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Research article

Potentiality of sustainable corn starch-based biocomposites reinforced with cotton filter waste of spinning mill

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ABSTRACT

The textile sector is among the leading industries globally in terms of releasing pollutants and producing waste. Despite being reusable, many wastes are squandered by disposing to landfills or incineration, creating a serious environmental threat. Because the cost of raw materials makes up a significant portion of the total product cost, manufacturers can obtain significant profits by exploiting waste generated during the manufacturing process. Herein, an attempt has been taken to utilize cotton filter waste (CFW) (collected from the humidification plant of the spinning mill) as reinforcement in manufacturing biocomposites with the corn starch (CS) matrix. Starch was considered to be the most suitable matrix as it is sustainable, abundant, natural, biodegradable, and, more importantly, capable of showing thermoplastic behavior under high temperatures. Sheets of corn starch composites reinforced with different wt% of cleaned cotton filter waste were fabricated using hand layup and compression molding techniques. The 50 wt% cotton waste was found to be optimum loading in terms of tensile strength, Young's modulus, bending strength, toughness, impact strength, and thermal Conductivity of the biocomposites. SEM micrographs revealed good interfacial adhesion (bonding) in matrix and filler interfaces, with the most substantial bonding for composites containing 50% fibers that concomitantly enhanced the mechanical properties of composites. The obtained biocomposites are deemed to be a sustainable alternative to non-degradable synthetic polymeric materials like Styrofoam for packaging and insulation applications.

1. Introduction

Textile wastes are produced throughout all stages of textile production, ranging from spinning to the manufacturing of finished garments, and even at the consumer level. In the past few decades, fashion trends have undergone rapid growth and evolution, leading to a significant increase in textile production and a surge in waste generation rates [1–3]. Textile spinning mills generate waste in different sections containing a great number of fibers which can be classified as useable and unusable waste (Fig. 1). Roughly 8% of waste materials can be found in the blow room and carding section, while the combing section generates about 15–20% waste [4–6]. These wastes, mainly composed of short fibers, are converted into coarser yarns by rotor spinning system to produce jeans and denim fabrics [7]. In addition, various spinning machines involved in the production of yarn make up approximately 1% of cotton fly waste that is accumulated in the humidification plant, called filter waste. They are either disposed of to landfill or directly incinerated in the environment or used with cow dung to make biofuels [8,9] (Fig. 2a and b).

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A recent estimation shows that the worldwide utilization of textile fibers is around 108 million tons, out of which cotton comprises 25% of the total share [11]. Every year, the global production of cotton fiber waste amounts to approximately 27 million tons [12]. Within this, about 1% of cotton fly waste is generated in various sections of spinning mills, while roughly 0.27 million tons of filter waste are produced from that cotton [8]. As per Bangladesh Textile Mills Association (BTMA), Bangladesh currently has 510 spinning mills and additional mills are being set up to fulfill orders for clothing exports to various countries including the USA, UK, Canada, Australia, and several nations within the European Union. Bangladesh imported up to 2.0 million tons of raw cotton in 2021 for the purpose of producing yarn and the import will be up by 43% year-on-year amid the rising demands [13]. If the collected cotton filter waste accounts for 1%, then it turns out to be a total of 20,000 tons filter waste every year.

The Environment Protection Act of 2017 established a structure to address responsibilities for individuals involved in the production, transportation, or receipt of industrial waste [14]. The act gave the Environment Protection Authority (EPA) enhanced powers to prevent and minimize the risks of environmental pollution and human health from waste. The act provides stronger penalties to bring the environmental polluters into account. The act also promotes and motivates the recycling of waste and the recovery of resources to minimize the amount of waste sent to landfills. From that perspective, the cost of waste-disposal systems, along with the reduction of the depletion of natural resources, has forced manufacturers to look for effective ways to utilize the waste.

Plastic packaging, especially polystyrene or Styrofoam, is widely used to protect and preserve foods, electronics and other fragile materials [15]. Single-use packaging materials, when discarded, can become a form of urban or marine waste, posing a risk to both the environment and human health. It has been reported that plastic is a global pollutant found in water sources, making up approximately 60–95% of marine waste [16]. This plastic waste is entering the bodies of marine animals and fish [17]. A study of 29 flooded areas in Swiss nature reserves revealed that 90% of floodplain soils had microplastic contamination [18]. This soil contamination with plastic is problematic for livestock production, and crops grown in such soil threaten human food security. Due to a large amount of environmentally harmful plastic waste, researchers are exploring the use of natural resources to produce polymers that are renewable, biodegradable, and sustainable.

Due to the growing environmental concerns associated with non-biodegradable plastics, there has been a significant interest in investigating biopolymers as a promising substitute for petroleum-based plastics [19,20]. Polysaccharides such as chitosan, cellulose, and starch, as well as proteins like whey protein, soy protein, and silk fibroin, have the potential as raw materials for creating biodegradable materials [21]. Starch is a crucial macronutrient found in many foods, serving as a major energy source for the human body and providing 86 glucose [22]. Starch-based fully biodegradable materials are largely studied since starch is naturally abundant, non-toxic, biocompatible, renewable, and more importantly, can form films [23–26]. These materials show great promise for use as sustainable food packaging, which would help to reduce environmental pollution. Additionally, the functional properties of these biodegradable materials can be improved by incorporating various biopolymers [21]. Natural fibers are sustainable, easily available, low cost, lightweight, renewable and biodegradable, and hence the composites based on natural fibers have led to an upsurge in their applications in various sectors to replace their synthetic counterparts.

A study conducted by Amin et al. investigated how adding titanium dioxide nanoparticles to corn starch affected the performance of composite bioplastics [27]. Hazrol et al. produced corn starch-based biocomposite film by using kenaf fiber as reinforcing material [28]. Kamble and Behera produced thermoset composites reinforced with cotton waste fiber and assessed their mechanical, thermal degradation, dynamic mechanical, and water absorption properties [29]. Yang Shi et al. developed a multilayer waste cotton fiber biocomposite using phenol-formaldehyde (PF) resin. The properties of the biocomposites were found to be better than the current medium-density dry fiberboard and bearing-type dry particle boards concerning bending strength and water expansion [30].

Taking the aforementioned studies into consideration, cotton filter waste from spinning mills can be considered to be a promising

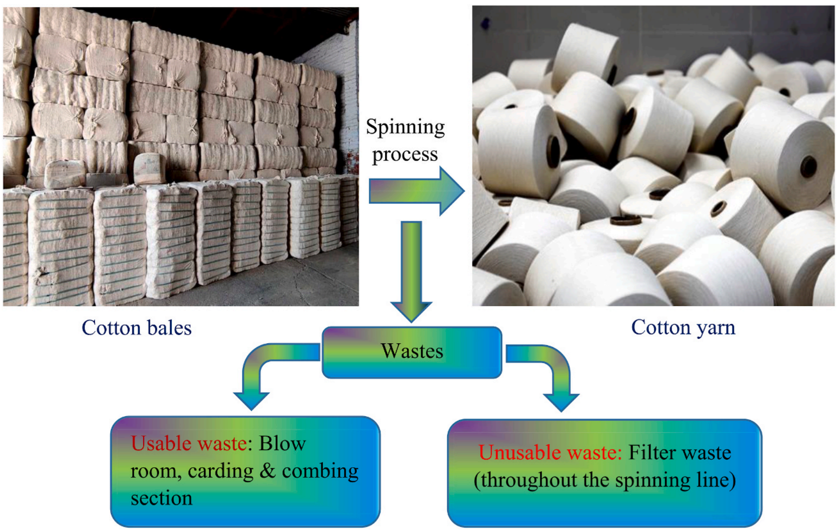

Fig. 1. Generation of cotton wastes in spinning line.

Fig. 2. (a) Typical view of dumping of textile wastes in Bangladesh [10], and (b) Biofuels made from cow dung mixing with filter waste.

candidate to reinforce starch-based materials that will ultimately be green composites. Green composites refer to composites that utilize natural fibers as reinforcement and a bio-based polymer as the matrix. One of the most significant attributes of these composites is their ability to biodegrade [31–34].

The present paper introduces potential applications of cotton filter waste from the spinning mill in developing corn starch-based

Fig. 3. (a) Rotary drum filter of ring frame section of spinning mill to collect cotton filter waste of humidification plant, (b) collected filter waste, and (c) cleaned filter waste after cleaning by Shirley analyzer.

biocomposite by using techniques such as hand layup and compression molding. The morphology and mechanical properties of prepared biocomposites were thoroughly investigated.

2. Materials and methods

2.1. Materials

Cotton filter waste that is accumulated by a rotary drum filter of spinning mill (Fig. 3a and b) was collected from Matin spinning mills limited, Gazipur, Bangladesh. To remove impurities and non-fiber materials like sand, dust, and leaf fragments, the waste was put twice through the Shirley Analyzer (Fig. 3c). After separating the impurities from the waste, short cotton fiber was found to be around 80%. Shirley Comb Sorter was used to measure the fiber length and it was found to be in the range of 3–5 mm.

Corn starch, consists of about 28% amylose and 72% amylopectin, was purchased from Hasan & Bono Trading Company Ltd, Thailand. Starch is characterized by poor processability and hence to produce a film based on starch, high content of plasticizer is required. The two most commonly used plasticizers with starch are water and glycerol [35,36]. When the amount of glycerol in starch-based thermoplastic composites is increased, it improves flexibility and reduces brittleness and tensile properties [37]. For the current work, glycerol (Sigma-Aldrich) with 99.5% purity was purchased from Shaheen Chemical, Dhaka, Bangladesh.

2.2. Manufacturing of biocomposites

The manufacturing process of biocomposites from corn starch and cotton filter waste of spinningmill is shown by a block diagram in (Fig. 4). Corn starch (15% w/w), glycerol (10% w/w) and water (75% w/w) were homogeneously mixed in a steel vessel and the mixture was heated at 90 °C with continuous stirring until gelatinization of starch [38]. To achieve this, a matrix solution was created by stirring together 60 g of corn starch, 40 g of glycerin, and 300 g of distilled water, until the total amount reached 400 g. A mother

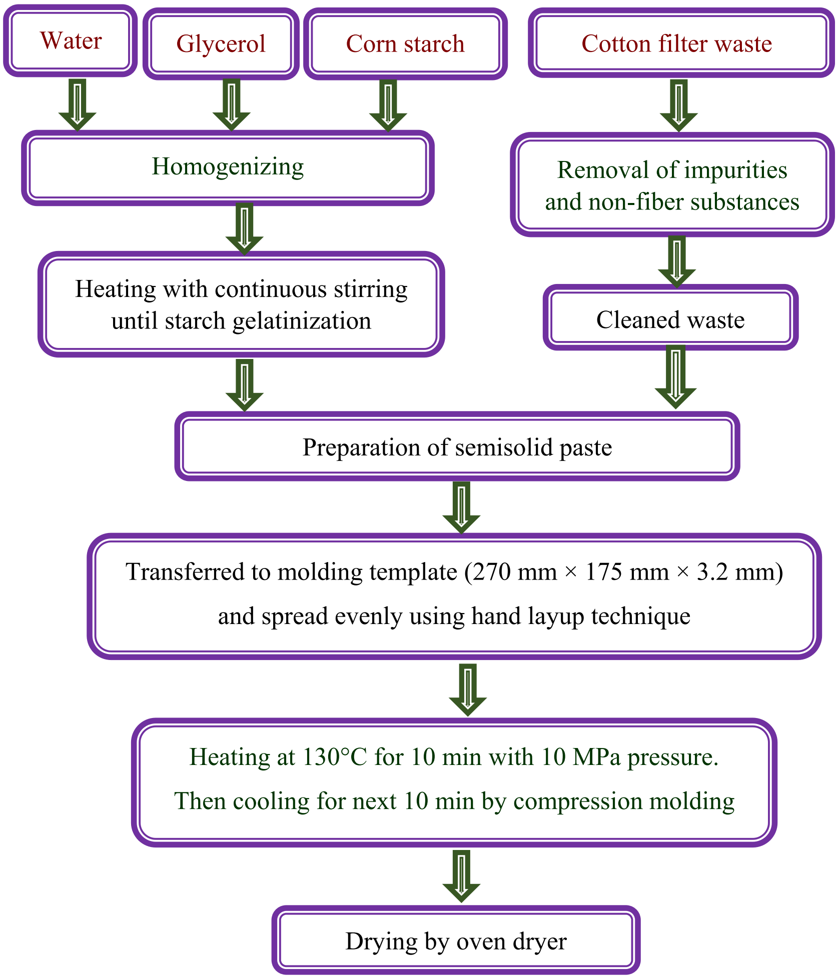

Fig. 4. Manufacturing of cotton filter waste/corn starch composites using hand layup and compression molding method.

starch paste was thus obtained. Varying amounts of cotton waste 20, 30, 40, 50 and 60% (% w/w of the corn starch) were added into it and mixed properly to obtain a semisolid paste. Then the paste was transferred to a mold (270 mm × 175 mm × 3.2 mm) and spread evenly to get a homogenous distribution using the hand layup technique. Composites were then prepared by the hot press with a compression molding machine (Model- 3895 4NE1000, CARVER, USA). The inner walls of the mold were covered with Teflon-coated paper. The temperature and pressure were kept constant at 130 °C and 10 MPa, respectively, for every sample. Each sample was heated and cooled separately for 10 min [39,40]. No loss or exudation of glycerol or plasticizer was observed during mixing, storage, or hot pressing [41]. The prepared samples were subsequently dried by an oven dryer. Finally, five types of composite samples with five reinforcement loadings (20, 30, 40, 50 and 60%) were obtained.

Similar replications with larger dimensions (300 mm × 300 mm × 3.2 mm) were also prepared to perform the thermal conductivity test.

2.3. Characterization

2.3.1. Thickness and density of composites

The density of composite samples was determined by calculating their weight (m) and volume (v) using the dimensions of 20 × 15 mm. The thickness measurement was taken using an Ames thickness gauge (AMES, BG 1110-1-04, USA) with an accuracy of ±0.001 inches. The average thickness value of ten random measurements for each composite was determined. The composite densities (ρ) were obtained via the equation (1):

$$\rho\left(\frac{g}{cm^3}\right)=\frac{m}{v} \tag{1}$$

2.3.2. Tensile properties

Universal testing machine (UTM; AG-X, SHIMADZU, Japan) was utilized to conduct tensile tests on dog-bone-shaped samples in accordance with ASTM D638. The specimen size was 165 mm (length) × 13 mm (width) × 3.2 mm (thickness). The measurements were taken after the samples were conditioned at 25 °C and 65% relative humidity, with a crosshead speed of 5 mm/min and a gauge length of 50 mm.

2.3.3. Flexural strength

The three-point bending test method was used with a UTM as per the ASTM D790 standard to determine flexural strength. The dimensions of the samples were 127 mm × 12.7 mm × 3.2 mm, and tested at a crosshead speed of 1.4 mm/min.

2.3.4. Impact strength

Impact tests were conducted as per the ISO 180:1993 on an Izod Analog Impact Tester (QPI–IC–21J, USA) according to ASTM D256. Rectangular samples measuring 63.5 ± 2 mm in length, 12.7 ± 0.2 mm in width, and 3.2 mm in thickness were prepared. The tests were conducted at a temperature of 25 °C and a relative humidity of 65%.

2.3.5. Scanning electron microscopy

The composites' surface morphologies were examined using a scanning electron microscope (SUI-510, Hitachi Co., Japan). The magnifications were set at 150 × with an accelerating voltage was 15 kV.

2.3.6. Thermal conductivity

Thermal conductivity tests of biocomposites were made using Thermal Guarded Hotplate (FANYUAN, INSTRUMEN (HF) CO., LTD, YG606D, China) according to ASTM D1518-2003. A 300 mm × 300 mm composite sample was placed on the flat plate where a 250 mm × 250 mm thermal guard (around the test plate and under the test plate) will keep the same constant temperature. The samples were conditioned before conducting the test with an atmosphere of 25 ± 2 °C and a relative humidity of 65% ± 2. During testing, the plate temperature was brought to be in equilibrium operating temperature within 35 ± 0.5 °C. Due to the presence of a thermal guard, the heat of the heating plate can only flow through the sample. After reaching the stable test condition, the thermal resistance and thermal conductivity are obtained following equations (2) and (3) respectively by measuring the heat flow that passes through the sample.

$$\text{Thermal resistance}, R_{ct}=\frac{(T_{m-T_a})\,A}{H-\Delta H_c}-R_{ct0} \tag{2}$$

$$\text{Thermal Conductivity}, K=\frac{10^{-3}.d}{R_{ct}} \tag{3}$$

where,

T_m = temperature of the test plate.

T_a = temperature of the climatic chamber.

A = area of the test plate (250 mm × 250 mm).

H = heating power of the test plate.

ΔH_c = the correction value of the heating power.
R_{ct0} = thermal resistance-value of the blank test plate
d = thickness of the sample.

3. Results and discussion

3.1. Appearance, thickness and density of biocomposites

An image of biocomposites produced with cotton filter waste and corn starch (hereinafter will be termed 'CFW/CS') is shown in Fig. 5. In the exterior of composites, they have a texture-like oriented strand board with a rough and variegated surface. Whitish clusters or aggregates of cotton fibers dispersed in the starch matrix have given composites a heterogeneous and unique look.

The thickness and density of CFW/CS composites are mentioned in Table 1. The table indicates that as the percentage of CFW in the composites increases, the thickness of the composites also increases while the weight or density decreases. The reason can be attributed to the generation of free spaces or voids with the increase of CFW in composites, resulting in the thickening of the composite thickness [42]. Similar findings were reported in earlier research, which observed decreased density values as the amount of fiber in the composites increased [43,44]. Nevertheless, such low density makes the biocomposites an attractive candidate as the alternative to synthetic non-biodegradable packaging materials as described in the later section of this article.

3.2. Tensile properties

Fig. 6 indicates the typical stress-strain graphs for CFW/CS biocomposites. The shapes of the curves express that all samples have a small linear elastic region, no apparent yield point, and a regime of rising stress until fracturing. As the strain increases, stress consistently rises until it reaches a point of fracture, which is typically referred to as plastic deformation. In the case of CFW loading 20% and 30%, curves show ductile nature and with further increase in CFW, curves gradually turn to brittle fracture. A steeper initial slope, especially for CFW 50% and 60% samples, indicates the stiffness in their nature i.e. larger initial resistance to the applied stress. The stress-strain behavior obtained here is similar to those found in the previous works reported in the literature for starch-based composites [45–47] and post-consumer cotton garments waste-reinforced epoxy composites [29].

Fig. 5. Images of biocomposites produced with cotton filter waste and corn starch.

Table 1
Thickness and density values of cotton filter waste/corn starch (CFW/CS) biocomposites.

Materials	Thickness (mm)	Density ($g.cm^{-3}$)
CFW 20%	3.16	0.67
CFW 30%	3.26	0.659
CFW 40%	4.55	0.574
CFW 50%	4.75	0.495
CFW 60%	5.65	0.434

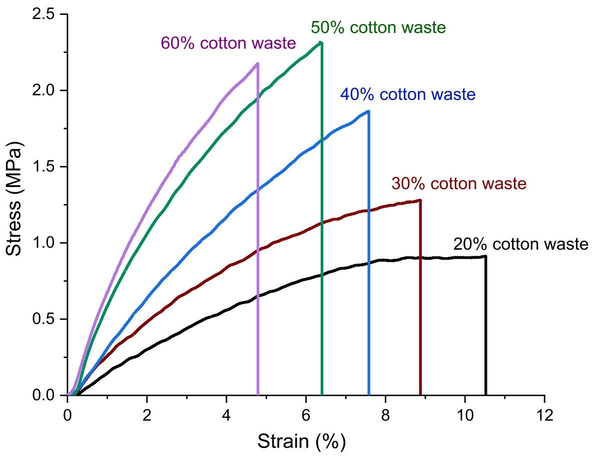

Fig. 6. Representative stress-strain curves for cotton filter waste and corn starch biocomposites.

Fig. 7 illustrates several tensile properties, including tensile strength, Young's modulus, and elongation at break that were assessed by closely analyzing the stress-strain curves.

Fig. 7a represents the tensile strength of CFW/CS biocomposites with various fiber loadings starting from 20% to 60%. The results indicate that the tensile strength of the composite increases as the proportion of cotton waste in the composite increases. The highest tensile strength is achieved with a 50% fiber-loaded sample, after which the strength decreases with further increases in fiber loading. This trend suggests that the increased fiber content in the composites facilitates effective stress transfer between the fiber and matrix where the fibers act as load carriers in the matrix [48].

It is apparent from Fig. 7b that Young's modulus consistently increased with the increase of cotton waste content indicating the corresponding increase in composite stiffness. It is a well-established fact that when stiffness values (Young's modulus) increase, the elongation property of composites decreases, as observed in Fig. 7c.

For composite materials to be useful, they not only must be strong, but they need also to be tough. Toughness refers to a material's capacity to absorb energy during the deformation process until it eventually fractures. Toughness can be measured from the area underneath the stress-strain curve [49].

The toughness of the CFW/CS composites is illustrated in Fig. 8. As seen, increasing CFW toughness of composites consistently increases up to 50% fiber loading while the value declines for 60% fiber loading.

The mechanical properties of fiber-reinforced composites are primarily dependent upon three factors: (i) strength and modulus (stiffness) of matrix and filler (fiber), (ii) length and orientation of filler and, most importantly, (iii) the effectiveness of the interfacial bonding that determines the matrix's ability to transfer loads across interfaces, through shear, to the reinforcing fibers. In the case of fiber-reinforced composites, it is expected that the reinforcement phase i.e. fibers will have higher strength and modulus than the matrix polymer which will carry the load applied to the matrix. To achieve this, there must be sufficient adhesion between the fiber and matrix [50].In terms of overall tensile properties, especially strength and toughness, the loading of 50% cotton waste in the starch matrix can be considered to be optimum reinforcement. Since both the matrix (starch) and filler (cotton) are hydrophilic materials, strong hydrogen bonds are expected to have formed in the interface [50]. Under tensile loading, there was an efficient stress transfer from the matrix to the fiber due to the strong interfacial adhesion created by hydrogen bonding between the fiber and matrix. The incorporation of 60% fiber may be considered to be over-loading of fibers in the matrix creating insufficient interfacial bonding that hinders the transfer of effective stress from matrix to fibers. Resultantly, the composite became brittle (high Young's modulus) with lower strength, toughness, and elongation [51].

3.3. SEM micrographs

The SEM micrographs of CFW/CS composite surfaces and fractured surfaces were captured to study the interfacial bonding and the internal morphology of the composites. Fig. 9(a–c) display the SEM images of composites' outer surfaces containing 20%, 50%, and

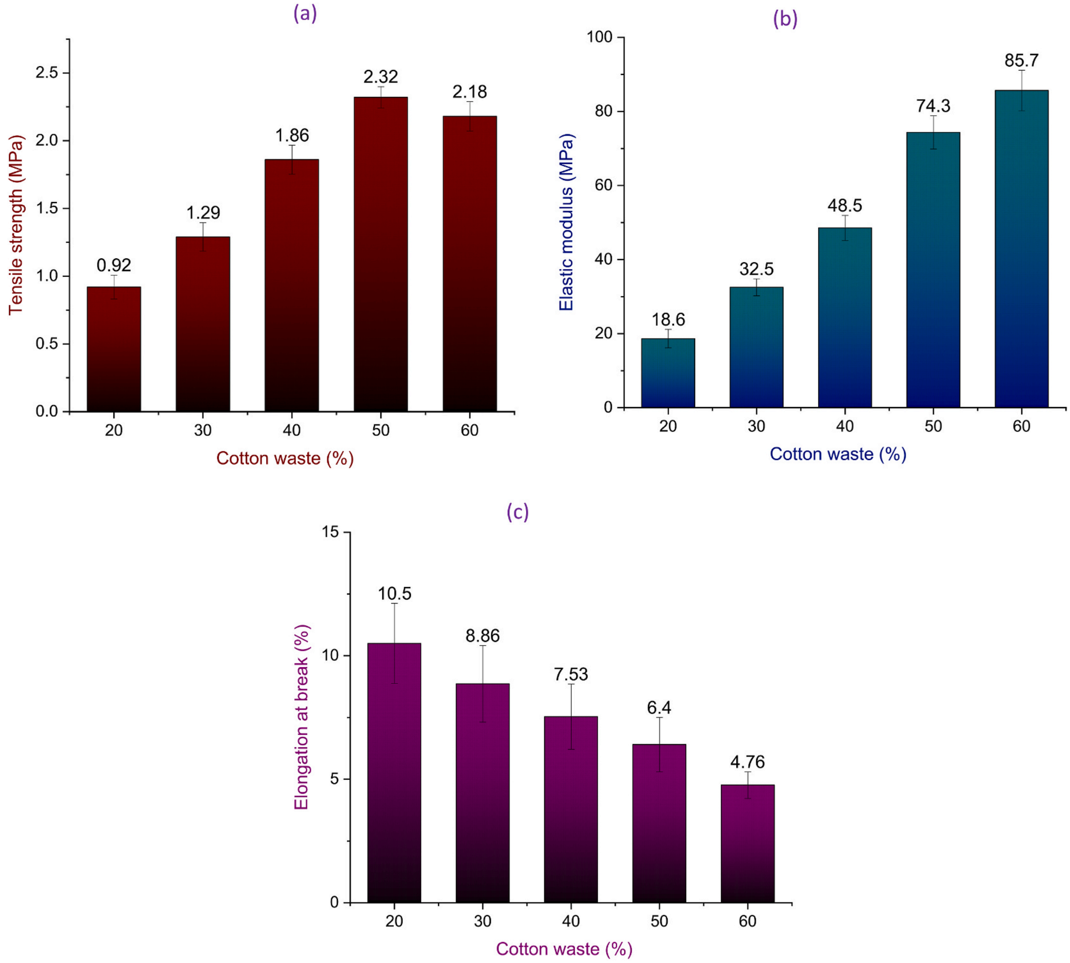

Fig. 7. (a) Tensile strength, (b)Young's modulus, and (c) elongation at break of cotton filter waste and corn starch biocomposites.

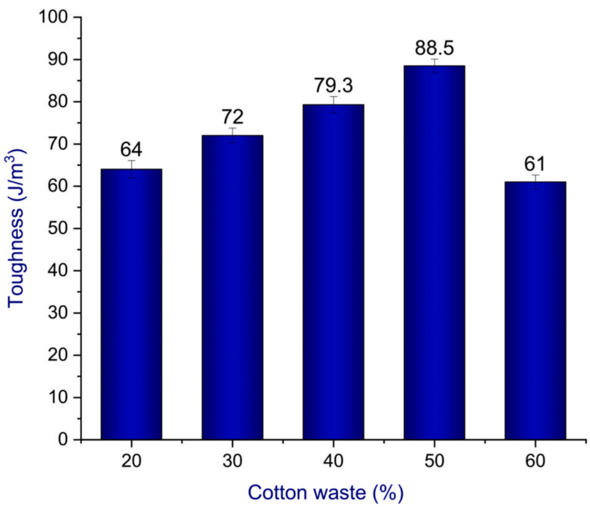

Fig. 8. Toughness of cotton filter waste/corn starch composites.

60% cotton waste. Here, good adhesion between reinforcement (cotton fiber) and starch (matrix) is visible for 20% and 50% fiber-loaded samples whereas comparatively inhomogeneous fiber distribution in the matrix and lower fiber-matrix adhesion is observed for 60% loaded sample due to excessive fiber loading.

Fig. 10(a–c) show the fractured SEM images of 20%, 50% and 60% fiber-loaded composites. In the case of 20% fiber-loaded composite, the low fiber content in matrix polymer is evident on the fractured surface. The lower fiber content imparted lower bonding between fibers and matrix, resulting in lower reinforcement and a lower composite's tensile strength. In the composite with 50% fiber content, shown in Fig. 10b, homogeneous dispersion of fibers into the matrix, less fiber pull out and fewer free spaces (voids) are seen that contributed to attaining the high tensile strength. The fiber cluster for the composite with 60% fiber content is visible due to the higher loading of cotton fibers, and lower fiber and matrix interfacial interaction results in lower strength.

3.4. Flexural/bending strength

The flexural or bending strength of a composite material means how much force is needed to bend the material. This property is determined by measuring the force required to bend the material in a three-point flexural test, which is particularly important for composites because it involves a combination of stresses such as compression and tension. During this test, the load is placed in the middle and the upper layer is compressed while the lower layer is stretched. As a result, strong adhesion between the fibers and matrix is essential for achieving good results in the flexural test. Bending strength is always higher than tensile strength [50]. It is defined by force per unit area.

Fig. 11 shows the bending strength data of the composites. It is evident that composites' bending strength increases as fiber content increases, and it is highest for 50% fiber loading. After further loading of fiber, the bending strength decreased. A similar trend of bending strength with fiber loading was also observed for tensile strength (shown in Fig. 7a) and toughness (shown in Fig. 8).

As mentioned above in the case of tensile strength, weak interfacial bonding between fiber and matrix was found for low fiber content in composites. Bending strength increased as the fiber percentage rises up to a certain point (as 50% in the present case), creating strong interfacial bonding. The reduction of bending strength at 60% fiber loading is due to the formation of fiber clusters that made the composite hard and brittle. The cluster of fiber indicates the lack of matrix polymer in the composite i.e. the amount of matrix is inadequate to bind the fibers properly leading to the deterioration of bending and tensile properties of composites [52].

3.5. Impact strength

The toughness of a sample under sudden loading and the concentration of stress at weak points caused by notches or cracks are evaluated by the impact test. In other words, the impact characteristic of a substance refers to how effectively it can absorb and release energies when subjected to sudden loads or impacts [53]. In composite materials, impact loading can result in various types of failures, such as the fracturing of the matrix, the debonding of fibers from the matrix, the breakage of fibers, and the pulling out of fibers. If the force applied to the fibers is greater than the bond between the fiber and matrix, then debonding happens. The bond is typically responsible for transferring the force to the fibers via shear force. If the stress on the fiber is higher than its strength, the fiber may fracture, causing energy to be dissipated when the broken fibers are pulled out of the matrix [48,54]. Composite materials that contain longer fibers, which need more force to pull them out, exhibit greater values for impact strength. Conversely, composites that have shorter fibers display considerably lower values for impact strength. Shorter fibers in composites with the same fiber content create more stress concentration areas at the fiber ends than longer ones [50,55].

Impact testing is a typical method employed to determine the durability of packaging materials when subjected to sudden deformation, such as being dropped or having something dropped on it. This test is conducted to measure the packaging's resilience or toughness [56].

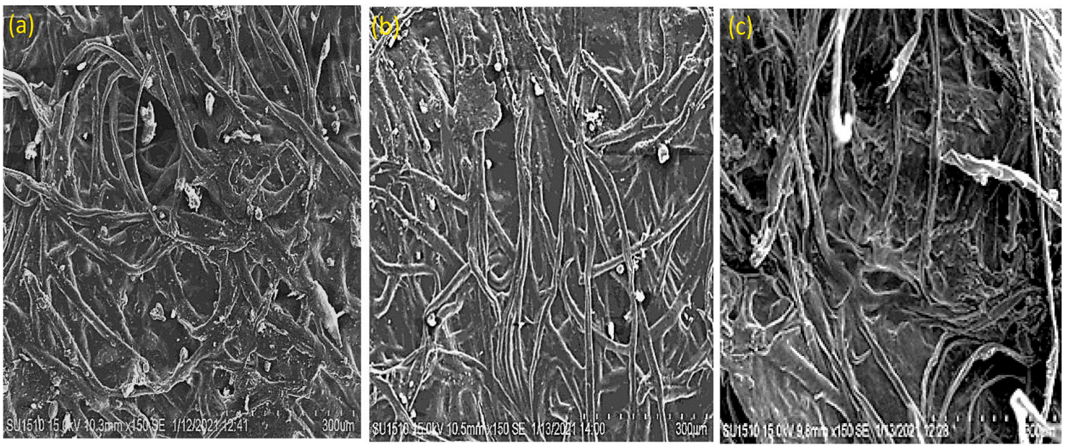

Fig. 9. SEM micrographs of composite surfaces with waste cotton content: (a) 20%, (b) 50%, (c) 60%.

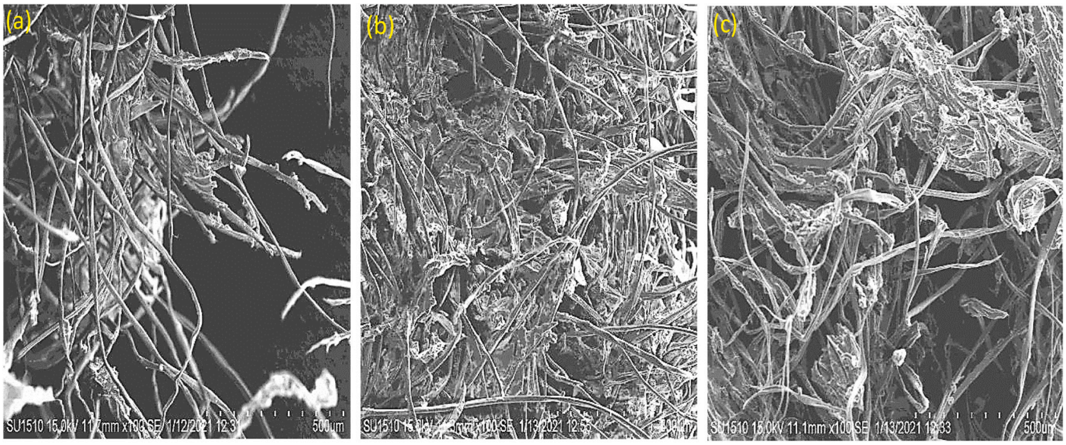

Fig. 10. SEM micrographs of fractured surfaces of composites (after tensile testing) with waste cotton content: (a) 20%, (b) 50%, and (c) 60%.

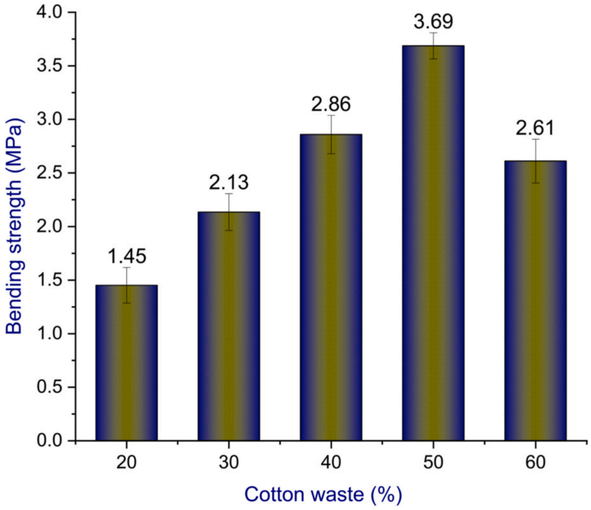

Fig. 11. Flexural strength of cotton filter waste and starch composites.

Fig. 12 illustrates the impact strength of the CFW/CS composites at different fiber loading. As seen, increasing CFW results in consistently increasing the composites' impact strength up to 50% fiber loading while these values decline for 60% fiber loading. Tensile strength and toughness values of composites were found to follow the same pattern as previously demonstrated in (Figs. 7 and 8) The increase in impact strength when the waste fiber is increased by up to 50% suggests good fiber-matrix interfacial adhesion where the polymer matrix absorbs the impact energy and effectively dissipates it to the fibers. The decrease of impact strength in the case of 60% CFW loading was due to the lower interaction of the matrix with clustered/agglomerated fibers as observed in the SEM image. Agglomerated fiber bundle generates micro-cracks in composites resulting in lower impact strength when the fiber load increases [57].

3.6. Possible applications of the prepared biocomposites

Currently, the packaging industry is indiscriminately using non-biodegradable plastic materials derived from petrochemicals, which has resulted in a significant challenge in disposing of the waste generated after their use. As a result, there has been greater emphasis on using polymers derived from natural sources to create packaging materials that can biodegrade. Several research studies have indicated that incorporating cellulosic material into the starch polymer matrix has resulted in enhanced properties of composite film and sheets [58].

Cotton filter waste (CFW) reinforced corn starch (CS) biocomposites prepared in this work can be considered to have potential applications as an alternative to conventional Styrofoam-based, non-degradable packaging materials in the protective packaging industry. CFW/CS composites showed remarkable reinforcement and a good combination of tensile strength, modulus, bending strength, and more importantly, toughness and impact strength which are essential for packaging applications. Though densities of CFW/CS

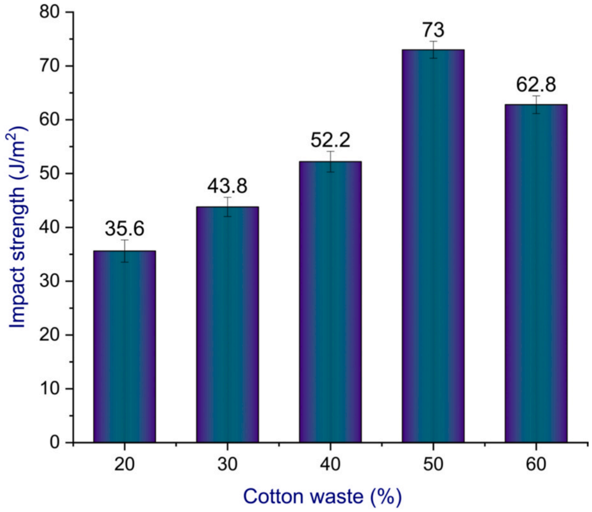

Fig. 12. Impact strength of cotton filter waste/corn starch composites.

composites (0.343–0.67 g cm^{-3} shown in Table 1) are higher than Styrofoam (0.02 g cm^{-3}), composites are still lighter (densities are far less than 1) and the biodegradability of CFW/CS composites makes them an alternative to polystyrene foam used as packaging materials. Fig. 13a shows the typical Styrofoam used as liners in the package, and Fig. 13b shows the possible application of the CFW/CS composites as box liners where the composite is used as a barrier between box walls to protect shock-sensitive goods and brittle materials from damage where the pack may suddenly drop or something may be dropped on it during shifting and transportation. However, proper design of composites according to the size and shape of the materials is required to obtain a more effective performance in protection.

Expanded polystyrene (EPS) is a type of plastic foam material that is created by expanding solid polystyrene beads, which are composed of 98% air. This material is mainly used for insulation and packaging purposes [59]. Ibragimov et al. prepared composite heat-insulating plates by soft acid modification of cotton spinning waste [60]. The prepared CFW/CS biocomposites in this work may also be useful in insulation applications as a sustainable alternative to EPS. In this connection, it is important to investigate the thermal conductivity of composites made of CFW/CS.

3.7. Thermal conductivity

Thermal conductivity refers to a material's ability to conduct or transfer heat. It can be defined as the rate at which heat is transferred by conduction through a unit cross-section area of a material when a temperature gradient exits perpendicular to the area. Heat moves slower through materials with low thermal conductivity compared to those with high thermal conductivity. Thermal resistivity is the reciprocal of this property, which is temperature dependant. Thermal conductivity is a useful parameter for thermal insulation materials and its values are used in the quantitative comparison of the thermal conductivity of various thermal insulating materials [61].

Fig. 14 compares the thermal conductivity of CFW/CS composites and expanded polystyrene (EPS) as a reference. It is clear that the thermal conductivity of all composites lies within a close range between 0.04885 and 0.03326 W/m.K. Referring to the thickness and density values of composites shown before in Tables 1 and it is obvious that lower the composite's density (due to creation of free spaces for higher fiber loadings such as 50% and 60%), lower the thermal conductivity of composites. Phonons scatter in empty areas or voids that are filled with air. In contrast, heat flows more quickly through solid substances than through voids, resulting in a lower thermal conductivity for the low-density composites that contain voids [62]. For a material to function effectively as a thermal insulator, it is required to possess a thermal conductivity value lower than 0.1 W/m.K. Traditional types of insulation materials, like mineral wool, foam glass, glass wool, and expanded polystyrene, exhibit thermal conductivity levels within the range of 0.034–0.045 W/m.K [63]. In this context, all CFW/CS biocomposites produced here can be considered to be useful as good insulating materials in packaging, construction, buildings, or other applications.

4. Conclusions

A huge quantity of cotton filter waste generates every day in spinning mills that are usually thrown away or used to make biofuels. The current work demonstrates a pathway to exploit cotton filter waste to produce value-added products like biocomposites. In this work, cotton filter waste (CFW) reinforced corn starch (CS) biocomposites were successfully manufactured with CFW loading ranging from 20% to 60% via compression molding. The comprehensive evaluation of the outcomes indicates that the characteristics of the CFW/CS biocomposites are greatly impacted by the quantity of CFW present. At 50% waste cotton loaded biocomposite exhibited a

Fig. 13. Box liners in packaging: (a) typical Styrofoam and (b) cotton filter waste/starch biocomposites.

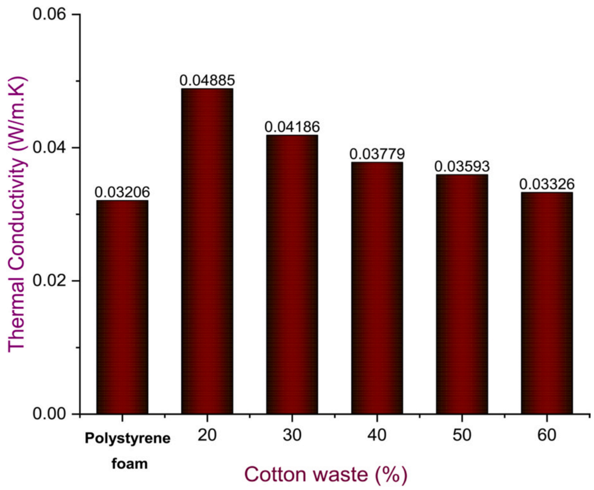

Fig. 14. Thermal conductivity of cotton filter waste/corn starch composites.

good combination of tensile strength, Young's modulus, toughness, bending strength, impact strength and thermal conductivity. SEM images of composites evidenced the 50% fiber loading having good fiber-to-matrix interfacial adhesion.

If appropriately designed and formed, the manufactured composites can be used as a replacement to non-degradable synthetic polymers, such as packaging made of polystyrene, foam boxes, rigid foam box inserts, trays and liners which are designed to protect, insulate and cushion products when stored or shipped. The composites can also be used as thermal insulators in packaging, building, or other applications where low heat conductivity is required. More importantly, the CFW/CS biocomposites produced here are fully biodegradable and environment friendly and even if they are thrown away after usage, they will improve the soil fertility by degradation.

This work provided an initial insight to utilize cotton filter waste from spinning mills to develop biocomposites with starch. However, the produced composites exhibited rough surfaces resulting from the small flocks of short CFW that were created during the manual mixing of CFW with gelatinized starch paste. By using a high-speed mixer or screw extruder, CFW/CS composites with homogeneous and smooth surfaces may be produced.

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Author contribution statement

Md. Masum Reza: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

Hosne Ara Begum: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Ahmed Jalal Uddin: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Data availability statement

Data will be made available on request.

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References

[1] B. Gedif, D. Atalie, Recycling of 100% cotton fabric waste to produce unsaturated polyester-based composite for false ceiling board application, Int. J. Polym. Sci. (2022) 1–9, https://doi.org/10.1155/2022/2710000.
[2] S.S. Rahman, S. Siddiqua, C. Cherian, Sustainable applications of textile waste fiber in the construction and geotechnical industries: a retrospect, Clean. Eng. Technol. 6 (2022), https://doi.org/10.1016/j.clet.2022.100420.
[3] B. Ütebay, P. Çelik, A. Çay, Effects of cotton textile waste properties on recycled fiber quality, J. Clean. Prod. 222 (2019) 29–35, https://doi.org/10.1016/j.jclepro.2019.03.033.
[4] 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. 108 (5) (2017) 835–839, https://doi.org/10.1080/00405000.2016.1193982.
[5] R. Alagirusamy, Process control in blow room and carding operations, in: A. Majumdar, A. Das, R. Alagirusamy, V.K. Kothari (Eds.), Process Control in Textile Manufacturing, Woodhead Publishing Limited, Cambridge, 2012, pp. 132–157, https://doi.org/10.1533/9780857095633.2.132.
[6] T.B. Ute, P. Celik, M. Bunyamin Uzumcu, Utilization of Cotton Spinning Mill Wastes in Yarn Production, Textile Industry and Environment, 2019, https://doi.org/10.5772/intechopen.85127.
[7] T.M. Halimi, B.M. Hassen, B. Azzouz, F. Sakli, Effect of cotton waste and spinning parameters on rotor yarn quality, J. Text. Inst. 98 (5) (2007) 437–442, https://doi.org/10.1080/00405000701547649.
[8] D. Rajput, S.S. Bhagade, S.P. Raut, R.V. Ralegaonkar, S.A. Mandavgane, Reuse of cotton and recycle paper mill waste as building material, Construct. Build. Mater. 34 (2012) 470–475, https://doi.org/10.1016/j.conbuildmat.2012.02.035.
[9] S. Suvunnapob, B.I.N. Ayudhya, B. Kusuktham, A study of cotton dust mixed with wood dust for bio-briquette fuel, Eng. J. 19 (4) (2015) 57–70, https://doi.org/10.4186/ej.2015.19.4.57.
[10] R.M.G. Bangladesh, Bangladesh in New Partnership to Exploit Textile Waste Potential, RMG Bangladesh, 2020. https://rmgbd.net/2020/12/bangladesh-in-new-partnership-to-exploit-textile-waste-potential/. (Accessed 22 December 2022). Accessed.
[11] Statista, Distribution of Fiber Consumption Worldwide in 2019, by Type of Fiber, Statista Research Department, 2020. https://www.statista.com/statistics/741296/world-fiber-consumption-distribution-by-fiber-type/.
[12] M.A. Khan, A. Wahid, M. Ahmad, M.T. Tahir, M. Ahmed, S. Ahmad, M. Hasanuzzaman, World cotton production and consumption: an overview, in: S. Ahmad, M. Hasanuzzaman (Eds.), Cotton Production and Uses: Agronomy, Crop Protection, and Postharvest Technologies, Springer Nature Singapore Pte Ltd., Singapore, 2020, pp. 1–7, https://doi.org/10.1007/978-981-15-1472-2_1.
[13] BTMA, Bangladesh to Import More than 1M Bales of Cotton from US, Dhaka Tribune, 2022. https://www.dhakatribune.com/business/2022/04/19/bangladesh-to-import-more-than-1m-bales-of-cotton-from-us.
[14] E.P. A Victoria, Summary of Waste Regulations, EPA Victoria State Government of Victoria, 2022. https://www.epa.vic.gov.au/about-epa/laws/new-laws/summary-of-regulations/summary-of-waste-regulations.
[15] R. Abhijith, A. Ashok, C.R. Rejeesh, Sustainable packaging applications from mycelium to substitute polystyrene: a review, Mater. Today: Proc. 5 (1) (2018) 2139–2145, https://doi.org/10.1016/j.matpr.2017.09.211.
[16] R.E.J. Schnurr, V. Alboiu, M. Chaudhary, R.A. Corbett, M.E. Quanz, K. Sankar, H.S. Srain, V. Thavarajah, D. Xanthos, T.R. Walker, Reducing marine pollution from single-use plastics (SUPs): a review, Mar. Pollut. Bull. 137 (2018) 157–171, https://doi.org/10.1016/j.marpolbul.2018.10.001.
[17] J.M. Gove, J.L. Whitney, M.A. McManus, J. Lecky, F.C. Carvalho, J.M. Lynch, J. Li, P. Neubauer, K.A. Smith, J.E. Phipps, D.R. Kobayashi, K.B. Balagso, E. A. Contreras, M.E. Manuel, M.A. Merrifield, J.J. Polovina, G.P. Asner, J.A. Maynard, G.J. Williams, Prey-size plastics are invading larval fish nurseries, Proc. Natl. Acad. Sci. U. S. A 116 (48) (2019) 24143–24149, https://doi.org/10.1073/pnas.1907496116.
[18] M. Scheurer, M. Bigalke, Microplastics in Swiss floodplain soils, Environ. Sci. Technol. 52 (6) (2018) 3591–3598, https://doi.org/10.1021/acs.est.7b06003.
[19] H. Abral, A. Atmajaya, M. Mahardika, F. Hafizulhaq, Kadriadi, D. Handayani, S.M. Sapuan, R.A. Ilyas, Effect of ultrasonication duration of polyvinyl alcohol (PVA) gel on characterizations of PVA film, J. Mater. Res. Technol. 9 (2) (2020) 2477–2486, https://doi.org/10.1016/j.jmrt.2019.12.078.
[20] R.A. Ilyas, S.M. Sapuan, M.R. Ishak, E.S. Zainudin, Development and characterization of sugar palm nanocrystalline cellulose reinforced sugar palm starch bionanocomposites, Carbohydr. Polym. 202 (2018) 186–202, https://doi.org/10.1016/j.carbpol.2018.09.002.
[21] H. Cheng, L. Chen, D.J. McClements, T. Yang, Z. Zhang, F. Ren, M. Miao, Y. Tian, Z. Jin, Starch-based biodegradable packaging materials: a review of their preparation, characterization and diverse applications in the food industry, Trends Food Sci. Technol. 114 (2021) 70–82, https://doi.org/10.1016/j.tifs.2021.05.017.
[22] L. Chen, H. Zhang, D.J. McClements, Z. Zhang, R. Zhang, Z. Jin, Y. Tian, Effect of dietary fibers on the structure and digestibility of fried potato starch: a comparison of pullulan and pectin, Carbohydr. Polym. 215 (2019) 47–57, https://doi.org/10.1016/j.carbpol.2019.03.046.
[23] M. Avella, J.J. De Vlieger, M.E. Errico, S. Fischer, P. Vacca, M.G. Volpe, Biodegradable starch/clay nanocomposite films for food packaging applications, Food Chem. 93 (3) (2005) 467–474, https://doi.org/10.1016/j.foodchem.2004.10.024.
[24] C. Zeppa, F. Gouanvé, E. Espuche, Effect of a plasticizer on the structure of biodegradable starch/clay nanocomposites: thermal, water-sorption, and oxygen-barrier properties, J. Appl. Polym. Sci. 112 (4) (2009) 2044–2056, https://doi.org/10.1002/app.29588.
[25] B.S. Kaith, R. Jindal, M. Maiti, Induction of chemical and moisture resistance in Saccharum spontaneum L fiber through graft copolymerization with methyl methacrylate and study of morphological changes, J. Appl. Polym. Sci. 113 (3) (2009) 1781–1791, https://doi.org/10.1002/app.29941.
[26] B.S. Kaith, R. Jindal, A.K. Jana, M. Maiti, Development of corn starch based green composites reinforced with Saccharum spontaneum L fiber and graft copolymers - evaluation of thermal, physico-chemical and mechanical properties, Bioresour. Technol. 101 (17) (2010) 6843–6851, https://doi.org/10.1016/j.biortech.2010.03.113.
[27] M.R. Amin, M.A. Chowdhury, M.A. Kowser, Characterization and performance analysis of composite bioplastics synthesized using titanium dioxide nanoparticles with corn starch, Heliyon 5 (8) (2019), E02009, https://doi.org/10.1016/j.heliyon.2019.e02009.
[28] M.D. Hazrol, S.M. Sapuan, E.S. Zainudin, N.I.A. Wahab, R.A. Ilyas, Effect of kenaf fiber as reinforcing fillers in corn starch-based biocomposite film, Polymers 14 (8) (2022) 1–16, https://doi.org/10.3390/polym14081590.
[29] Z. Kamble, B.K. Behera, Mechanical properties and water absorption characteristics of composites reinforced with cotton fibers recovered from textile waste, J. Eng. Fiber. Fabr. 15 (2020) 1–8, https://doi.org/10.1177/1558925020901530.
[30] Y. Shi, J. Jiang, H. Ye, Y. Sheng, Y. Zhou, S.Y. Foong, C. Sonne, W.W.F. Chong, S.S. Lam, Y. Xie, J. Li, S. Ge, Transforming municipal cotton waste into a multilayer fiber biocomposite with high strength, Environ. Res. 218 (3) (2023), 114967, https://doi.org/10.1016/j.envres.2022.114967.
[31] F.P. La Mantia, M. Morreale, Green composites: a brief review, Compos. Part A Appl. Sci. Manuf. 42 (6) (2011) 579–588, https://doi.org/10.1016/j.compositesa.2011.01.017.

[32] E. Vázquez-Núñez, A.M. Avecilla-Ramírez, B. Vergara-Porras, M. del R. López-Cuellar, Green composites and their contribution toward sustainability: a review, Polym. Polym. Compos. 29 (9) (2021) S1588–S1608, https://doi.org/10.1177/09673911211009372.
[33] J.I.P. Singh, V. Dhawan, S. Sing, Development and characterization of green composites: a review, in: International Conference on Advancements and Recent Innovations in Mechanical, Production and Industrial Engineering, 2015, pp. 4–7, https://doi.org/10.16962/elkapj/si.arimpie-2015.47.
[34] V.K. Thakur, M.K. Thakur, R.K. Gupta, Review: raw natural fiber-based polymer composites, Int. J. Polym. Anal. Char. 19 (3) (2014) 256–271, https://doi.org/10.1080/1023666X.2014.880016.
[35] B. Balla, A. Bartos, D. Kun, E. Csiszár, J. Móczó, E. Fekete, Improving mechanical and water sorption properties of thermoplastic starch by incorporating chitosan filler, Polym. Test. 101 (2021), https://doi.org/10.1016/j.polymertesting.2021.107278.
[36] F.G. Torres, O.H. Arroyo, C. Gomez, Processing and mechanical properties of natural fiber reinforced thermoplastic starch biocomposites, J. Thermoplast. Compos. Mater. 20 (2) (2007) 207–223, https://doi.org/10.1177/0892705707073945.
[37] P.A. Sreekumar, N. Leblanc, J.M. Saiter, Effect of glycerol on the properties of 100 % biodegradable thermoplastic based on wheat flour, J. Polym. Environ. 21 (2) (2013) 388–394, https://doi.org/10.1007/s10924-012-0497-3.
[38] X. Ma, R. Jian, P.R. Chang, J. Yu, Fabrication and characterization of citric acid-modified starch nanoparticles/plasticized-starch composites, Biomacromolecules 9 (11) (2008) 3314–3320, https://doi.org/10.1021/bm800987c.
[39] J.S. Jung, K.H. Song, S.H. Kim, Biodegradable acetylated kenaf fiber composites, Fibers Polym. 22 (12) (2021) 3437–3443, https://doi.org/10.1007/s12221-021-1237-x.
[40] S. Ochi, Development of high strength biodegradable composites using Manila hemp fiber and starch-based biodegradable resin, Compos. Part A Appl. Sci. Manuf. 37 (11) (2006) 1879–1883, https://doi.org/10.1016/j.compositesa.2005.12.019.
[41] A. Wattanakornsiri, K. Pachana, S. Kaewpirom, M. Traina, C. Migliaresi, Preparation and properties of green composites based on tapioca starch and differently recycled paper cellulose fibers, J. Polym. Environ. 20 (3) (2012) 801–809, https://doi.org/10.1007/s10924-012-0494-6.
[42] F. Versino, M.A. García, Cassava (Manihot esculenta) starch films reinforced with natural fibrous filler, Ind. Crop. Prod. 58 (2014) 305–314, https://doi.org/10.1016/j.indcrop.2014.04.040.
[43] A. Edhirej, S.M. Sapuan, M. Jawaid, N.I. Zahari, Cassava/sugar palm fiber reinforced cassava starch hybrid composites: physical, thermal and structural properties, Int. J. Biol. Macromol. 101 (2017) 75–83, https://doi.org/10.1016/j.ijbiomac.2017.03.045.
[44] M.I.J. Ibrahim, S.M. Sapuan, E.S. Zainudin, M.Y.M. Zuhri, Preparation and characterization of cornhusk/sugar palm fiber reinforced Cornstarch-based hybrid composites, J. Mater. Res. Technol. 9 (1) (2020) 200–211, https://doi.org/10.1016/j.jmrt.2019.10.045.
[45] C. Menzel, C. González-Martínez, A. Chiralt, F. Vilaplana, Antioxidant starch films containing sunflower hull extracts, Carbohydr. Polym. 214 (2019) 142–151, https://doi.org/10.1016/j.carbpol.2019.03.022.
[46] H. Peidayesh, K. Mosnáčková, Z. Špitalský, A. Heydari, A.O. Šišková, I. Chodák, Thermoplastic starch–based composite reinforced by conductive filler networks: physical properties and electrical conductivity changes during cyclic deformation, Polymers 13 (21) (2021), https://doi.org/10.3390/polym13213819.
[47] L.A. Toro-Márquez, D. Merino, T.J. Gutiérrez, Bionanocomposite films prepared from corn starch with and without nanopackaged Jamaica (Hibiscus sabdariffa) flower extract, Food Bioprocess Technol. 11 (11) (2018) 1955–1973, https://doi.org/10.1007/s11947-018-2160-z.
[48] N.H. Zakaria, M.Z. Ngali, M.Z. Selamat, F. Abdul Munir, M.A. Aman, Characteristic of thermoplastics corn starch composite reinforced short pineapple leaf fiber by using laminates method, J. Mech. Eng. Sci. 14 (3) (2020) 7058–7070, https://doi.org/10.15282/jmes.14.3.2020.08.0553.
[49] W.E. Morton, J.W.S. Hearle, Physical Properties of Textile Fibers, Fourth, Woodhead Publishing Limited, Cambridge, 2008, https://doi.org/10.1533/9781845694425.
[50] K.E. Mazur, A. Borucka, P. Kaczor, S. Gądek, R. Bogucki, D. Mirzewiński, S. Kuciel, Mechanical, thermal and microstructural characteristic of 3D printed polylactide composites with natural fibers: wood, bamboo and cork, J. Polym. Environ. 30 (6) (2022) 2341–2354, https://doi.org/10.1007/s10924-021-02356-3.
[51] G. Rajesh, G. Siripurapu, A. Lella, Evaluating tensile properties of successive alkali treated continuous pineapple leaf fiber reinforced polyester composites, Mater. Today: Proc. 5 (5) (2018) 13146–13151, https://doi.org/10.1016/j.matpr.2018.02.304.
[52] J.E.G. Van Dam, M.J.A. Van Den Oever, W. Teunissen, E.R.P. Keijsers, A.G. Peralta, Process for production of high density/high performance binderless boards from whole coconut husk. Part 1: lignin as intrinsic thermosetting binder resin, Ind. Crop. Prod. 19 (3) (2004) 207–216, https://doi.org/10.1016/j.indcrop.2003.10.003.
[53] J. Santhosh, N. Balanarasimman, R. Chandrasekar, S. Raja, Study of properties of banana fiber reinforced composites, Int. J. Res. Eng. Technol. 3 (11) (2014) 144–150, https://doi.org/10.15623/ijret.2014.0311022.
[54] N. Razali, M.S. Salit, M. Jawaid, M.R. Ishak, Y. Lazim, A study on chemical composition, physical, tensile, morphological, and thermal properties of roselle fiber: effect of fiber maturity, Bioresources 10 (1) (2015) 1803–1823, https://doi.org/10.15376/biores.10.1.1803-1824.
[55] Z.L. He, J.K. Xu, L. Zhang, H.Y. Ren, S.Y. Fu, Dramatically enhanced tensile strength and impact toughness of polydicyclopentadiene composites by covalent bond formation between phenyl-functionalized silica and dicyclopentadiene, Compos. B Eng. 170 (2019) 31–40, https://doi.org/10.1016/j.compositesb.2019.04.040.
[56] DOUG, LEATHERDALE, Pack Impact Resistance, Smithers, 2022. https://www.smithers.com/industries/packaging/manufacturers-and-users/primary-pack-testing/pack-strength-and-durability/pack-impact-resistance.
[57] I. Arvanitoyannis, C.G. Biliaderis, H. Ogawa, N. Kawasaki, Biodegradable films made from low-density polyethylene (LDPE), rice starch and potato starch for food packaging applications: Part 1, Carbohydr. Polym. 36 (2–3) (1998) 89–104, https://doi.org/10.1016/S0144-8617(98)00016-2.
[58] A. Mittal, S. Garg, S. Bajpai, Fabrication and characteristics of poly (vinyl alcohol)-starch-cellulosic material based biodegradable composite film for packaging application, Mater. Today: Proc. 21 (2020) (2020) 1577–1582, https://doi.org/10.1016/j.matpr.2019.11.210.
[59] Expanded Polystyrene (Eps), Ultimate guide on foam insulation material. https://omnexus.specialchem.com/selection-guide/expanded-polystyrene-eps-foam-insulation, 2023.
[60] A. Ibragimov, T. Vakhnina, I. Susoeva, The improvement of composite plates' indicators from cotton and flax spinning waste by modification of raw materials, MATEC Web of Conferences (2018) 239, https://doi.org/10.1051/matecconf/201823901009.
[61] M.S. Al-Homoud, Performance characteristics and practical applications of common building thermal insulation materials, Build. Environ. 40 (3) (2005) 353–366, https://doi.org/10.1016/j.buildenv.2004.05.013.
[62] X. yan Zhou, F. Zheng, H. guan Li, C. long Lu, An environment-friendly thermal insulation material from cotton stalk fibers, Energy Build. 42 (7) (2010) 1070–1074, https://doi.org/10.1016/j.enbuild.2010.01.020.
[63] O. Faruk, M. Sain, Lignin in Polymer Composites, First, Elsevier, 2015, https://doi.org/10.1016/C2014-0-01101-X.