers and the matrix is no longer sufficient to bear the stress transfer, resulting in fracture via de-bonding. Moreover, voids (Fig. 5-C) were detected within the tensile fractured surface of the specimens (Fig. 5 A-D).

Fig. 6 presents the three-point bending flexural properties of developed composites with different fiber weight fractions. According to the test results, both flexural strength and flexural modulus of the developed composite have gradually increased with increasing fiber loading and then decreased. Out of the weight loadings tested, 10 wt% fiber-reinforced composites exhibited the highest flexural strength and flexural modulus of 16.31 MPa and 359.63 MPa, respectively. The high flexural strength shows good fiber-matrix adhesion. Increasing the fiber reinforcement to 15 wt% decreased the flexural strength and flexural modulus to 13.31 MPa and 306.18 MPa, respectively.

While 7.5 wt% weight fiber reinforced composite shows better tensile properties, 10 wt% weight fiber reinforced composite exhibits better flexural properties. The discrepancy between tensile and flexural properties in the composite samples could be due to several factors. This includes differences in fiber distribution and orientation between the 7.5 wt% and 10 wt% samples, the distinction between matrix-dominated and fiber-dominated behaviors in different loading scenarios, and possible synergistic effects between fiber content and matrix properties.

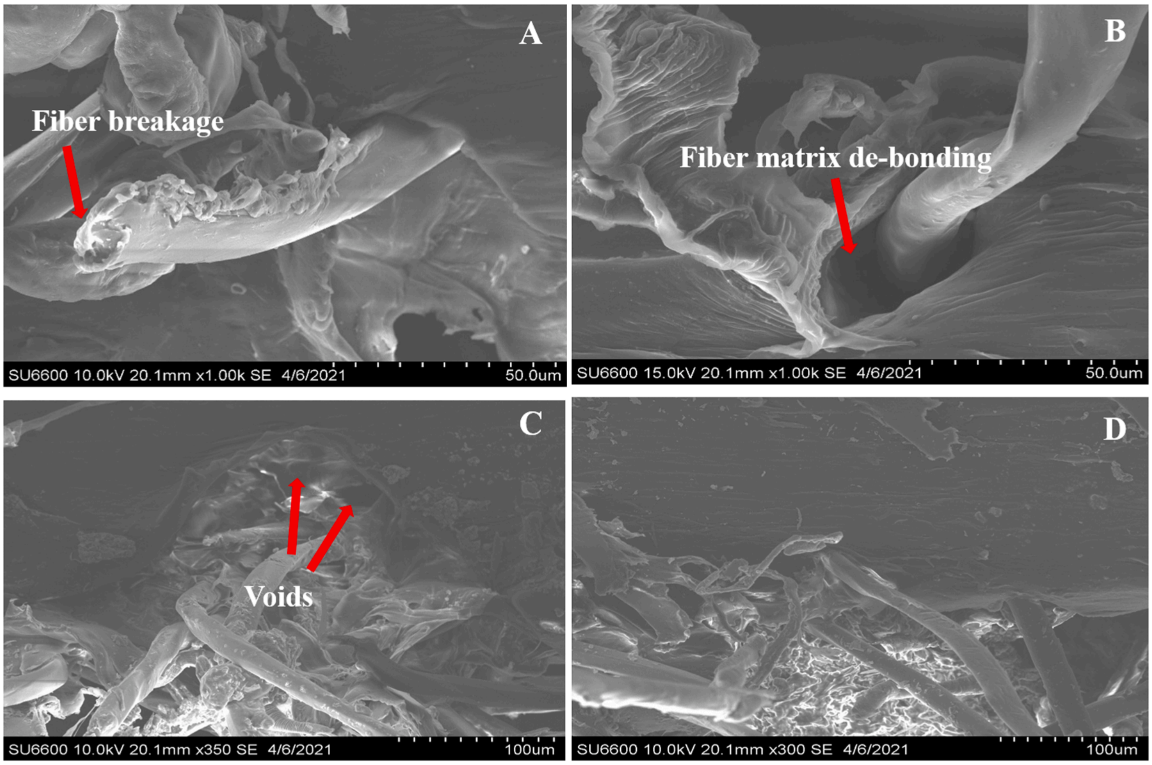

Fig. 5. Scanning Electron Microscopic images of tensile fractured surface of composite specimens showing A) Fiber breakage, B) Fiber matrix de-bonding, C) Voids, and D) Tensile fractured specimen.

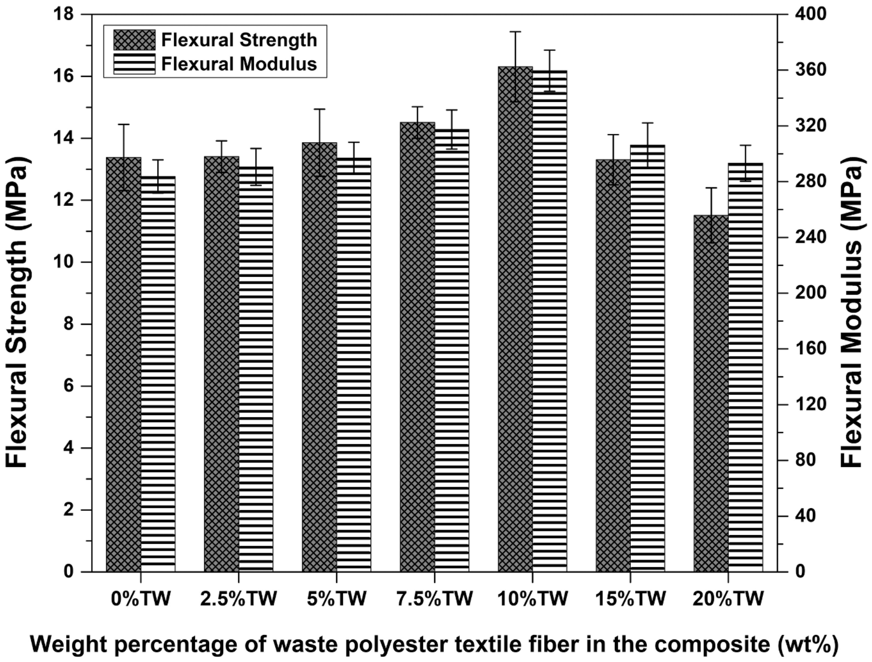

Fig. 6. **:** Flexural properties of waste polyester textile fiber-reinforced composites with different compositions of textile waste (TW).

The decreasing trend of flexural properties can be attributed to the polymer matrix being insufficient to effectively transfer the load to the increased fiber population. This is caused by the polymer matrix not completely encapsulating the reinforcement fibers, leading to poor interfacial adhesion in the composite [58]. The applied load cannot be optimally transferred from the polymer matrix to the higher reinforcement fiber loading. This results in a relatively higher amount of cracks forming upon loading, leading to lower flexural properties.

The flexural strength of these composites is higher than the commercially available general-purpose wood particleboard (> 11.5 MPa) [33]. Moreover, the flexural strength exhibits lower values than the commercially available plywood board (48.3–60 MPa) [27]. The flexural strength of these composites exhibits great potential for use in partitioning, door panels, and automobile interiors owing to their flexural properties [67].

Fig. 7 presents the Izod impact strength of the composites. The impact properties of polymers are directly associated with their toughness. Toughness is the ability of a material to absorb the applied energy and resist fracturing under applied load. Impact failure of fiber-reinforced polymer composites occurs through the processes of plastic deformation of the matrix, de-bonding at the fiber/matrix interface, fracturing reinforcement fiber, and fiber pull-out [44].

As results indicated, the impact strength has increased with the increment of fiber loading in the developed composites, indicating that waste polyester textile fibers have a positive contribution to the Izod impact strength of the composites. The fiber volume fraction plays a

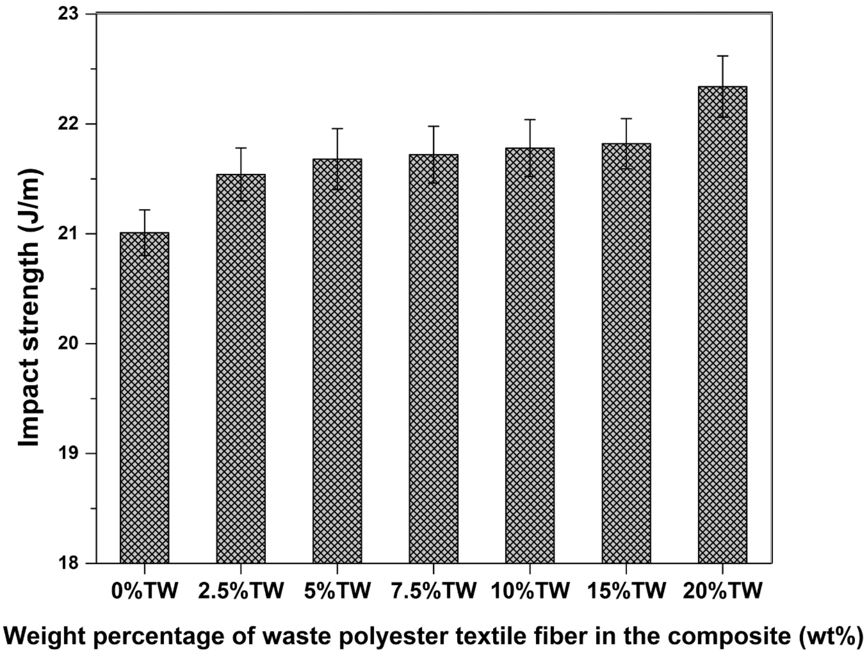

Fig. 7. **:** Izod impact strength of waste polyester textile fiber-reinforced thermoplastic composites with different compositions of textile waste (TW).

major role in impact strength increase [62]. However, there is no significant increase in the impact strength of all the developed composites with the values remaining between 21– 22.4 J/m. Moreover, the izod impact strength of developed composites is lower than the commercial medium-density fiberboard –MDF (< 37 J/m) [66].

Unlike the other mechanical properties such as tensile strength, flexural strength, and hardness, the Izod impact strength exhibits an improving trend with increasing fiber loading in the composites. This kind of observation is identified because there is a critical fiber fraction for the composites for effective energy absorption [62]. After passing the critical fiber fraction of the composites, the impact strength will be decreased, followed by the lower energy absorption, because above that critical fiber fraction, there is no possibility for increment in energy absorption [44].

The shore D hardness values of the composites are presented in Fig. 8 (a).

As per the hardness results, it was observed that the shore D hardness value of the developed composite has decreased with the addition of fibrous reinforcement. This observation can be attributed to the formation of porosity or voids developed within the composite during the addition of fiber reinforcement [53]. The SEM image in Fig. 8(b) the porosity or voids developed within the composite.

Even though the shore D hardness values of the developed composites have been slightly reduced than the unreinforced matrix (0 wt%), the shore hardness of composites has increased and again decreased with the increasing fiber loading in the composites. However, the hardness values varied from point to point within the same composite specimen. This observation might be due to the uneven random distribution of discontinuous fibers within the matrix [21]. Out of the fiber-reinforced composites tested, 10 wt% fiber-reinforced composites proved to have the highest shore D hardness (41.05 HD). The high shore hardness shows good fiber-matrix adhesion. Increasing the fiber reinforcement to 15 wt% decreased the shore D hardness to 36.22 HD. Moreover, the shore D hardness values of developed composites are lower than the commercial medium-density fiberboard –MDF (< 45–55 HD) and commercial plywood board (<45 HD) [4,29].

The percentages of weight gain followed by water absorption were calculated at regular time intervals and the results are compared in Fig. 9. As presented, the rate of water absorption initially accelerated before gradually slowing as the equilibrium condition was reached. The duration of immersion and the fiber weight percentage of the composites might have contributed to the rate of water absorption. It was observed that the water absorption needs approximately 192 hours (8 days) to reach equilibrium for the composites developed in this research. Among the composites developed in this study, the composites with 20 wt% reinforcement presented the highest water absorption value (3.36 %) compared to the other composites with different fiber loadings.

The results have shown that these composites absorbed a higher amount of water than the unreinforced matrix (0 wt%). This observation can be explained by the fact that the addition of fibers into the polymer matrix has developed the porosity or voids within the composite, which were also evidenced in SEM (Fig. 8-b), This can also be attributed to the extra gaps developed within the composite when adding textile fibers as the poor interfacial adhesion between matrix and reinforcement [16, 17]. Such voids and gaps can facilitate the physisorption of water and then trap the penetrated water within those voids and gaps in the composites. The penetrated water will fill up the voids and gaps rapidly until the space becomes limited.

Although both polyester fabric and polyethylene materials are hydrophobic, water absorption has increased with increasing reinforcement. The hydrophobicity followed by the size of the contact angle for water is higher for PE compared to that of polyester, which means polyester is more hydrophilic [52]. Because of this comparatively high hydrophilicity of the polyester fibers, the water absorption may increase with the increase of fiber reinforcement.

However, these composites have exhibited significantly low values for weight gain percentages for all samples with different fiber loadings, which can be attributed to the hydrophobic nature of both polyester fibers and matrix [24]. All the developed composites have absorbed a negligible quantity of water after 8 days. Additionally, even the 20 wt% fiber-reinforced composites exhibited a lower water absorption value than the commercially available wood particleboards (< 30.8 %) [33, 49]. Furthermore, the composites developed in this study showed show comparable water absorption properties to the commercial asbestos ceiling boards (0.5–3 %) and lower water absorption properties than commercial trilite ceiling boards (< 35 %) [34].

The polyester textile-reinforced composites burned with higher horizontal burning rates, ranging from 31.9 to 40.1 mm/min (Table 1).

The burning rates of these composites have increased with increased fiber loading. While PE is generally considered to be a highly flammable material, polyester fabric is not [26]. At the same time, polyolefin including PE has a relatively Low Oxygen Index (LOI), and it causes dripping when it is burning, which further increases the fire spreading [71]. Although polyester textiles tend to be slow to ignite, they can melt easily at high temperatures. However, once it is ignited, severe burning and dripping occur at a higher rate [22], which is also observed from the obtained results. A major drawback of these composites is their flammability as they tend to burn at higher burning rates with continuous dripping. This suggests the need to use flame retardant additives to delay the burning process.

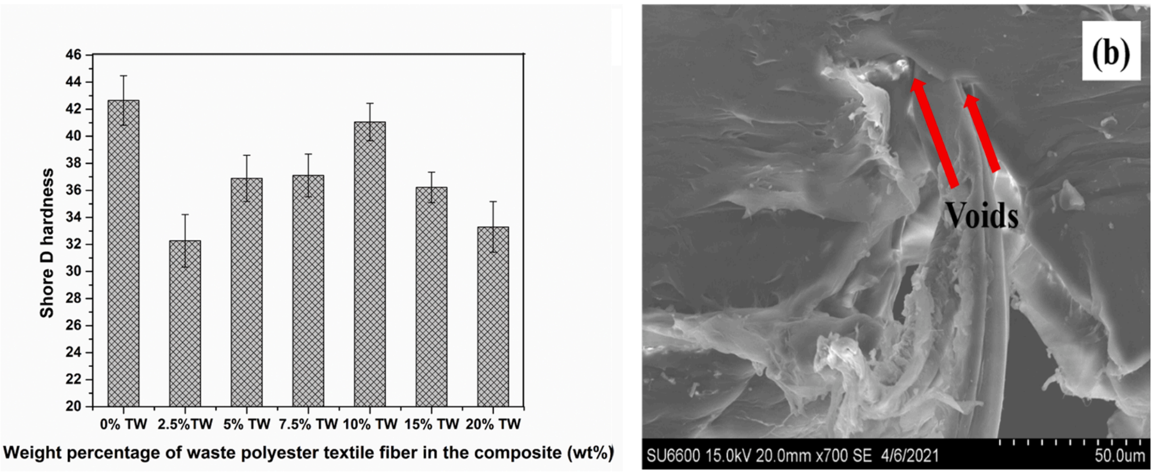

Fig. 8. : a) Shore D hardness of waste polyester textile fiber-reinforced composites with different compositions of textile waste (TW) and b) SEM images showing voids developed in the composite.

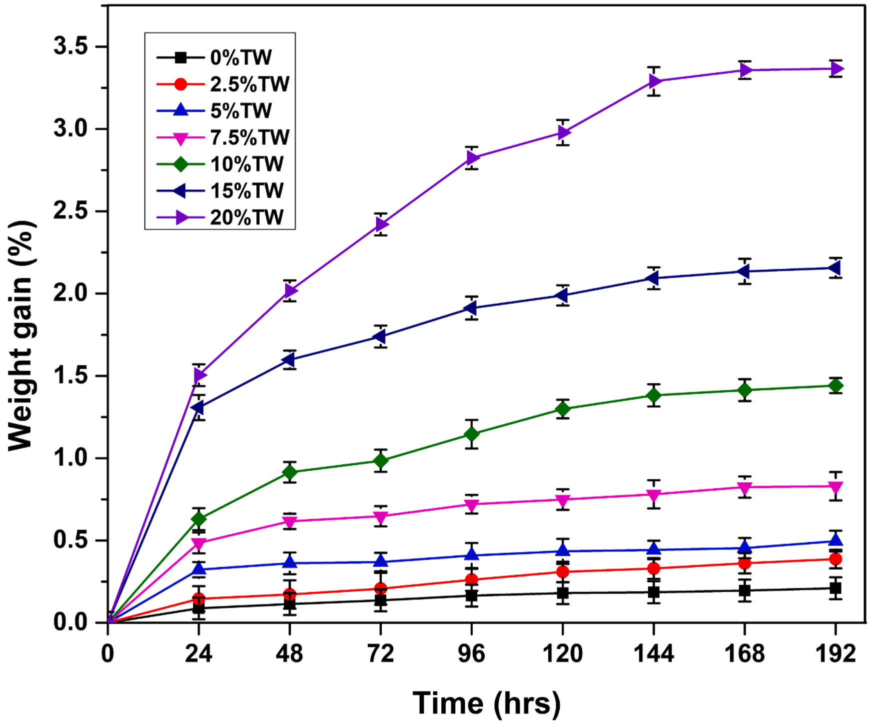

Fig. 9. : Change in weight gain percentage of water-immersed waste polyester textile fiber-reinforced composite specimens with different fiber loadings against time.

Table 1
Flammability test results for waste polyester textile reinforced composites with different weight compositions of textile waste (TW).

Sample name by textile fiber weight percentage	Burning rate (mm/min)
0 %TW	31.91
2.5 % TW	32.47
5 % TW	34.88
7.5 % TW	35.71
10 % TW	35.38
15 % TW	38.46
20 % TW	40.11

Some of the tested properties have been compared with the properties of commercial materials in Table 2.

The findings demonstrate that the developed composites exhibit comparable properties, indicating their potential as substitutes for commercially available materials used in similar applications. If the developed waste-based composite materials become commercially accessible, they possess significant potential for reducing post-industrial waste in the textile industry thereby enabling a significant decrease in environmental impact. This innovative composite not only addresses waste-related issues but also adds value to waste materials while giving a second life to the waste.

4. Conclusions

The current study focused on developing an innovative composite using waste textile and waste packaging materials from the textile industry as the primary raw materials. This approach aims to add value to these waste materials through sustainable chemistry and to evaluate the feasibility of these composites for non-structural building applications. The experimental results, compared with existing literature, suggest that the proposed composites could serve as a viable alternative sustainable material for such applications. The tensile strength of the developed composites ranged from 9.14 to 12.53 MPa, while the Young's Modulus ranged from 0.25 to 0.38 GPa. These values indicate that the composites have higher tensile strength and lower Young's Modulus compared to wood particleboards used in structural applications. The flexural strength ranged from 11.51 to 16.31 MPa, which is higher than that of commercially available general-purpose wood particleboards but lower

Table 2
Comparison of mechanical and physical properties with values reported in the literature.

	Polyester textile waste-based thermoplastic composite	Commercial wood particleboard – general purpose	Commercial plywood board	Medium-density fiberboard - MDF
Tensile strength (MPa)	9.1–12.5	6–10	27.6–31	18
Young's modulus (MPa)	251.3–381.4	550–3100	6000–7000	2500–5000
Flexural strength (MPa)	11.5–16.3	11.5	48.3–60	28–80
Flexural modulus (MPa)	283.7–359.6	Not available	8200–10300	877
Shore hardness (HD)	32.2–42.7	Not available	45	45–55
Density (gcm^{-3})	0.97–1.31	0.5–0.8	0.4–0.7	0.6–0.8
Water absorption (%)	0.08–3.36	70	7.3–12.7	5–8
Reference	This study	(Chiang et al., 2015; [33,49]; Mirindi et al., 2021)	Anderson [4,27]	(Carbide processors inc., 2022; [29])

than plywood boards. The flexural modulus was between 293.27 and 359.63 MPa. Additionally, the Shore D hardness ranged from 32.27 to 42.65 HD, which is slightly lower than that of commercial MDF and plywood boards. The Izod impact strength varied between 21.01 and 21.82 J/m, which is lower than that of commercial MDF. However, the highest observed water absorption value was 3.36 %, which is lower than that of commercially available wood particleboards and comparable to the water absorption properties of commercial asbestos ceiling boards (0.5–3 %).

The study demonstrates that the developed composites possess properties that are either slightly lower than, comparable to, or even superior to those of traditional particleboards, plywood boards, and MDF. Notably, the 7.5 % and 10 % weight fiber-reinforced composites exhibited particularly superior properties among the samples tested. However, a limitation observed during the experiments was the flammability of the developed composites. Future research should focus on enhancing the fire-resistant properties of these composites by incorporating sustainable flame retardants while maintaining their other physical and chemical properties. Additionally, properties that are slightly lower than those of commercial materials could be improved with the use of sustainable additives. This approach shows promise for addressing textile waste issues and creating value-added materials for the construction industry, including applications such as partitioning materials, door panels, lightweight ceiling sheets, signboards, and interior fixtures.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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CRediT authorship contribution statement

R.M.N. Sulochani: Writing – original draft, Visualization, Validation, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **R.A. Jayasinghe:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Data curation, Conceptualization. **G. Priyadarshana:** Writing – review & editing, Validation, Supervision, Resources, Methodology, Data curation, Conceptualization. **A.H.L.R. Nilmini:** Writing – review & editing, Validation, Supervision, Resources, Methodology, Data curation, Conceptualization. **M Ashockline:** Writing – review & editing, Resources, Methodology. **P.D. Dharmaratne:** Writing – review & editing, Resources, Methodology.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author(s) used ChatGPT suitably to improve readability and the English language. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication

Data Availability

Data will be made available on request.

References

[1] S. Acharya, S.S. Rumi, Y. Hu, N. Abidi, Microfibers from synthetic textiles as a major source of microplastics in the environment: a review, Text. Res. J. *9* (17–18) (2021) 2136–2156, https://doi.org/10.1177/0040517521991244.

[2] M.A. Al Faruque, R. Remadevi, J. Razal, X. Wang, M. Naebe, Investigation on structure and characteristics of alpaca-based wet-spun polyacrylonitrile composite fibers by utilizing natural textile waste, J. Appl. Polym. Sci. *137* (7) (2019), https://doi.org/10.1002/app.48370.

[3] N.M. Aly, M.A. Saad, E.H. Sherazy, O.M. Kobesy, A.A. Almetwally, Impact properties of woven reinforced sandwich composite panels for automotive applications, J. Ind. Text. *42* (3) (2013) 204–218, https://doi.org/10.1177/1528083711433912.

[4] C. Anderson, Hardness Testing with a Durometer, Retrieved March 22 (2021) 2022. ⟨https://andersonmaterials.com/hardness-testing-with-a-durometer/g⟩ (from).

[5] R.C. Asensio, M.S.A. Moya, J.M. de la Roja, M. Gómez, Analytical characterization of polymers used in conservation and restoration by ATR-FTIR spectroscopy, Anal. Bioanal. Chem. *395* (7) (2009) 2081–2096, https://doi.org/10.1007/s00216-009-3201-2.

[6] M. Asim, M. Jawaid, A. Khan, A.M. Asiri, M.A. Malik, Effects of Date Palm fibres loading on mechanical, and thermal properties of Date Palm reinforced phenolic composites, J. Mater. Res. Technol. *9* (3) (2020) 3614–3621, https://doi.org/10.1016/j.jmrt.2020.01.099.

[7] ASTM. (2010a). *Standard Test Method for Water Absorption of Plastics* (Vol. 16). West Conshohocken, United States.

[8] ASTM. (2010b). *Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials*. West Conshohocken, United States.

[9] ASTM. (2014). *Standard Test Method for Tensile Properties of Plastics*. https://doi.org/10.1520/D0638-14.1.

[10] ASTM. (2015). *Standard Test Method for Rubber Property — Durometer Hardness*. https://doi.org/10.1520/D2240-15.2.

[11] ASTM. (2016). *Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics*. https://doi.org/10.1520/D0256-10.

[12] C. Baillie, D. Matovic, T. Thamae, S. Vaja, Waste-based composites — Poverty reducing solutions to environmental problems, Resour. Conserv. Recycl. *55* (11) (2011) 973–978, https://doi.org/10.1016/j.resconrec.2011.05.006.

[13] M. Bakkal, M.S. Bodur, O.B. Berkalp, S. Yilmaz, The effect of reprocessing on the mechanical properties of the waste fabric reinforced composites, J. Mater. Process. Technol. *212* (11) (2012) 2541–2548, https://doi.org/10.1016/j.jmatprotec.2012.03.008.

[14] S. Bhattacharya, S.B. Chaudhari, Study on Structural, Mechanical and Functional Properties of Polyester Silica Nanocomposite Fabric, Int. J. Pure Appl. Sci. Technol. *21* (1) (2014) 43–52.

[15] M.S. Bodur, M. Bakkal, M. Savas, O.B. Berkalp, A new approach for the development of textile waste cotton reinforced composites (T-FRP): laminated hybridization vs. coupling agents, J. Polym. Eng. *34* (7) (2014) 639–648, https://doi.org/10.1515/polyeng-2013-0281.

[16] M.S. Bodur, M. Bakkal, H.E. Sonmez, A study on the Photostabilizer additives on the textile fiber reinforced polymer composites: mechanical, thermal, and physical analysis, Polym. Eng. Sci. (2017), https://doi.org/10.1002/pen.24670.

[17] M.S. Bodur, K. Englund, M. Bakkal, Water absorption behavior and kinetics of glass fiber / waste cotton fabric hybrid composites, J. Appl. Polym. Sci. *134* (47) (2017), https://doi.org/10.1002/app.45506.

[18] S. Bolduc, K. Jung, P. Venkata, M. Ashokcline, R. Jayasinghe, C. Baillie, L. Lessard, Banana fiber/low-density polyethylene recycled composites for third world eco-friendly construction applications – Waste for life project Sri Lanka, J. Reinf. Plast. Compos. *37* (21) (2018) 1322–1331, https://doi.org/10.1177/0731684418791756.

[19] E. Bozaci, B. Arik, A. Demir, E. ÖzdoĞan, Potential use of new methods for identification of hollow polyester fibres, Tekst. Konfeksiyon *4* (2012) 317–323.

[20] V.O. Bulatović, L. Mandić, A. Turković, D.K. Grgić, A. Jozinović, R. Zovko, E. G. Bajsić, Environmentally Friendly Packaging Materials Based on Thermoplastic Starch, Chem. Biochem. Eng. Q. *33* (3) (2019) 347–361, https://doi.org/10.15255/CABEQ.2018.1548.

[21] N.G. Chanshetti, A.S. Pol, Wear Behavior of TiO 2 and WC Reinforced Epoxy Resin Composites, Int. Res. J. Eng. Technol. *3* (7) (2016) 2342–2346.

[22] City of Phoenix. (2021). Flammable Fabrics. Retrieved February 12, 2023, from ⟨https://www.phoenix.gov/fire/safety-information/home/fabrics⟩.

[23] M.J. Cran, S.W. Bigger, J. Scheirs, Characterizing blends of linear low-density and low-density polyethylene by DSC, J. Therm. Anal. Calorim. *81* (2005) 321–327, https://doi.org/10.1007/s10973-005-6624-9.

[24] C.A. Echeverria, W. Handoko, F. Pahlevani, V. Sahajwalla, Cascading use of textile waste for the advancement of fibre reinforced composites for building applications, J. Clean. Prod. *208* (2)) (2019) 1524–1536, https://doi.org/10.1016/j.jclepro.2018.10.227.

[25] Ellen MacArthur Foundation. (2017). *A new textiles economy: redesigning fashion's future*. Retrieved from ⟨http://www.ellenmacarthurfoundation.org/publications⟩.

[26] Emily. (2022). Polyester Flammability – How Does It Stand Up To Heat? Retrieved March 21, 2022, from THe creative folk website: ⟨https://www.thecreativefolk.com/polyester-flammability/⟩.

[27] Engineering ToolBox. (2011). Wood, Panel and Structural Timber Products - Mechanical Properties. Retrieved March 25, 2022, from ⟨https://www.engineeringtoolbox.com/timber-mechanical-properties-d_1789.html⟩.

[28] R.L.S. Fernando, Solid waste management of local governments in the Western Province of Sri Lanka: An implementation analysis, Waste Manag *84* (2019) 194–203, https://doi.org/10.1016/j.wasman.2018.11.030.

[29] Freeman. (2021). MDF - Medium Density Fiberboard. Retrieved January 20, 2023, from FREEMAN manufacturing & supply company website: 〈https://www.freemansupply.com/products/machinable-media/mdf—medium-density-fiberboard〉.

[30] Gannoruwa, G.K.B.M., Nanayakkara, S.M.A., & Muthurathna, S.S.K. (2019). Utilization of Textile Waste in Development of Interlocking Paving Blocks for Foot Paths. In R. Dissanayake, P. Mendis, K. Weerasekera, S. De Silva, & S. Fernando (Eds.), *Proceedings of the 10th International Conference on Structural Engineering and Construction Management* (pp. 543–554). https://doi.org/https://doi.org/10.1007/978-981-15-7222-7_44.

[31] U.B. Govalkar, R. Rao, Structural and non-structural components, *Habitat.: Holist. Approaches Build., Inter. Tech. Syst.* (2024) 64–75, https://doi.org/10.52458/9788196897444.nsp2024.eb.ch-04.

[32] J.V. Gulmine, P.R. Janissek, H.M. Heise, L. Akcelrud, Polyethylene characterization by FTIR, Polym. Test. *21* (5) (2002) 557–563, https://doi.org/10.1016/S0142-9418(01)00124-6.

[33] T.E. Hamouda, A.H. Hassanin, N. Saba, M. Demirelli, A. Kilic, Z. Candan, M. Jawaid, Evaluation of Mechanical and Physical Properties of Hybrid Composites from Food Packaging and Textiles Wastes, J. Polym. Environ. *27* (31) (2019) 489–497, https://doi.org/10.1007/s10924-019-01369-3.

[34] A.H.I. Ibrahim, P.A.S. Ern, M.S. Abdullah, Preliminary Study of Ceiling Board from Composite Material of Rice Husk, Rice Husk Ash and Waste Paper, Prog. Eng. Appl. Technol. *1* (1) (2020) 104–115.

[35] M.M. Islam, P. Perry, S. Gill, Mapping environmentally sustainable practices in textiles, apparel and fashion industries: a systematic literature review, J. Fash. Mark. Manag. *25* (2) (2021) 331–353, https://doi.org/10.1108/JFMM-07-2020-0130.

[36] R. Jayasinghe, C. Baillie, Engineering with people: a participatory needs and feasibility study of a waste-based composite manufacturing project in Sri Lanka. In *Green.* Composites: Waste and nature-based materials for a sustainable future, Woodhead Publishing, 2017, pp. 149–180.

[37] R. Jayasinghe, N. Liyanage, C. Baillie, Sustainable waste management through eco - entrepreneurship: an empirical study of waste upcycling eco - enterprises in Sri Lanka, J. Mater. Cycles Waste Manag. *23* (5) (2020) 557–565, https://doi.org/10.1007/s10163-020-01140-0.

[38] M. Jayaweera, B. Gunawardana, M. Gunawardana, A. Karunawardena, V. Dias, S. Premasiri, S. Thilakasiri, Management of municipal solid waste open dumps immediately after the collapse: An integrated approach from Meethotamulla open dump, Sri Lanka, Waste Manag. *95* (2019) 227–240, https://doi.org/10.1016/j.wasman.2019.06.019.

[39] C. Jönsson, R. Wei, A. Biundo, J. Landberg, L.S. Bour, F. Pezzotti, P.-O. Syrén, Biocatalysis in the Recycling Landscape for Synthetic Polymers and Plastics towards Circular Textiles, ChemSusChem *14* (2021) 4028–4040, https://doi.org/10.1002/cssc.202002666.

[40] M.R. Jung, F.D. Horgen, S.V. Orski, V.R. C, K.L. Beers, G.H. Balazs, J.M. Lynch, Validation of ATR FT-IR to identify polymers of plastic marine debris, including those ingested by marine organisms, Mar. Pollut. Bull. *127* (2018) 704–716, https://doi.org/10.1016/j.marpolbul.2017.12.061.

[41] Z. Kamble, B.K. Behera, Mechanical properties and water absorption characteristics of composites reinforced with cotton fibres recovered from textile waste, J. Eng. Fibers Fabr. *15* (2020) 1–8, https://doi.org/10.1177/1558925020901530.

[42] Z. Kamble, B.K. Behera, Fabrication and performance evaluation of waste cotton and polyester fiber-reinforced green composites for building and construction applications, Polym. Compos. *42* (6) (2021) 3025–3037, https://doi.org/10.1002/pc.26036.

[43] M.I. Khan, L. Wang, R. Padhye, Textile waste management in Australia: A review, Resour., Conserv. Recycl. Adv. *18* (2023) 200154, https://doi.org/10.1016/j.rcradv.2023.200154 (Available).

[44] A. Koffi, D. Koffi, L. Toubal, Mechanical properties and drop-weight impact performance of injection-molded HDPE / birch fiber composites, Polym. Test. *93* (2021), https://doi.org/10.1016/j.polymertesting.2020.106956.

[45] J. Korol, A. Hejna, K. Wypiór, K. Mijalski, E. Chmielnicka, Wastes from Agricultural Silage Film Recycling Line as a Potential Polymer Materials, Polym *13* (9) (2021) 1383, https://doi.org/10.3390/polym13091383.

[46] S.S. Kumar, G. Kanagaraj, Investigation on Mechanical and Tribological Behaviors of PA6 and Graphite-Reinforced PA6 Polymer Composites, Arab. J. Sci. Eng. *41* (2016) 4347–4357, https://doi.org/10.1007/s13369-016-2126-2.

[47] W. Leal Filho, D. Ellams, S. Han, D. Tyler, V. Boiten, A. Paço, A.-L. Balogun, A Review of the socio-economic advantages of textile recycling, J. Clean. Prod. *218* (2019) 10–20, https://doi.org/10.1016/j.jclepro.2019.01.210.

[48] R.E. Marshall, K. Farahbakhsh, Systems approaches to integrated solid waste management in developing countries, Waste Manag. *33* (2013) 988–1033, https://doi.org/10.1016/j.wasman.2012.12.023.

[49] R.R. de Melo, M. Muhl, D.M. Stangerlin, R.F. Alfenas, F.R. Junior, Properties of particleboards submitted to heat treatments, Ciênc. Florest. *28* (2) (2018) 776–783, https://doi.org/10.5902/1980509832109.

[50] E.C. Miranda, P.G. Prado, C. León-Velarde, A Systematic Review of Polluting Processes Produced by the Textile Industry and Proposals for Abatement Methods, Text. Leather Rev. *7* (2024) 88–103, https://doi.org/10.31881/TLR.2023.165.

[51] R. Muthuraj, C. Lacoste, P. Lacroix, A. Bergeret, Sustainable thermal insulation biocomposites from rice husk, wheat husk, wood fibers and textile waste fibers: Elaboration and performances evaluation, Ind. Crops Prod. *135* (2019) 238–245, https://doi.org/10.1016/j.indcrop.2019.04.053.

[52] N. Myshkin, A. Kovalev, Adhesion and surface forces in polymer tribology — A review, Friction *6* (2) (2018) 143–155, https://doi.org/10.1007/s40544-018-0203-0.

[53] M.U. Obidiegwu, O. Ogbobe, Mechanical and flammability properties of low density polyethylene/ Kola Nitida wood fibre composites, Acad. Res. Int. *2* (3) (2012) 230–238.

[54] S. Özturk, Effect of Fiber Loading on the Mechanical Properties of Kenaf and Fiberfrax Fiber-reinforced Phenol-Formaldehyde Composites, J. Compos. Mater. *44* (19) (2010) 2265–2288, https://doi.org/10.1177/0021998310364265.

[55] Park, C. (2017). *TransTextile Project: High Value Innovation For Industrial Textile Waste in Sri Lanka*". UK.

[56] N. Pensupa, Recycling of end-of-life clothes, *Sustain. Technol. Fash. Text.* (2020) 251–309, https://doi.org/10.1016/B978-0-08-102867-4.00012-8.

[57] N. Pensupa, S.L. Yunzi, H. Chenyu, Recent Trends in Sustainable Textile Waste Recycling Methods: Current Situation and Future Prospects. Top. Curr. Chem. *375* (76) (2017) https://doi.org/10.1007/s41061-017-0165-0.

[58] K. Ramraji, K. Rajkumar, M. Dhananchezian, P. Sabarinathan, Key Experimental Investigations of cutting dimensionality by Abrasive Water Jet Machining on Basalt Fiber / Fly ash Reinforced Polymer Composite, Mater. Today.: Proc. *22* (2020) 1351–1359, https://doi.org/10.1016/j.matpr.2020.01.428.

[59] J. Rathke, U. Muller, J. Konnerth, G. Sinn, Strain Measurements within Fibreboard. Part III_ analyzing the process zone at the crack tip of medium density fiberboards (MDF) double cantilever i-beam specimens, Mater *5* (11) (2012) 2190–2204, https://doi.org/10.3990/ma5112190.

[60] S.I. Sarker, I. Bartok, Global trends of green manufacturing research in the textile industry using bibliometric analysis, Case Stud. Chem. Environ. Eng. 9 (2024) 100578, https://doi.org/10.1016/j.cscee.2023.100578.

[61] M. Schmutz, C. Som, Identifying the potential for circularity of industrial textile waste generated within Swiss companies, Resour. Conserv. Recycl. *182* (2022) 106132, https://doi.org/10.1016/j.resconrec.2021.106132.

[62] Y.S. Song, J.T. Lee, D.S. Ji, M.W. Kim, S.H. Lee, J.R. Youn, Viscoelastic and thermal behavior of woven hemp fiber reinforced poly (lactic acid) composites. *Compos. B. 43* (3) (2012) 856–860, https://doi.org/10.1016/j.compositesb.2011.10.021.

[63] Statista. (2024). Global synthetic fibers market value 2022-2030. Retrieved August 9, 2024, from 〈https://www.statista.com/statistics/1308221/global-synthetic-fibers-market-value/〉.

[64] R.M.N. Sulochani, R.A. Jayasinghe, A.H.L.R. Nilmini, G. Priyadarshana, Towards a sustainable textile industry: A preliminary status quo analysis of the textile waste management in Sri Lanka, Proc. 7th Int. Conf. Multidiscip. Approaches (ICMA) – 2020 30 (2020). Retrieved from, 〈http://graduate.sjp.ac.lk/icma/past-conferences/icma-2020/〉.

[65] R.M.N. Sulochani, R.A. Jayasinghe, A.H.L.R. Nilmini, G. Priyadarshana, Recent Developments in Textile Reinforced Polymer Composites - A Review, Asian J. Chem. *34* (3) (2022) 487–496.

[66] A. Thumm, D. Even, P.-Y. Gini, M. Sorieul, Processing and properties of MDF Fiber-reinforced Biopolyesters with Chain Extender Additives, Int. J. Polym. Sci. (2018), https://doi.org/10.1155/2018/9601753.

[67] M. Umar, K. Shaker, S. Ahmad, Y. Nawab, M. Umair, M. Maqsood, Investigating the mechanical behavior of composites made from textile industry waste, J. Text. Inst. (2016), https://doi.org/10.1080/00405000.2016.1193982.

[68] K. Vadiwala, M. Vaghani, An Overview Reuse of Solid Waste for Constructing Building Materials, Int. J. Sci. Res. Dev. *3* (2015).

[69] R.E. Vera, A. Suarez, F. Zambrano, R. Marquez, J. Bedard, A.K. Vivas, R. Gonzalez, Upcycling cotton textile waste into bio-based building blocks through an environmentally friendly and high-yield conversion process, Resour. Conserv. Recycl. *189* (February)) (2023) 106715, https://doi.org/10.1016/j.resconrec.2022.106715.

[70] S. Yousef, M. Tatariants, M. Tichonovas, Z. Sarwar, I. Jonuškienė, A new strategy for using textile waste as a sustainable source of recovered cotton, Resour. Conserv. Recycl. *145* (February) (2019) 359–369, https://doi.org/10.1016/j.resconrec.2019.02.031.

[71] J.D. Zuo, S.M. Liu, Q. Sheng, Synthesis and application in polypropylene of a novel of phosphorus-containing intumescent flame retardant, Mol *15* (11) (2010) 7593–7602, https://doi.org/10.3390/molecules15117593.