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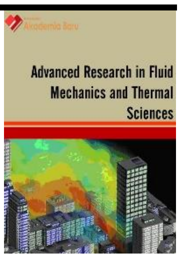

Water Transport and Physical Properties of Sugarcane Bagasse Fibre Reinforced Thermoplastic Potato Starch Biocomposite

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ABSTRACT

Nowadays, development of bio composites from renewable resources has become great interest as the alternative to replace petroleum-based polymer. Starch is one of the examples of bio polymer that are biodegradable. However, there is limitation on starch usage where starch based polymer has poor mechanical properties and high water sensitivity. Sugarcane waste produced from the extraction of sugarcane juice has potential application to be used as reinforcement material for producing bio-based composites. In this study, Thermoplastic Potato Starch reinforced Sugarcane Fibre (TPPS/SF) composites were developed by using dry mixing and hot press method at 145°C for 1 hour by maintaining the composition of starch and glycerol at ratio 80:20. The sugarcane fibres content ranged from 0 to 15wt.%. This paper presents the results of water transport and physical properties of TPPS/SF composites by using water absorption, thickness swelling, water solubility and moisture content tests. In terms of water transport, the composites show decrease in water absorption capacity of the composites following the addition of sugarcane fibre. Dimensional stability of the composites was increased indicated through the lower thickness swelling reading of the composites. In terms of physical properties, the water solubility of the composites was decreased which indicate improved resistance against water. The moisture content of the composites was decreased gradually following increasing amount of sugarcane fibre in TPSS matrix. Overall, this study shows that incorporation of sugarcane fibre into TPPS has improve the functional properties of this green material.

Keywords:
Thermoplastic starch; sugarcane fibre; natural fibre composite

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1. Introduction

In recent, plastic is widely used in industries of packaging, electric and electronic devices and automotive. However, plastic that comes from non-biodegradable material which produced from petroleum-based fuel gives critical issues on the environmental problems and human being [1-3]. Development of biodegradable products has been great progress based on agricultural materials [4]. Hence, to tackle the environmental and sustainable issues, this century has focused on greater achievement in green technology product in the field of materials through development of bio-composite. Starch has been one of the most promising bio-polymer among the biodegradable polymer due to their advantage of abundant resources, low cost, biodegradability and renewability [5]. Potato starch is among the most common starch found in the market, however, to the date, there are very few studies reported on utilizing potato starch for the development of thermoplastic starch.

Starch can be transformed into thermoplastic material by addition of plasticizer, heat, and shear. Plasticizer is one of the most significant element in modifying the properties of starch to increase its flexibility and process ability as a thermoplastic materials [3]. However, there is limitation on starch usage for commercial plastic production in industry where starch based plastic has poor mechanical properties and high water sensitivity [6]. Thus, starch need to be modified to overcome the drawback when making strong rigid composite. The uses of natural reinforcing fibres like flax, ramie and hemp into bio-polymer matrix derived from starch have been the new development of bio-composite. The composites derived from this biodegradable polymer matrix and fibre has promising potential to be used as packaging material due to the excellent biodegradability, non-toxic, and always renewable for future usage.

Sugarcane plant is a natural and renewable resources for production of sugar for human daily use [7]. However, large amount of bagasse was produced after the extraction of sugarcane juice. This bagasse has high potential as a reinforcement to enhance the properties of thermoplastic starch. Even though there are previous studies reported on utilizing sugarcane bagasse in composites, no study was reported on utilizing this agriculture waste as reinforcement for thermoplastic potato starch. Hence, the objective of this study is to investigate the effect of sugarcane bagasse on the water transport and physical properties of thermoplastic potato starch.

2. Materials and Methodology

2.1 Materials

Sugarcane waste was obtained from the extraction of sugarcane juice at the night market. In the preparation of Sugarcane Fibre (SF), the bagasse needs to be clean to remove the sediments. The cleaned bagasse was dried under the sun for 7 days until completely dry. SF was manually separated from the delicate centre part of sugarcane bagasse to get the fibre. Then the fibre was cut into small uniform strips of 5cm. Potato starch (powder) was purchase from Roquette. Glycerol was purchased from QReC Chemicals and used as plasticizer.

2.2 Fabrication of Thermoplastic Potato Starch

The fabrication of thermoplastic potato starch (TPPS) was conducted according to the modified method of the previous work [8]. The fabrication of TPPS was carried out by incorporating starch and glycerol at ratio 80:20 respectively. The mixture was mixed at 1200 rpm and mixing time was fixed at 6 min. The mixture was then poured and compact into a stainless steel mould with 3 mm thick plates and Myla Film 25 micron was placed between granulate and mould to facilitate removal of samples. Afterwards, the processed specimens were hot pressed at 145°C for 1 hour by using hydraulic moulding press machine (Go-Tech Testing Machine) under the load of 10 tonnes. After cooling process at 30°C for 15 min, the TPPS specimen was removed from the mould and the precautions were taken during removal in order to avoid fracture of specimens.

2.3 Fabrication of Composites

TPPS/SF composite was fabricated by using TPPS as the matrix. TPPS/SF composites was prepared based on the method in Section 2.1 by maintaining the composition of starch and glycerol at 80:20 respectively. The modification of TPPS was performed by incorporating it with a different amount of sugarcane fibre (1, 5, 10 and 15wt.%) into the polymer matrix as shown in Table 1. This followed by the mixing of sugarcane fibre with the mixture of starch and glycerol in dry mixer at 1200 rpm for 6 min. After the preliminary step, the resulting mixture was taken out from the mixer after the mixing cycle was stopped to avoid hardening of the material in the machine.

This mixture was transferred and compact into 3 mm mould thick plates and Myla Film 25 micron 400°C was placed between granulate and mould. Afterwards, the processed specimens were hot pressed at 145°C for 1 hour under the load of 10 tonnes. After cooling process at 30°C for 15 min, the composite specimen was removed from the mould and precautions were taken during removal in order to avoid fracture of specimens.

Table 1
Composition of Composites

Composite	Glycerol & Potato Starch (wt.%)	Sugarcane Fibre (wt.%)
TPPS/SF 1	99	1
TPPS/SF 5	95	5
TPPS/SF 10	90	10
TPPS/SF 15	85	15

2.4 Determination of Moisture Content

Five specimens (10 ×10 × 3mm) were prepared for each composition in order to determine the moisture content. The samples were heated in air circulating oven for 24 hours at 105°C±2. The weight of the specimens before (Mi) and after (Mf) heating was measured in order to calculate the amount of moisture content. The moisture content of sugarcane waste was calculated by following the Eq. (1).

$$\text{Moisture content (\%)} = \frac{M_i - M_f}{M_i} \times 100 \qquad (1)$$

2.5 Water Absorption

The samples (10 × 10 × 3mm) were conditioned for 24 h at 105°C and cooled in a desiccator. Then, the samples were immediately weighed to the nearest 0.001g, Wi (ASTM D570-98). The sample is then soaked in distilled water at room temperature for 0.5h. After that, all surface water were softly remove with a dry cloth, and then the samples were weighed again to the nearest 0.001g, Wf. The differences between the initial weight, Wi and after immersion, Wf of final weights of the samples are calculated by using the equation.

$$\text{Water absorption (\%)} = \frac{Wi-Wf}{Wi} \text{ x } 100 \quad (2)$$

2.6 Thickness Swelling

For thickness swelling investigation, the existing moisture in samples were removed by drying the samples (10mm×10mm×3 mm) in an air circulating oven at 105°C±2 for 24 hours. The initial thickness of the samples, Ti were measured prior to immersion in water. Then, the samples were immersed in distilled water for 0.5h before taken out and immediately measured for the final thickness, Tf. The thickness of the samples were measured by using digital caliper (Model: Mitutoyo) having an accuracy 0.01cm [9]. The thickness swelling ratio of the samples were computed by using the following equation:

$$\text{Thickness swelling (\%)} = \frac{T_i - T_f}{T_i} \times 100 \quad (3)$$

2.7 Water Solubility

A section of the specimen was cut (10mm×10mm×3mm) and dried at 105°C±2 for 24 hours. Before the specimens were immersed in distilled water (30ml), the initial weight (Wo) of the specimen was measured. Then, the specimens were gently stirred in the distilled water for 24 hours. After 24 hours, the remaining specimens were taken from the container and the remaining water was removed. The final weight (Wf) was determined by drying the specimens again at 105°C±2 for 24 hours. The water solubility of the specimen was calculated as follows:

$$\text{Water solubility (\%)} = \frac{W_o - W_f}{W_o} \times 100 \quad (4)$$

3. Results and discussion

3.1 Moisture Content

Moisture content was carried out to measure the equilibrium moisture content of thermoplastic potato starch and sugarcane fibre. Moisture content of material is the amount of water contained in a material that has significant effect on water absorption and thickness swelling behaviour [10]. This test can evaluate the performance of the material during service.

The moisture content of the matrix and composite is shown in Figure 1. In general, incorporation of sugarcane fibre from 0 to 15 wt.% into TPPS matrix shows a decrease in moisture content from 9.96% to 6.44% respectively. Moisture content of biocomposite decreased with the addition of fibres which contributed to better interfacial bonding between matrix and fibres as the resistance to absorb moisture [11]. The moisture sensitivity of starch matrix can be reduced by the cellulosic fibres due to their acting as hydrophobic agent [12]. Adding fibre into starch matrix will cause increase in crystalline phase of semi-crystalline of starch material which was highly contributed to the decrease of moisture content. Therefore, the decrease in moisture content can be related to the increase in crystalline fraction with the addition of fibres into composite structure which resulted on different water absorption compare to starch-matrix.

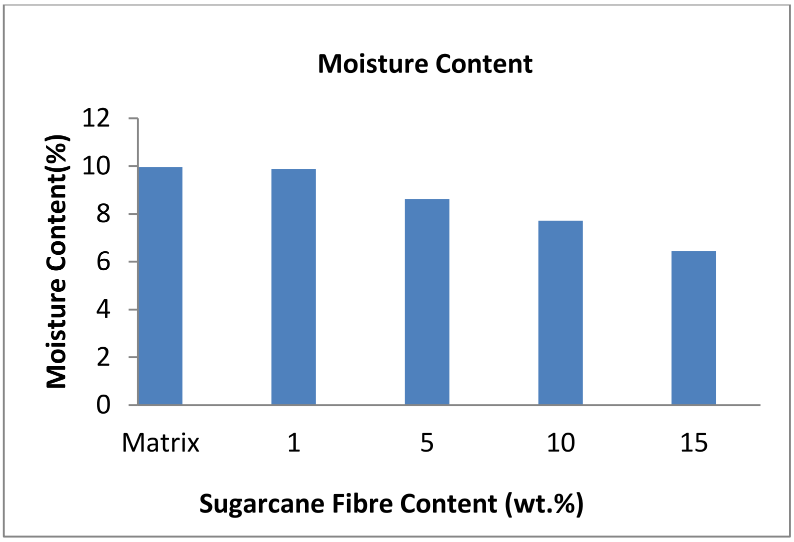

Fig. 1. Moisture content for TPPS/sugarcane bagasse composites

3.2 Water Absorption

Water absorption of the thermoplastic starch-based composite is another important characterization in humidity environment because these properties can determine their performance [13]. Since one of the problems of the thermoplastic starch is its sensitive to water and the bio-composite are hydrophilic in nature, water absorption was evaluated [9].

Figure 2 shows the water absorption capacity of the TPPS matrix and its composite after immersion for 0.5 hour. It can be seen that the addition of different amount of sugarcane fibre into starch matrix decrease the water uptake of the material. The most significant effects were evident after 0.5 hour where it is obvious that the TPPS matrix showed 20.30% of higher water absorption while the composite of TPPS with 15wt.% of sugarcane fibre showed only 9.12%. This finding revealed that the composite has better water resistance than TPPS matrix.

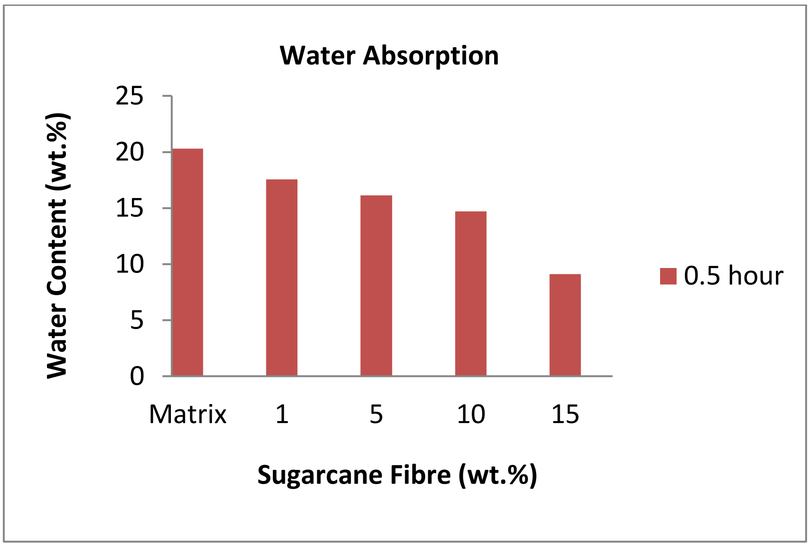

Fig. 2. Water Absorption of TPPS/sugarcane composites

According to Ramirez *et al.*, [9], decreasing in water uptake of composite can be influenced by the good interfacial bonding between fibre and matrix, higher affinity of the matrix for water compared to fibres induces and the linkage formed by the higher fibre content which restrain the absorption of water through the starch-matrix. This positive finding on percentage of water absorption of the TPPS/sugarcane fibre composite also might be due to the chemical composition of lignin and wax in fibre surface which hindrance the absorption of water. Matrix have poor resistance to water because starch is a multi-hydroxyl polymer that consist three hydroxyl groups per monomer and more hydrophobic behaviour [14]. As a whole, at high humidity, the water absorption of TPPS matrix can restrain effectively due to the fibre element and indirectly reduced the water sensitivity of TPS matrix [15].

3.3 Thickness Swelling

Dimensional stability of composite is a vital characteristic that may affect the final performance of the product. It can became a serious disadvantage when the size of the material changes due to moisture absorption from the surrounding [9]. Thus, swelling characteristic of TPPS/SF composite were analysed using the swelling ratio in order to investigate the effect of sugarcane fibre on the dimensional stability of the TPPS matrix. Figure 3 shows the swelling percentage of pure TPPS matrix and its composite with different amount of fibres. It is obvious that the thickness of matrix and the composites was affected by increasing of fibre content. The matrix shows the highest swelling and began to decrease with increasing amount of sugarcane fibre in the composites. The slight decrement in swelling percentage can be seen after 0.5 hour immersion, where the swelling reduced from 17.19% to 8.26% for the 0% SF and 15%SF composites respectively. The TPS/SF composite with 15wt.% fibre has the lowest swelling than the TPS matrix due to lower water uptake during test. This might be due to the hygroscopic nature of starch matrix which tends to absorb more water than the fibre [16]. This finding indicates that the TPPS/SF composite has improved dimensional stability than the TPS matrix.

In addition, the decrease in swelling might be associated with the cellulosic fibres characteristic which is less hydrophilic than the TPS matrix [17]. It is reported that hemicellulose is more compatible with the starch amylose and tend to form closed branch that cause lower water uptake [18]. Ramírez *et al.*, [9] also reported that increasing amount of coir fibres resulted in decrease of swelling ratio of TPS/coir fibre composite.

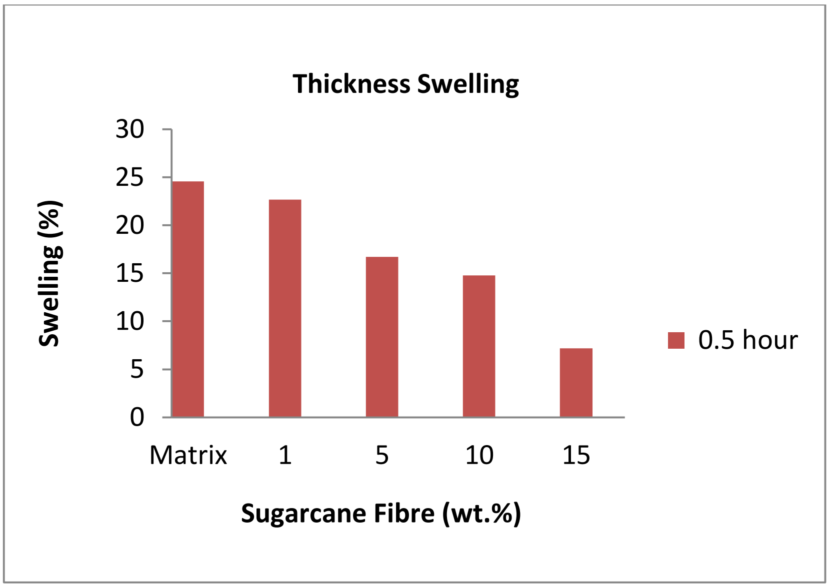

Fig. 3. Thickness Swelling for TPPS/sugarcane fibre composites

3.4 Water Solubility

In the development of biodegradable materials, starch is one of the promising materials due to its advantages as thermoplastic material. However, thermoplastic starch have some limitation such as higher water solubility [11]. Thus, water solubility test for matrix and composite should be investigated and evaluated by measuring the weight loss of material when subjected to continuous stirring for a specific time. Apart from that, this test also presents the degradation behaviour of material when disposed in water [19].

Figure 4 shows the solubility result of TPPS/SF composites with different amount of sugarcane fibre. It can be seen that incorporation of sugarcane fibre into TPPS matrix has decrease the solubility of composite. After 24 hours immersion, TPPS/SF composite with 15wt.% sugarcane fibre shows only 24.41% solubility whereas TPPS matrix shows higher percentage of solubility with 61.12%. This can be attributed to less hydrophilic of fibre that tends to absorb less water than TPS matrix [20]. TPPS matrix absorbs more water due to their abundant free hydroxyl groups on their repeating unit of starch molecules and thus resulting in its hygroscopic nature [16]. This finding also shows that TPPS/SF composite has slightly better water resistance as compared to TPPS matrix. This might be associated with less hygroscopic and higher crystalline of fibre than starch. This finding is in agreement with Gaspar *et al.*, [18] which reported that incorporation of natural fibre might reduce the hygroscopic behaviour of thermoplastic starch matrix. However, this assumption depends on the type of natural fibre used for the composites. For example, previous study reported increase in the hygroscopic behaviour of thermoplastic starch composites following the incorporation of seaweed [21] which was attributed to higher hydrophilicity of the seaweed filler than the TPS matrix.

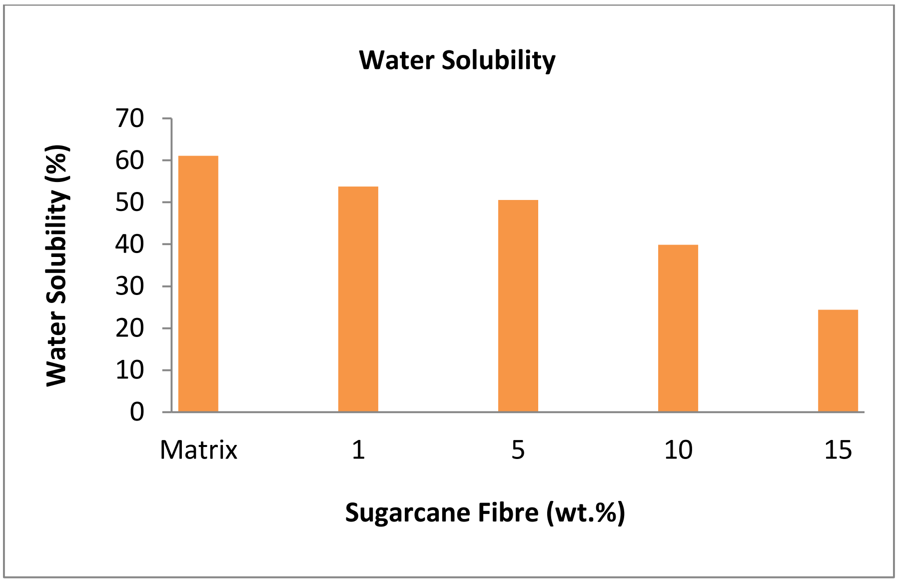

Fig. 4. Water Solubility for TPPS/sugarcane fibre composites

4. Conclusions

Biobased composites derived from sugarcane bagasse and thermoplastic potato starch have been developed in this study. The combination of these materials has led to variations in their physical properties. Moisture content of TPPS matrix and its composite decrease with increasing of sugarcane fibre content. This was accompanied with reduce water uptake and thickness swelling upon immersion. The water solubility of the composite has reduced with incorporation of sugarcane fibre.

Overall, these findings show that incorporation of sugarcane bagasse fibre into TPPS matrix has reduce the hydrophilicity and improves the dimensional stability of the material. This modification has improved the properties of this material to serve as a green packaging material.

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