An Approach to Recycle Plastic Waste to Create Woven Products

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ABSTRACT:

In today's world, it's hard to imagine life without plastics. Plastic production surged due to their low cost and superior tensile, physical, and chemical properties. One of the biggest environmental challenges faced is dealing with plastic waste. Plastics are often discarded in landfills or disposed of offshore. Many countries are implementing new regulations to promote the recycling of plastic waste. Hence, questions arise about the potential for creating new products from recycled plastics and the role of advanced processing technologies. These technologies intersect with design, allowing innovative concepts to transition from creative ideas to tangible products. This paper explores the potential of using post-consumer bottle poly (ethylene terephthalate) (PET) in fiber making to create textile using simple approaches to be used at homes with the aim to reuse and decrease plastic waste. PET bottles have been processed in two different ways to produce fibers. First, the filament plastic fiber, executed through melting and pulling, where its length is according to personal preference. Produced fiber is smooth and luster. The second way involves using a centrifugal melting device where produced staple fibers are very fragile and easy to break. It was found that these staple fibers should be spun beforehand before use in the hand-weaving process while the filament fibers should have consistency in its thickness for it to be strong. Accordingly, further experimentation is needed to determine the best conditions while putting into consideration the application that it'll be used in.

1. Introduction

One of the leading contributors to the global environmental pollution is the accumulation of plastic waste such as PET bottles. According to Jambeck et al. (2015), more than 8 million tons of plastic waste end up in the oceans every year, where PET bottles represent a significant portion of this waste. PET is a popular thermoplastic polymer used in various consumer products, specifically packaging. Despite its widespread use, the recycling of PET has been considered to be a challenge due to its contamination and variations in material quality. Yet the recycling of PET waste into fibers presents a promising solution for reducing plastic waste and having a positive input on the environmental problems. (Rahimi & Garcia, 2017; Sharma & Kaur, 2020).

Fibers derived from PET are widely used in the textile industry, especially for creating fabrics like polyester. However, most of the fibers that are being used in the textile industry nowadays are made from virgin PET. So, the use of recycled PET remains limited in the textile industry and this is due to concerns over mainly the fiber quality followed by the contamination and the inefficiency of existing recycling processes (Chen et al., 2017; Sharma & Kaur, 2020).

This paper explores two different approaches of recycling PET bottles and turning it into fibers with the aim to see to whether or not its applicable for textile applications. The first method involves melting or in other words melt spinning via filament pulling the melted PET manually, while the second utilizes centrifugal spinning, which creates staple fibers through centrifugal force. These methods were analyzed for their efficiency and quality of the fibers produced.

2- Background and Literature Review

2.1 Plastic Waste and PET Recycling

Polyethylene terephthalate (PET) has become, worldwide, one of the most commonly used plastics in the consumers' daily products. But due to its widespread use globally, PET waste represents a significant environmental problem. Studies have revealed that PET bottles could reach up to, if not more, than 20% of the plastic waste that are thrown in wide oceans and seas (Jambeck et al., 2015). Thus, different approaches of recycling plastic were introduced. Using the Traditional recycling methods, such as mechanical recycling, was found that they are often inefficient for converting PET waste into high-quality products and this is due to the potential of significant degradation of material properties (Chen et al., 2017; Liu et al., 2020).

However, there are different types of recycling used for PET and they are the mechanical recycling, chemical recycling and thermal recycling. Mechanical recycling, which is the most commonly used method for recycling PET, involves shredding and melting PET with the aim to reform it into new products. This method often causes the polymer chain length to start breaking which causes a decrease in the material's strength. This may cause limitation in its applicability in high-performance products like textiles (Zhu et al., 2020). Chemical recycling, on the other hand, involves breaking PET down into its monomers and repolymerizing them to form new, high-quality PET. While this method offers higher-quality recycled material, it is more energy-intensive and less commonly used in the textile industry due to its higher costs (Cunningham et al., 2020). As for the Thermal recycling, it is executed through melt spinning. Creating such fibers through thermal recycling, has caught attention due to its ability to directly process PET into yarn-like forms. Melt spinning can be performed using various techniques, including manual filament pulling and centrifugal spinning. In the filament pulling method, molten PET is extruded through a comb-like shape, which is pulled to form continuous fibers (Gupta & Rathi, 2018). Centrifugal spinning involves the use of centrifugal forces to extrude molten PET through small holes in a spinning head, producing staple fibers (Zhang et al., 2021).

2.2 Fiber Production from PET Bottles

The production of fibers from PET bottles has been the subject of various studies in the field. Melt spinning, which is a well-established method, forces the melted polymer to pass through a nozzle in order to form continuous fibers. However, when using post-consumer PET, there are some differences in the extruded fibers which may result in differences in fibers' diameter and texture especially when the plastic is contaminated or degraded which may affect its viscosity This limitation is one of the key challenges that the textile industry faces when recycling PET. Thus, it is important to control the extrusion parameters such as temperature and pressure to maintain uniformity in fiber production. (Huang et al., 2020). According to Gupta & Rathi, 2018, in traditional melt spinning, the fiber diameter is typically controlled by adjusting the melt flow rate and extrusion temperature. However, variations in the material, such as inconsistent viscosity or contamination, can result in non-uniform fiber thickness. This is particularly problematic when recycling post-consumer PET, as the material often contains impurities and varying polymer chain lengths.

However, Centrifugal spinning is a more recent approach that has shown promising results when producing staple fibers from recycled PET. It has gained recently attention due to its potential of producing high-quality fibers (Zhang et al., 2021). In centrifugal spinning, a polymer melt is placed in a spinning head, where centrifugal forces push the molten material through tiny holes, forming fibers. These fibers that are collected are staple fibers. The advantage of centrifugal spinning is its ability to produce fibers with varying textures, which may be suitable for specific applications, such as insulation or geotextiles, but according to Ramsay, not necessarily for traditional woven fabrics (Ramsay et al., 2019).

Unlike traditional melt spinning, centrifugal spinning can create fibers with a more varied texture, which can be useful for applications such as nonwoven fabrics or insulation materials. However, for woven textiles, it is essential to control the fiber properties, such as diameter consistency and strength. Studies have shown that the timing of fiber collection in centrifugal spinning can affect the texture and quality of the fibers, with fibers collected at different stages exhibiting varying levels of roughness, smoothness, and strength (Ramsay et al., 2019).

2.3 Polyethylene Terephthalate (PET) Recycling Challenges

PET is a thermoplastic polymer that, due to its strong mechanical properties, is widely used in consumer products such as beverage bottles. However, the increasing accumulation of PET waste presents a major environmental challenge. According to research by Liu et al. (2020), while PET can be mechanically recycled, it often degrades during the process, leading to a loss in the mechanical and thermal properties of the material. This degradation limits the applications of recycled PET, particularly in the production of high-performance textiles.

One of the key barriers to recycling PET into fibers is the contamination of post-consumer PET bottles. The presence of additives such as dyes, labels, and caps can introduce variability into the recycled material, affecting the quality of the fibers produced. Mechanical recycling typically involves shredding and melting PET to reform it into new products. However, mechanical recycling can lead to a reduction in polymer chain length, which diminishes the material's strength and durability (Zhu et al., 2020).

3- Objectives

Investigate the Potential of Plastic Waste as a Raw Material for Hand-Woven Products

- To explore the feasibility of using recycled plastic waste as an alternative material for creating hand-woven products.
- To analyze the properties of different types of plastic waste and their suitability for weaving processes.

Develop a Sustainable Method for Plastic Waste Recycling

- To identify and develop efficient methods for recycling plastic waste into usable fibers or threads.
- To assess the environmental impact of the recycling process, focusing on energy consumption, emissions, and waste reduction.

Design and Manufacture of Woven Products from Recycled Plastic

- To design various woven products (e.g., mats, bags, textiles) using recycled plastic materials.

Promote Circular Economy Practices

- To highlight the social and environmental benefits of recycling plastic waste to produce hand- woven products contributes to a circular economy through reducing plastic waste and creating a sustainable product cycle.

Examine the Challenges and Opportunities of Hand-Woven Products from Plastic Waste

- To identify the key challenges in the production and acceptance of woven products made from plastic waste.
- To propose solutions and strategies to overcome these challenges and maximize the potential of recycled plastic.

4- Experimental Material & Methods

4.1 Materials

For the experimental work, PET bottles were collected from local waste disposal systems. After cleaning to remove labels, caps, and contaminants, the bottles were mechanically shredded into small flakes, which were then used in the fiber production process (Fig.1).

Figure 1. Shredded flakes of PET bottles

Two methods were employed to convert the PET flakes into fibers: melt spinning via manual filament pulling and centrifugal spinning.

4.2.1 Method 1: Melting Spinning and Filament Pulling

In the first method, PET flakes were melted in a temperature-controlled furnace. The molten PET was then manually drawn into fibers using a comb-like tool. The length of the fibers was controlled by adjusting the speed at which the comb was pulled from the molten material. The filament produced was smooth and continuous, with some variation in thickness, particularly where the molten PET was more viscous or heterogeneous. The diameter of the fibers was not fully controlled, and variations in thickness was observed, which is a common challenge in this method. (Figure.2)

The filament pulling method produced fibers with smooth surfaces and a consistent texture, although the thickness of the fibers varied slightly due to the heterogeneous nature of the PET melt.

Key Parameters:

- Temperature: 250°C
- Comb speed: Adjustable (based on required fiber length)
- Melt viscosity: Varies due to polymer degradation and impurities

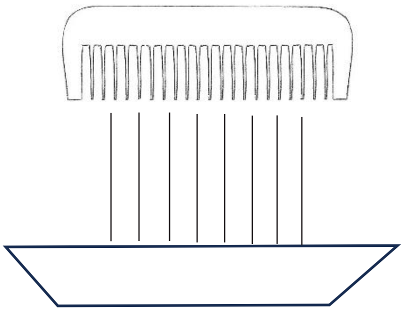

Figure 2: Filament pulling process schematic

This method produced fibers that were consistent in texture but exhibited variability in diameter. The smoothness of the fibers made them suitable for further processing into woven fabrics, but their varying thicknesses posed challenges for large-scale textile production.

4.2.2 Method 2: Centrifugal Spinning

The second method employed centrifugal spinning. In this process, 2.5 grams of PET flakes (Figure.1) were loaded into a small bowl inside the centrifugal spinning machine (Figure.3). The spinning head was heated to ca. 230°C, causing the PET to melt. The molten PET was forced through tiny holes by centrifugal forces, creating staple fibers. The centrifugal force created by the rotating head pushed the molten PET through small holes in the head, forming fibers (Figure.4). The fibers were collected at regular intervals (every 2 minutes) to assess the effect of the collection timing on fiber characteristics.

Key Parameters:

- PET amount: 2.5 grams
- Heating temperature: 230°C
- Collection interval: Every 2 minutes

Figure 3: Centrifugal Melting Device

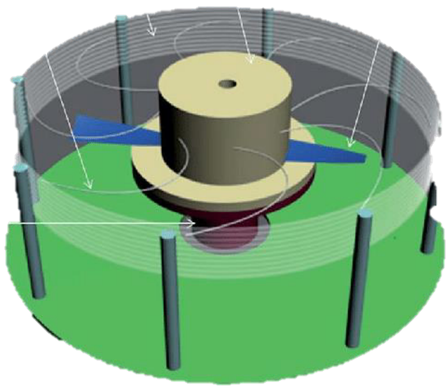

Figure 4: Schematic of the centrifugal spinning process

This method produced staple fibers with varying properties based on the timing of collection, demonstrating the potential for customizing fiber characteristics for specific applications.”.

The fibers that were collected at different time intervals created three different categories:

1. **Coarse and Rough Fibers**: Collected immediately after adding the PET flakes, first time interval, to the centrifugal device. These fibers were too rough to be spun. Collected fibers had uneven texture and were considered to be unsuitable for hand-woven textile applications due to their roughness but rather be used in fillings.
2. **Smooth but Contaminated Fibers**: Collected at the second time interval. These fibers exhibited smoother textures but contained plastic particles and impurities, which limited their application to nonwoven materials and unsuitable for high-quality products.
3. **Soft and Fragile Fibers**: Collected at the third time interval, resulting in delicate fibers suitable for hand spinning. It was observed that these fibers were soft and fragile, suitable for hand spinning but lacked the strength

5- Results & Discussions

5.1 Fiber Properties

The fibers produced through both methods exhibited distinct characteristics:

Melt Spinning Filament Pulling: The fibers produced by filament pulling were relatively smooth and continuous, with minimal defects. However, the diameter of the fibers was not entirely uniform, which could pose challenges for large-scale weaving processes. The smoothness of the fibers, combined with their consistent texture, made them suitable for applications requiring higher-quality yarns, but the variability in diameter needs to be addressed (Figure.5). However, some variability in fiber diameter was observed. The main challenge with this method was maintaining a uniform thickness throughout the length of the fiber, which could potentially impact the quality of woven textiles.

Centrifugal Spinning: The fibers produced by centrifugal spinning varied significantly depending on the collection timing (Figure.4). The coarse and rough fibers, collected immediately after adding PET, had uneven diameters and surface roughness, making them unsuitable for most textile applications. The smooth but contaminated fibers were more uniform but contained plastic particles that could degrade the quality of woven fabrics. The soft and fragile fibers, collected later in the process, were ideal for hand spinning but lacked the strength required for machine-based textile production.

The fibers produced through centrifugal spinning showed a wider range of textures. The coarse fibers were too rough to be used in textiles, while the smooth fibers with plastic particles were better suited for nonwoven applications. The soft fibers, which were collected later in the process, were delicate and suitable for hand spinning but lacked the strength for potential use in industrial applications.

Table 1: Fiber Characteristics from Different Methods

Method	Fiber Type	Texture	Use Case
Filament Pulling	Smooth and consistent	Smooth, consistent	Suitable for woven fabrics
Centrifugal Spinning	Coarse and rough	Rough, uneven	Nonwoven, insulation
Centrifugal Spinning	Smooth with particles	Smooth, contaminated	Nonwoven applications
Centrifugal Spinning	Soft and fragile	Soft, delicate	Hand spun yarn

Table 1: Fiber Characteristics

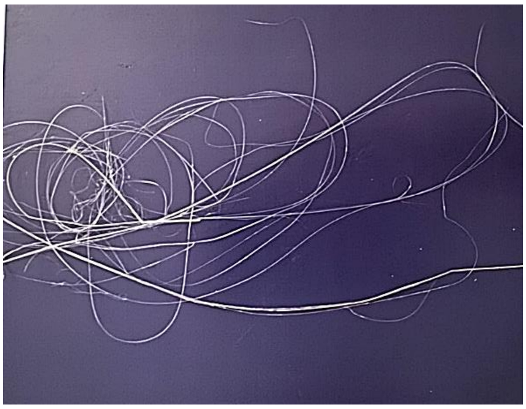

Figure.5: Filament Fibers

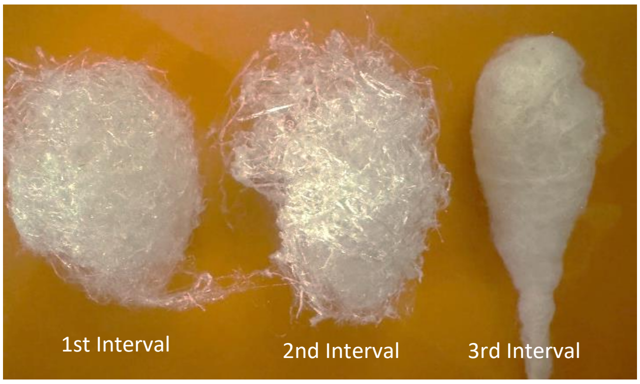

Figure 6: produced fibers at different time intervals using Centrifugal Spinning

6- Analysis of Fiber Properties

The melt spinning method (filament pulling) produced fibers with a smooth texture, which is ideal for textile applications. However, the variability in fiber thickness limits its scalability to be used in production since in the finest areas of the fiber it tends to break. It is clear that the filament pulling method has the potential to offer the advantage of producing smooth fibers that are ideal for woven fabric production. However, the inherent challenge with this method is controlling the thickness of the fibers, which can vary due to changes in melt viscosity or minor fluctuations in the pulling speed.

On the other hand, centrifugal spinning provided a broader range of fiber characteristics, allowing for more tailored products but with limitations. Using this kind of method offered more flexibility in producing fibers with different textures, but its variability in fiber quality is significant (Table.1). While coarse fibers (1st Interval sample) are unsuitable for weaving, the smoother (2nd Interval sample), contaminated fibers can be used for nonwoven applications. However, the staple fibers, collected at the 3rd interval of time, are smooth but yet fragile (Figure. 6).

The different kinds of samples collected at different intervals from the centrifugal device is believed to be due to numerous reasons. First, is due to the degradation of polymer chains. Degradation of polymer chains often involves thermal degradation of the polymer, which reduces molecular weight and weakens the mechanical properties of the fibers (Singh et al, 2008). Also, it is believed to be due to contaminants or additives in recycled plastic which can disrupt fiber uniformity and bonding (Ulcay, Y., 2004). Lastly, since the centrifugal device is not tightly controlled (e.g. spin rate, cooling, etc), it can produce inconsistent or porous fibers that are mechanically weaker. (Vo, P.P et al, 2018).

Figure 7: A single strand of staple fibers

Figure 8: Weaving trial of staple fibers

7- Conclusion

This study has demonstrated two methods for recycling PET bottles into fibers suitable for Hand-weaving textile production: melt spinning via filament pulling and centrifugal spinning. Both methods have shown potential for converting PET waste into usable fibers, but each has its challenges. The filament pulling method produced smooth fibers with relatively consistent texture, allowing it to be used in decorative applications that requires softness and luster.

Centrifugal spinning produced fibers with a wider range of textures, making it suitable for different applications. The lack of uniformity and the presence of contaminants present in samples, 1st and 2nd interval samples, makes it challenging to be used in fabric production. Therefore, due to its texture, these samples may be used in furniture fillings like for e.g. pillows, mattresses, sofas, etc. Yet fibers from the 3rd interval, after being spun, it had the potential to be used in hand-weaving production.

Future research will focus on optimizing both methods to improve the uniformity of fibers produced from recycled PET, with a particular focus on controlling the thickness in the filament pulling method and reducing contamination in the centrifugal spinning method. Future research will also focus on executing standard tests on the fibers to be able to determine the approaches that may be used to enhance the physical and mechanical properties of the fibers. The scalability and efficiency of these techniques can significantly contribute to the sustainability by reducing reliance on virgin materials and promoting the use of recycled plastics.

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