Kenaf/polypropylene key chain product fabricated by injection moulding

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Abstract. The natural fiber composites product becomes popular among the world to promote sustainable development. Unlike the synthetic fibers, natural fibers can absorb as much as the carbon dioxide to prevent the global warming happened. Natural fiber composites such as kenaf mixed with polypropylene, have been commercialized in automotive parts due to its lightweight ability which can improve the fuel efficiency. The main objective of this study is to investigate the effect of injection moulding temperature to the shrinkage and tensile properties of kenaf/polypropylene key chain product. The optimum weight fraction of 30 wt% kenaf and 70 wt% polypropylene was fabricated using different temperatures of the injection moulding process. The best physical appearance of the key chain was prepared at 180°C. The sample that was fabricated at 210°C has higher tensile stress and tensile modulus which are 12.48 MPa and 1.03 GPa, respectively. As a conclusion, the kenaf/polypropylene specimen prepared at 210 °C has better tensile strength and less shrinkage if compared to others. Brittleness due to voids formation was evident in the SEM image of the kenaf/polypropylene. By using the injection moulding process, a high volume of products could be produced in a very short time.

1. Introduction
Nowadays, the reinforcement of the natural fiber composites product becomes popular among the education sector and the industry. Natural fibers resources are renewable and less chemical reaction, which will produce a biodegradable compound during the production process. The advantages of natural fiber over synthetic fiber include lower cost, wide availability, light weight, low-energy production as well as biodegradability. Kenaf fiber is an extremely environmental friendly due to its high absorption rate of carbon dioxide as well as absorbing the nitrogen and phosphorous from the soil [1]. This is the reason that natural fiber with thermoplastic material was used in this study.

Kenaf natural fibers were used as the reinforcement in this study as the fiber is easily obtained in Malaysia. The optimum weight fraction of kenaf/polypropylene composites has been determined by several previous studies. Kamardin et al. [2] concluded that kenaf/polypropylene composite with 30 % weight fraction (wt%) fiber exhibits the highest tensile strength and impact toughness than the 20 wt% and 40 wt% kenaf/polypropylene composite that fabricated using hot press method. Loh et al. [3] also obtained the best sample by using design of experiment, which the 30 wt% of kenaf fiber that reinforced with polypropylene has the highest impact strength. Hence, the optimum weight fraction of 30% wt kenaf and 70% wt polypropylene was used in this study.
The injection moulding machine consists of high pressure injection of the material which can produce a complex and intricate geometries of plastic parts at low cost [4]. This will improve the productivity as the injection moulding is an automated process where it could help to reduce the manufacturing cost and labor cost. Moreover, the injection moulding is a short time process to fabricate a high volume of the product. The product can be produced within few minutes. The waste produced from the injection moulding machine can be recycled or reused but only for thermoplastic polymer material. However, the injection parameters may influence the performance of final part. Marom [5] investigated the effect of temperature on the fracture properties of the composites. The study showed that the fracture energy was decreased by increasing the temperatures. Various research reports [6-8] also evident the temperature is the most significant parameter in many composite processing such as injection moulding, compression moulding and hot press forming.

Hence, different injection moulding temperatures of kenaf/polypropylene product was investigated in this study as temperature is the main factor contributing to defect and strength of the final product. The effect of injection moulding temperature on shrinkage, appearance, tensile and hardness properties of the kenaf-polypropylene composite was focused in this work.

2. Experimental work

2.1. Sample preparation

The materials used in this study were kenaf powders and polypropylene (PP). The 30% weight fraction of kenaf powder and 70% weight fraction polypropylene was chosen as the composition to be studied based on previous finding [3]. The kenaf powders and polypropylene resins were mixed by using a thermal mixer at 180°C, 20 minutes and 30 rpm. The mixing temperature should be higher than the melting point of the polymer matrix to ensure that the polymer was homogenously mixed with the fiber particles. After the mixing process, the materials were crushed into pellets using a crusher machine. The kenaf/polypropylene products were then fabricated using MA-23 injection moulding machine. The melting temperature was set from 170°C to 190°C to produce the key chain product. As for the tensile testing specimen, the melting temperature was varied from 180°C to 230°C according to ASTM D 638.

2.2. Mechanical testing and fracture surface analysis

Physical observation of the kenaf/polypropylene specimen was carried out to know which specimen has the best appearance by using the naked eyes. Shrinkage measurement was carried out in order to determine whether the specimen has shrinkage problem or swelling for the specimen fabricated at different injection temperatures. The fracture surface of the tensile specimen was examined using Hitachi TM3030PLUS scanning electron microscope (SEM).

Tensile test was conducted according to the ASTM D638 using the SHIMADZU AG-IS Universal Testing Machine in order to investigate the tensile strength and tensile modulus for the kenaf/polypropylene specimen. The test was done at the crosshead speed of 5mm/min with load of 10kN.

The hardness test was conducted using micro Vickers hardness machine. The indenter was in diamond shape and the test was done using two different loads which were 0.031kg and 0.1kg.

3. Results and discussion

3.1. Physical appearance of products

The best physical appearance of the key chain product was prepared at temperature of 180°C. It is clearly seen in the Figure 1(a) that the specimen has a smooth and clear figure on the surface. At 170°C, the kenaf/PP materials were not completely melted that formed a blemished surface. However, the tensile specimen was only successfully produced at 210°C and above as seen in Figure 1(b). All samples experienced swelling in thickness due to kenaf powders were un-treated. It is known that kenaf has lignocellulose which will absorb water [9]. Thickness swelling of the product occurs when the cell wall
is bulked by the water at the cell wall regions. The thickness of the tensile specimen at 230°C was swelling the most which might be due to the prolonged exposure at the elevated temperature and caused the fiber degradation occurred [10]. The brittleness of the kenaf/PP specimen was clearly seen in Figure 2 where there was a relatively flat surface at break due to a very little plastic deformation has occurred. This phenomenon was observed in both tensile samples produced at 210°C and 230°C which showed that kenaf/PP is a brittle material.

![Figure 1. (a) Key chain product (b) Tensile specimens.](image)

3.2. Shrinkage
The Shrinkage measurement was conducted using equation stated in reference [11]. The shrinkage found in the kenaf/polypropylene key chain is low (less than 2%). The tensile specimen that produced at 210°C has less volumetric shrinkage than the tensile specimen at 230°C as shown in table 1. This might be due to the specimens that had been heated in the barrel for longer time than usual which caused the specimen to swell and increasing in width and thickness of the specimen. Hence, the thickness swelling in the specimens was larger when the moulding temperature was increased.

![Figure 2. Flat surface failure of tensile specimen.](image)
In general, kenaf fiber is hydrophilic in nature where it has a poor resistance towards moisture which has high water absorption. Moisture that absorbed by this fiber will influence the dimensional stability and durability [12]. Gamstedt [13] stated that the water molecules from the environment were diffused into the material and break the hydrogen bonds which caused the voids between the molecular chains of the lignocellulosic fibers. During the heating process, the steam was formed due to the moisture content of the fibers and produced the voids. Entrapped air would flow into the injection mold which caused it to form voids inside the specimen. On the other hand, Joffre et al. [14] found that the thickness swelling is larger than the in-plane swelling of the composites, which is similar with the present result that the larger thickness swelling at the kenaf/polypropylene specimen that produced at 230°C.

### 3.3. Tensile performance

The sample that was fabricated at 210°C has higher tensile stress and tensile modulus which were 12.48MPa and 1.03GPa, as shown in Figure 3 and Figure 4, respectively. The tensile strength was decreased at the temperature of 230°C which is about 25% less (9.36MPa) than the tensile strength of specimen at 210°C. It is stated by the previous researchers that the strength of the composites was influenced by the factors such as fiber content, interfacial bonding of the fiber and matrix as well as the fiber or matrix strength [15]. Previous studies have stated that the higher temperature could cause the degradation of the fiber in the molten matrix which it could lead to decreasing in tensile properties [10]. Besides, the thickness swelling of the specimen produced at 230°C could also reduce the mechanical properties of the composites [12]. This is because swelling could lead to some micro-cracks and debonding occurred between the matrix and fiber [16].

#### Table 1. Shrinkage and thickness swelling of kenaf/polypropylene product.

| Temperature (°C) | Volumetric shrinkage (%) | Thickness swelling (%) |
|------------------|--------------------------|------------------------|
| 170 (key chain)  | 1.21                     | 0.59                   |
| 180 (key chain)  | 2.07                     | 1.06                   |
| 190 (key chain)  | 1.21                     | 1.53                   |
| 210 (tensile specimen) | 16.19             | 18.33                  |
| 230 (tensile specimen) | 33.48             | 30.50                  |

![Figure 3. Tensile stress of the kenaf/polypropylene specimen](image)
The porosity and density of the composites was also crucial in increasing the tensile strength or tensile modulus where the previous studies reported that less porosity of the composites revealed better mechanical properties [17]. Fiber orientation was also crucial in determining the performance for the kenaf/PP composites. The fibers powders compared to the long and short fibers exhibit the lowest reinforcement efficiency for the composites material [18]. In general, the voids occurred during the injection moulding process would influence the mechanical properties of the kenaf/PP composites. When compared with the previous studies, Akhtar et al. [19] fabricated the kenaf/PP specimen using the injection moulding produced a higher tensile strength and tensile modulus than the present results. This might be due to the fiber orientation that used by the authors was short fibers. The reinforcement efficiency for short fibers are higher than the fibers in powder form [18].

Kamardin et al. [2] have carried out the impact and tensile properties for kenaf/PP composite that fabricated using hot press machine. It was found that the tensile strength for the 30wt% kenaf/PP specimen was slightly higher at about 8.17% (13.50MPa) than the present result. There was not so much difference in using the same fiber orientation which is in powder form but the present result was lower might due to the specimen that fabricated had voids.

3.4. Hardness
High value of hardness can withstand the greater load when applied to an application. Since kenaf/PP composite has been widely used in the automotive industry, the composites need to possess a high hardness. The kenaf/PP sample at temperature of 210°C has higher hardness value in both loads when compared to the sample at temperature of 230°C, as clearly shown in Figure 5. Low hardness was occurred due to the porosity or voids that presence within the specimen as mentioned by previous researchers [20].

![Figure 4. Tensile modulus of the kenaf/polypropylene specimen](image-url)
3.5. Scanning electron images
The UiTM key chain that fabricated by using the MA-23 injection moulding machine at 180°C was chosen to carry out the SEM due to its physical appearance was better than the other two specimens that fabricated at temperature of 170°C and 190°C. Figure 6 illustrates the micrograph for UiTM key chain at temperature of 180°C. There is a good interfacial adhesion between the kenaf and PP that can be seen clearly in the Figure 6. The composites seem to be bonded well with each other. The tensile specimen that at temperature of 210°C was used to observe the SEM morphology due to its low volumetric shrinkage measurement, high tensile strength, high tensile modulus and high hardness value. The fracture surface of the tensile specimen after conducted the tensile test was clearly seen in Figure 7. It can be assumed that the specimen experienced a brittle failure where the failure was mainly due to fiber fracture. Besides, the tensile specimen that fabricated at temperature of 210°C shows some voids as seen in Figure 7(a) in the microstructure after conducted the tensile test. The specimen has a poor adhesion between the fiber and matrix due to the fiber degradation that caused by excessive heat.

Figure 5. Vickers hardness of the kenaf/polypropylene specimen

Figure 6. SEM image on the surface of key chain produced at 180°C
Figure 7. SEM images on the fracture surface of tensile specimen at 210°C (a) voids (b) fiber fracture

4. Conclusion
From the physical observation, the temperature of 180°C was able to fabricate better appearance of the UiTM key chain. The kenaf/PP tensile specimens were able to be fabricated at 210°C and 230°C. The tensile specimen prepared at 210°C performed better due to its higher mechanical properties of tensile strength, tensile modulus and hardness. SEM image showed the voids were found in the kenaf/PP tensile specimen. Kenaf/PP product was brittle as the fracture surface was flat and the failure is mainly contributed from fiber fracture. In future study, it is recommended that the effect of kenaf fibers mixed with recycled PP can be further investigated in order to compare the performance of the kenaf/virgin PP with kenaf/recycled PP. Thus, the cost of production for the composites can be reduced by using the recycled polypropylene materials.

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