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*Research Article*

# Mechanical Properties of Hemp Fiber-Reinforced Polypropylene Composites for Drone Propeller Guard Application

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**ABSTRACT**

A propeller guard is an instrument that helps to avoid Unmanned Aerial Vehicles (UAVs) or drone damage. Commercially, they are made from an engineering plastic such as Acrylonitrile Butadiene Styrene (ABS). This work aims to introduce the hemp fiber-reinforced polypropylene composites as a new competitive material for propeller guards. In this study, polypropylene was thermally mixed with different ratios of hemp fibers by internal mixing at 190°C. Tensile and impact testing were carried out according to ASTM D638 and ASTM D256, respectively. The results showed that the high contents of hemp fibers can enhance the modulus of their composites. Polypropylene composite with 45 wt.% of hemp fibers obtained the highest modulus at 1169.4 MPa. Also, the impact resistances of these composites were higher while the fiber contents were increased. Furthermore, application in drone propeller guard was executed by SIMCENTER 3D software for proving their propeller protection performance of as-prepared composites. The results indicated that polypropylene and its hemp fibers-reinforced composites could be the materials for this drone propeller guard.



## 1. Introduction

Unmanned Aerial Vehicles (UAVs) or drones were applied to several activities in daily life such as military, photography, and agriculture [1]. Aerial photography by drones is increasingly seen in public places, especially in tourist attractions. The high rate of drone usage brings high concern about the danger to humans and their properties [2]. Many drone cameras were installed with drone propeller guards. The drone propeller guard is a protective instrument for drone propellers. The main reason for using these propeller guards is safety. The drone propeller guard can reduce the impact of drone propeller-to-human collision. However, drone

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damage often occurs to propeller components due to unexpected obstacles hitting them. The drone propeller guards were also used to protect against this accident and avoid the damage cost.

Commercially, drone propeller guards are made from an engineering plastic called Acrylonitrile Butadiene Styrene (ABS) polymers. The presence of three components with different properties in ABS polymers provides balanced properties of ABS materials. This material is rigid, highly thermal resistant, and has good impact strength [3]. These properties meet the desired performance for drone propeller guards. The main function of a drone propeller guard is protecting the propellers from collision so that means the propeller guard usually is broken. The cost of ABS propeller guard and their disposal are restricted [4]. Other competitive materials are required for this solution.

Polypropylene (PP) is a commodity plastic that is mainly used daily. Because of its good mechanical properties, lightweight, ease of fabrication, and recyclability, it is popular in several applications. However, their mechanical properties are lower than ABS. Many researchers have studied the improvement in the mechanical properties of polypropylene or other commodity polymers by a variety of methods such as blending [5, 6], particle reinforcement [7 - 9], and fiber reinforcement [10 – 14]. Fiber reinforcement was mainly a method for enhancing impact resistance and toughness [10]. Both synthetic and natural fibers were candidates for improving polypropylene performance [15 - 18]. Kurien and coworkers [19] introduced abaca fibers as a highly mechanically reinforced material for structural polymer composites. Moreover, rigid thermosetting polymers like epoxy resins can also be reinforced with abaca fibers [20].

Among other things, hemp fibers are proven that they dominantly have high strength-to-weight and were applied in aerospace applications [21]. Shah and coworkers [22] indicated that an impact strength increased by about 35–40% for hemp fiber-reinforced recycled-carbon fiber polypropylene composites. Also, hemp was generally planted in Northern, Thailand, and hemp fibers were produced as raw materials for the textile industry. Because of their performance and cost, hemp fibers were a good competitive fiber to reinforce polypropylene polymers in this work.

To discover new materials for drone propeller guards, the hemp fibers reinforced polypropylene composites were fabricated with different fiber compositions. Their mechanical properties were studied according to ASTM D638 [23] and ASTM D256 [24]. Furthermore, application in drone propeller guard was executed by SIMCENTER 3D software for proving their propeller protection performance of as-prepared composites.

## 2. Materials and Methods

### *2.1. Raw Materials*

Polypropylene pellets (POLYMAXX, IRPC Public Company Limited, Thailand) were used as polymer matrices. Hemp fiber yarns, from a local producer in Chiang Mai, Thailand, were used as reinforced material. They were chopped to fabricate the short fibers in a range of 5 to 7 millimeters with fiber diameters less than 1 millimeter. Polypropylene-grafted-maleic anhydride (PP-g-MA) (Sigma-Aldrich) was mixed with each composite as a compatibilizer.

### *2.2. Preparation of Hemp Fiber-Reinforced Polypropylene Composites*

To control parameters, polypropylene pellets were thermally mixed by an internal mixer (Chareon Tut Co., Ltd.) at 190 °C with a rotor speed of 50 rpm for 15 minutes. They were ground into small pellets after cooling down and were kept in a vacuum bag. Three different weight compositions of hemp fibers were fabricated including 15 wt.%, 30 wt.%, and 45 wt.%, respectively, for composite preparation. All desired fiber-reinforced composites and 2 wt.% of PP-g-MA compatibilizer were mixed at 190 °C with a mixing speed of 50 rpm for 15 minutes. Similarly, the composites were ground and kept in vacuum bags.

### *2.3. Sample Preparation and Testing*

There are two mechanical tests in this work, tensile and impact testing. Polypropylene and its fiber-reinforced composites were fabricated into the mold of specimen forms introduced according to ASTM D638 for tensile test and ASTM D256 for impact test. The sample pellets were filled in a stainless-steel mold and were compressed with a pressure of 1500 Pa, 190 °C for 10 minutes. After cooling down, the specimens were kept in vacuum bags.

Modulus of elasticity, tensile strength, and elongation of polypropylene and their fiber-reinforced composites were obtained from tensile test according to ASTM D638. The specimens were tested by using a Universal testing machine (LLOYD) with a loadcell of 50 kN and test speed at 50 mm/min. On the other hand, the impact resistance of polypropylene and their fiber-reinforced composites were investigated by Impact tester (INSTRON). Notched specimens were tested with 2.75 J. and provided the absorbed impact energy. Morphological study of the fracture surface of the specimens was examined via Scanning Electron Microscopy or SEM (QUANTA250) analysis.

For a feasibility study of drone propeller guard application, SIMCENTER 3D software (SIEMENS) was used to simulate stress distribution on a commercial propeller guard model for a drone camera DJI Tello (fig.1.). In analysis, the maximum force derived from the maximum speed (8 m/s) and weight of the drone (80 grams) were calculated for simulation.

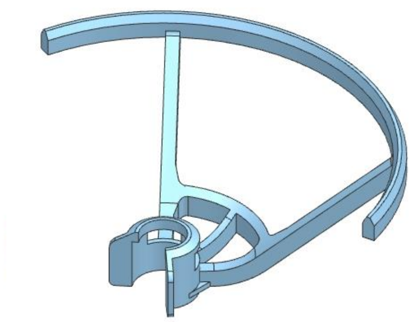

**Fig. 1.** A 3D model of DJI Tello propeller guard

## 3. Results and Discussion

Hemp fibers-reinforced polypropylene composites could be prepared via thermal mixing with the addition of a PP-g-MA compatibilizer. The existence of hemp fibers in these composites resulted in dark brown colored samples. For morphological analysis, SEM images of these composites were presented in Fig. 2.

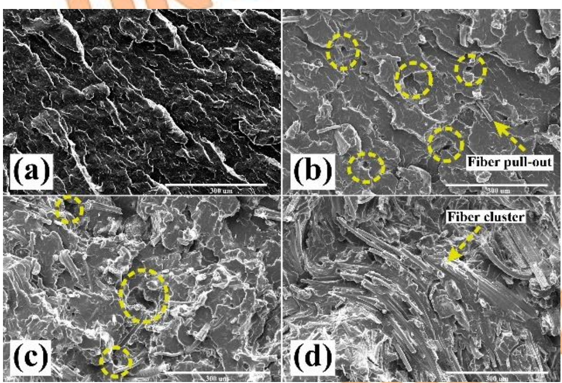


**Fig. 2.** SEM images of (a) Polypropylene, (b) 15 wt.% of hemp fibers-reinforced polypropylene composite, (c) 30 wt.% of hemp fibers-reinforced polypropylene composite, and (d) 45 wt.% of hemp fibers-reinforced polypropylene composite

A continuous surface of polypropylene was noticed in Fig. 2(a). However, the addition of hemp fibers in polypropylene introduced some discontinuous areas in their composites. More voids, fiber pull-out, and fiber-matrix debonding occurred while more hemp fiber contents were increased as seen in Fig.2(b) – Fig.2(d). Hemp fiber clusters appeared in high fiber content of 45 wt.%. This observation indicated the poor compatibility between hemp fibers and polypropylene matrix. Other researchers had discovered that poor interaction between fibers and matrix was the main reason for those results [25]. Furthermore, Patil and coworkers stated that a 5–10% filler content in composites can provide an optimum void content and their mechanical value [26].

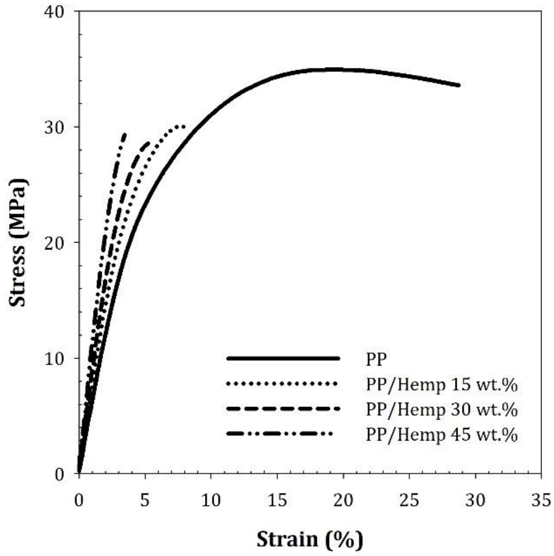


**Fig. 3.** Tensile stress-strain curves of polypropylene and their hemp fibers-reinforced composites

The results of Young's modulus, tensile strength, and strains at the break of polypropylene and their hemp fibers composites were obtained from stress-strain curves in Fig. 3. It was clearly shown that an addition of hemp fibers in the polypropylene matrix decreased their ductility.

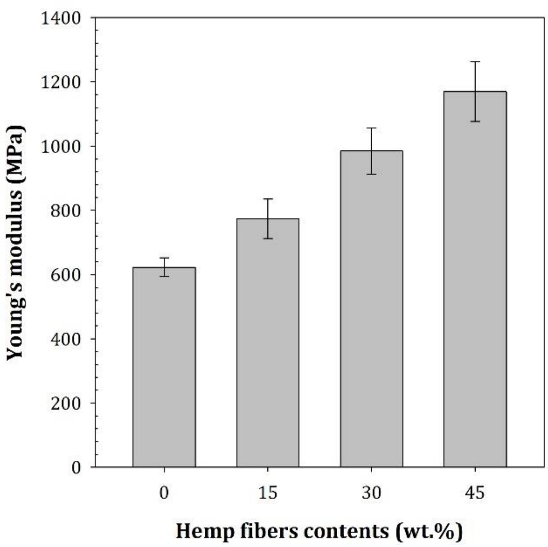


**Fig. 4.** Young's modulus of polypropylene and their hemp fibers-reinforced composites with different fiber contents

The results of Young's modulus in Fig. 4 confirmed the rigidity of the fiber-reinforced composites. The modulus of the composites increased when the fiber contents in composites were increased. In this study, the highest modulus (1169.40 MPa) was obtained from the composite with 45 wt.% of hemp fibers. This is twice as high as the modulus of the polypropylene sample. The existence of fibers in the polypropylene matrix affected molecular dislocation, then the specimens were rigid and provided a higher modulus [27].

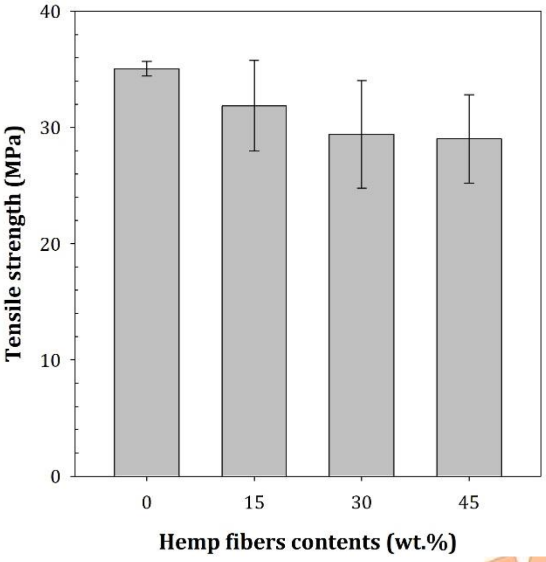


**Fig.5.** Tensile strength of polypropylene and their hemp fibers-reinforced composites with different fiber contents

In contrast, the tensile strengths of the hemp fiber-reinforced polypropylene composites were decreased with increasing fiber contents as shown in Fig. 5. These phenomena are generally observed in poor interaction between fillers and polymer matrix [28]. Although filling the compatibilizer, the hydrophilic natural fibers, like hemp fibers, often are oriented together in the hydrophobic polymer matrix as seen in Fig. 2(d). The compatibilizer compositions and their types will be studied in the future.

Lacks interaction in these composites significantly affected sample deformations. As seen in Fig. 6, strains of the fiber-reinforced composites (3.97-8.42%) were extremely decreased compared to polypropylene (28.31%). Poor interaction between fibers and matrix reduced the opportunity of fiber entanglement [29]. Moreover, the rigidity of these composites is the main reason for this result as in the previous discussion. However, the values of tensile strength and strain at the break of these composites could be compared with the abaca fibers/polypropylene composites [19].

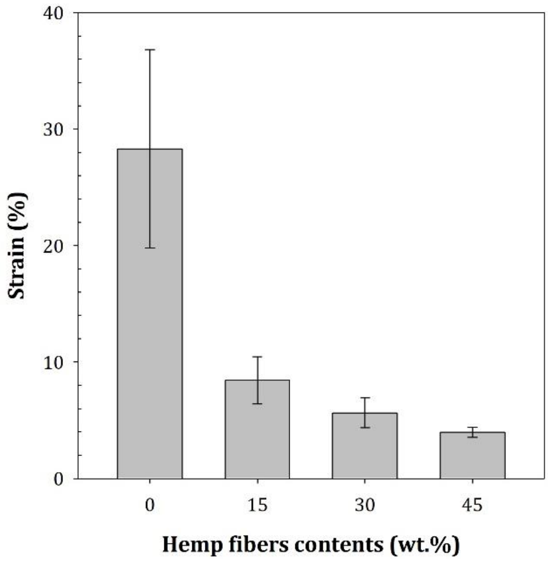


**Fig. 6.** Strains at break of polypropylene and their hemp fibers-reinforced composites with different fiber contents

Impact resistance is an important property of a drone propeller guard. The impact strength of the polypropylene and their hemp fibers-reinforced composites were calculated and shown in Fig. 7. The impact strength of polypropylene and their composites with 45 wt.% of hemp fibers was slightly close. The lower contents of hemp fibers in composites decreased their impact strength.

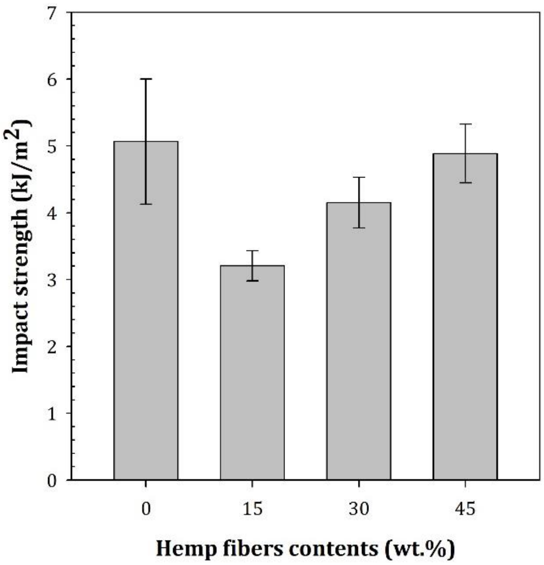


**Fig. 7.** Impact strength of polypropylene and their hemp fibers-reinforced composites with different fiber contents.

The feasibility study of applying the hemp fibers-reinforced polypropylene composites as the competitive material for drone propeller guards was determined via computer simulations. The stress distribution and its maximum stress would be obtained from SIMCENTER 3D simulation software. In this work, the drone propeller guard model for the DJI Tello drone camera was created by NX CAD software (SIEMENS) before simulation. The force of 0.64 N was determined to attack the model at the edge of the propeller guard. The results in Fig. 8 showed the stress distribution on the propeller guard model and indicated the maximum stress of 1.637 MPa. Compared to the tensile strengths of all samples in this work, it considers that polypropylene and its hemp fibers-reinforced composites can be the materials for this drone propeller guard. Costs and lifetime analysis of hemp fiber-reinforced polypropylene composites for drone propeller guards should be studied in the next opportunity.

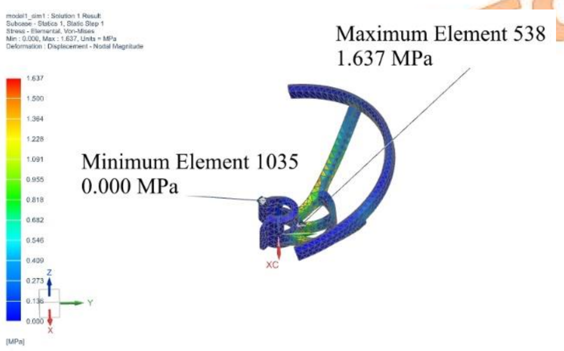


**Fig. 8.** Stress distribution of DJI Tello propeller guard derived from SIMCENTER 3D simulation

## 4. Conclusions

The polypropylene and their hemp fibers-reinforced composites were fabricated by thermal mixing and hot compression. The different contents of hemp fibers in the composites affected their mechanical properties. The moduli of these composites were increased with increasing hemp fiber contents. The highest modulus (1169.40 MPa) was obtained from the composite with 45 wt.% of hemp fibers. Unfortunately, the lack of interaction between fibers and matrix leads to a lower tensile strength and percentage of strain. Furthermore, the hemp fibers failed to improve the impact resistance of polypropylene. The morphological analysis by SEM technique confirmed their lack of interaction between hemp fibers and polypropylene matrix. The results showing maximum stress of 1.637 MPa for DJI Tello propeller guard and the stress distribution from model simulation indicated that polypropylene and their hemp fibers-reinforced composites are good candidates for drone propeller guard applications.

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## Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

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