Polymer composites from natural fibers and recycled waste surgical masks during COVID-19 pandemic

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Abstract
The crucial role of face masks is highlighted in our day-to-day life during the COVID-19 pandemic. Polypropylene (PP)-based disposable face masks are widely used to hold back viral transmission. The discarded masks can create a huge burden of contamination on the environment. The purpose of this work is to recycle and reuse discarded masks to reduce environmental pollution. A simple and innovative technique to recycle surgical masks into composites of higher mechanical strength and antimicrobial properties is explored to reuse in packaging materials and cutleries. The surgical masks composed of PP fibers are recycled to use as a matrix material to reinforce with sisal and hemp fibers. The hot compression molding technique is used to sandwich the PP masks with natural fibers. The tensile strength of the composites is remarkably increased by 197% and 305% for sisal fiber composites and hemp fiber composites, respectively. The tensile elongation also increased to 574% for sisal fiber composites. The resulting composites exhibit notable antimicrobial properties against Staphylococcus aureus, a pathogen responsible for common staphylococcal food poisoning. The composites are found to be suitable to use as food contact cutleries and packaging materials.

KEYWORDS
antimicrobial packaging, COVID-19, natural fibers, recycling, surgical masks

1 | INTRODUCTION

Recently, the outbreak of novel coronavirus diseases 2019 (COVID-19) causes severe acute respiratory syndrome (SARS-CoV-2) to infect patients rapidly worldwide. On March 11, 2020, the world health organization (WHO) had declared it a pandemic. The breathing problem, fever, cough, shivering, tastelessness, and so forth are the significant symptoms in humans suffering from COVID-19. Hence, to restrain this virus, the world goes ahead with the WHO's recommended vaccination and strategies to maintain health and hygiene. Some simple precautions, such as physical distancing, wearing a mask, cleaning hands, keeping rooms well ventilated, avoiding crowds, and coughing into a bent elbow or tissue are a part of a comprehensive strategy of measures to suppress transmission and save lives. The lion's share of the people of the world is wearing face masks daily to stay safe through COVID-19 as a primary protection measure that may shield us from the respirational droplets, which are appeared by sneezing, coughing, etc., which can spread the viruses. A report estimated that ca. 129-billion

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single-use face masks are used every day worldwide and thrown open without proper treatment which causes pollution to soil and the environment. Some masks are found to be scattered on our roads, shores, and seas, which make wildlife jeopardized. Some garbage management firms are using portable incinerators in cities to dispose of the massive amount of abandoned face masks that may create air pollution. The COVID-19 situation makes our years-long global fight tougher to decrease plastic trash contamination. The health department is worried about the possible health threats associated with mask garbage.

To address this issue, recycling is a well-accepted technique to design and transform waste mask substances into new products to reduce the quantity of trash. Among different masks, polypropylene (PP) based three-layered surgical mask is vastly used throughout the world. The PP is a thermoplastic polymer utilized within a broad class of packaging materials. It is the second most commonly manufactured plastic material after polyethylene but is more rigid and higher temperature resistant than polyethylene. Commonly, it is tough as well as costly to make identical goods as original ones through recycling. So, it is preferable to make composite by reinforcing agents to attain several improved properties.

The interest in natural fibers as reinforcing agents in polymer composites has grown considerably due to their significant properties, such as easy availability, low cost, low density, high mechanical strength, renewability, lower environmental impact, lower abrasive damage, good insulation properties (thermal, electric and acoustic) and can be incinerated easily. Furthermore, the durability of the composites made from natural fiber and polymer matrix shows promising results under long-term weathering conditions. In this work, sisal and hemp fiber are used as reinforcing agents to develop recycled composites of PP-made waste masks.

The aim of the present study is to achieve recycled PP composites of higher mechanical strength and stability as well as its application in the field of packaging material and cutleries thereof. We correlate and compare the influences of the two different fibers on recycled PP masks in light of tensile strength (MPa) and tensile elongation percentage. Apart from remarkable strength and elongation, the food packaging industry necessitates antimicrobial active packaging materials to fulfill customer demands on ensuring the food safely. Therefore, the antimicrobial properties of the two different composites are tested and the outcomes encourage us to use them as packaging material and cutleries. Moreover, it opens a very promising way to understand fibers’ behavior during processing as well as to predict the final properties of the composites.

2 | METHODOLOGY

2.1 | Sample preparation

A facile method to fabricate food packaging materials and cutleries using recycled mask and natural fiber composites are discussed. Initially, acquisition of waste masks is done by workers and volunteers collecting the used masks from residences, offices, group localities, markets, manufacturing zones, bins etc. After recovering mask, it is cleaned to eliminate dust, sticker, adhesive, bits and supplementary substances. The nylon belts are cut off and separated from masks and then rest part of masks are crushed into small pieces to make it granular size.

Natural fibers are obtained from sisal and hemp plants and processed into woven fabric prior to production. Hot compression molding technique is used to sandwich the polypropylene (PP) masks with natural fibers (compression machine brand: Comtech and model: QC-601T). The temperature is set at 170°C for upper and lower platens of the compression machine for melting PP at 25 kg/cm² pressure. The melted PP under compression pressure enters into the warps and wefts of natural fiber to obtain worthy polymer-fiber bonding through hot-press followed by re-shaping methodology (Figure 1). Table 1 shows the properties and parameters of sisal and hemp fibers as reported in Reference [29]. To develop composites the taken wt% of the materials are given in the Table 2. The weight fractions of the materials are given by equation:

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W_f = \frac{W_f}{W_f + W_{pp}} \quad \text{and} \quad W_m = \frac{W_m}{W_f + W_{pp}}.
\]

In the equation, \(W_f\) is the weight of fiber (ca. 5.32 and 4.99 g each layer for sisal and hemp respectively), \(W_{pp}\) is the weight of a cleaned mask (1.83 g per layer), \(W_f\) is weight fraction of fiber and \(W_{pp}\) is weight fraction of polymer mask. All weights in the table are calculated by the average weight of 20 respective samples.

2.2 | Microscopy

The surface morphology and weaving pattern of the natural fibers were analyzed using scanning electron microscopy (SEM) imaging technique. The SEM images of the natural fibers were recorded on FEI Quanta 450 scanning electron microscope operated at 15 kV.

2.3 | Tensile test

Tensile strength (TS) and tensile elongation (TE) of the composites were determined using a Comtech tensile testing
2.4 Antimicrobial test

Antimicrobial properties of the recycled composites were determined using standard disc diffusion method against a gram negative *Staphylococcus aureus* bacteria. To observe the antimicrobial activity, a 2 cm diameter disk is cut from the sample and disinfected using UV light prior to testing. The inhibition zone resulting around the area of the disk represents efficiency of the composites to stop the bacterial growth. This is photographed and compared for evaluation of antimicrobial activity of the composites.

3 | RESULTS AND DISCUSSION

3.1 Surface morphology of fibers

Surface morphology of the sisal and hemp fibers is given in Figure 2. It is observed that both sisal and hemp fiber yarns are ca. 500 μm in diameter. Sisal fibers consist of smaller diameter fibers twisted into yarns. However, hemp fibers are twisted using larger diameter yarns resulting in smoother surface. Thus bonding surface area between the fibers and matrix are higher. As a result of this higher roughness and twisted fiber, an increase in the tensile strength of the sisal fiber composites can be anticipated. On the other hand, hemp fibers are smoother and gap in between the fibers are less resulting in lower bonding surface area between the fibers and matrix. This can be very evident in the tensile strength and elongation at break of the composites.

3.2 Mechanical properties

TS and TE of the composites were studied using UTM machine. The tensile strength of pure PP melted from masks (dimension 10 cm × 1 cm × 0.3 cm), PP/sisal fiber and PP/hemp fiber composites are given in Figure 3. The TS of the composites is found to increase 197% and 305% for sisal fiber composites and hemp fiber composites, respectively. This huge rise in tensile properties is directly related to roughness of the fibers. The higher surface area due to roughness leads to better bonding of the fibers and

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**TABLE 1** Properties and parameters of sisal and hemp fibers

| Parameters       | Sisal fiber | Hemp fiber |
|------------------|-------------|------------|
| Cellulose content (%) | 60–67       | 72         |
| Hemicellulose (%)  | 10–15       | 10         |
| Lignin content (%) | 8–12        | 3          |
| Density (g/cm³)    | 1.45        | 1.48       |
| Moisture content (%) | 10         | –          |
| Tensile strength (MPa) | 227–400    | 550–900    |
| Tensile elongation (%) | 2–14       | 1.6        |

**TABLE 2** Taken weight fractions to develop the composites

| Samples                  | Weight (g) | Weight fraction (%) |
|--------------------------|------------|---------------------|
|                          | w_f        | w_pp               | W_f    | W_pp  |
| PP                       | –          | 14.64               | –      | 100.00|
| PP/sisal fiber           | 15.96      | 9.15                | 63.56  | 36.44 |
| PP/hemp fiber            | 14.97      | 9.15                | 62.06  | 37.94 |

Machine with a load cell of 2500 kgf. Five identical test specimens were used for tensile test. The test was carried out as per the ASTM D3039 standard. The experiments were performed at room temperature at a crosshead speed of 2.5 mm/min.
polypropylene. Further, the tensile elongation also are remarkably increased to 574% for sisal fiber composites. This is highly recommended for food packaging applications where the material can undergo stress deformations under loading conditions. However, the tensile elongation of hemp fiber composites are increased notably 161%. This material is suitable for cutlery applications owing to its stiffness. This may be due to the closely packed warp and weft layers in the woven fabric, which restricts the PP to penetrate inside. Moreover, the fiber properties are showing more evident when melted PP only bonded with the outermost layers. Thus, we can summarize that the properties of the recycled PP/natural fiber composites can be tailored to the requirement of final product.

### 3.3 Thermal properties

Thermal degradation studies using thermogravimetric analysis (TGA) are important to understand the thermal stability of the composites used in cutleries and packaging materials. Figure 4 shows the onset, endset and maximum degradation of the composite materials made from hemp, sisal and PP masks. As expected, the fibers are undergoing two-step degradation, while the masks are showing single step degradation. This is due to degradation of fibers are initiated at a lower temperature than polymer. The maximum degradation of both sisal and hemp fibers are observed at 320–350°C, whereas pure polypropylene shows maximum degradation at 450°C. On the other hand, the final degradation temperatures are increased from 459.77 to 470.47 and 473.79 for pure PP masks, sisal and hemp respectively. This implies that thermal stability of PP masks based composites are enriched by the addition of natural fibers. Also, the char content show the percentage degradation at each stage of degradation. Table 3 summarizes the degradation temperatures and char content of all the composites.
3.4 | Antimicrobial studies

The antimicrobial properties of the composites are carried out using the disk diffusion method. The composites are cut into small disks and placed on the LB broth containing microorganisms. In this study, *Staphylococcus aureus* (*S. aureus*) is the microorganism. The test is conducted in lab conditions where the samples were placed on a glass petri dish containing LB broth medium and the bacteria. The pure PP was taken as the control sample. Figure 5 shows the activity of composites against bacteria. In all the cases, no significant inhibition zone is observed on pure PP. The composites show remarkable results against *S. aureus*. The sisal fiber composites and hemp fiber composites show inhibition zones of ca. 3 mm and 1 mm, respectively. This is due to the lignin present in the fibers which are restricting bacterial growth in its neighbor. Therefore, the results are noteworthy for its application in food packaging and cutlery.

4 | CONCLUSION

An innovative method for recycling of surgical mask from mask-bin into a definite shape comprising of the steps: collecting the mask, removal of nylon cord, cleaning properly and reformed it by compression molding. The TS of the composites is found to increase 197% and 305% for sisal fiber composites and hemp fiber composites, respectively. Further, the tensile elongation also is remarkably increased to 574% for sisal fiber composites. This material is suitable for cutlery applications owing to their stiffness. Significant inhibition of *Staphylococcus aureus* bacterial growth by fiber/PP composites for both sisal and hemp fibers indicating its effective use in the food packaging industry which necessitates antimicrobial active packaging materials to fulfill customer demands on ensuring the food safely.
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