Influence of processing methods on flexural strength in interwoven hemp/ PET reinforced POM hybrid composite.

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Abstract. One of the challenges of utilizing natural fibre as reinforcement in polymer composite is poor interfacial bonding with thermoplastic matrix. In this study, hemp and polyethylene terephthalate (PET) fibre were selected to develop the interwoven fabric as reinforcement and polyoxymethylene (POM) was chosen as the matrix. The interwoven Hemp/PET fabric was used to produce hybrid composite using hot-press moulding technique. Different production methods of using POM layers and POM pellets were investigated. Three point bending test was used to determine the flexural modulus and compared. The results show that the different process in producing Hemp/PET/POM hybrid composite did not give significant effect towards the flexural property of composite. The modulus of elasticity for both specimens produced with POM layers and POM pellets is 2.24 GPa and 2.15 GPa, respectively. Modulus of elasticity of composite with POM layers is higher than POM pellets by 4%. This may due to POM thermoplastic characteristic which can be reversibly melted and re-solidified without significant changes to the mechanical properties.

1. Introduction
Composite industries have been trying to minimize the used of petroleum-based reinforcement in composites due to environmental issues. Substitution of petroleum-based or synthetic reinforcement needs to be made with the increment of high performance engineering products. In this research, interwoven hemp/polyethylene terephthalate (PET) fibre reinforced polyoxymethylene (POM) hybrid composite’s flexural properties are studied as there is lacking information regarding the mechanical properties of such composite. Natural fibre has many appealing properties such as high strength to weight ratio, light weight, corrosion resistance, non-irritating, low energy consumption during production, carbon dioxide free of emission when burned, and biodegradable [1,2]. Hemp fibre is used in this research because it is a fast grown plant [3] with extremely strong and durable characteristics. However, natural fibre becomes less attractive compared to synthetic fibre due to low resistant to moisture absorption, low degradation temperature and insufficient of good interfacial bonding with hydrophobic matrix. PET is used as interweave reinforcement because it is light weighted and it makes a good barrier for gas, moisture, and alcohol. In addition, PET is strong and impact-resistant. Interwoven of hemp and PET significantly changes to become stronger and more durable. Furthermore, POM is used as matrix because it has advantages such as low friction coefficient, high abrasion resistance, good electrical and dielectric properties, high heat resistance, and low water absorption.
2. Methodology

2.1. Materials
Hemp and PET fibres used in this research were form into twisted yarn as its enhanced the composite’s mechanical properties [4]. Hemp and PET yarns were used to produce interwoven fabric. In this research POM, hemp and PET fiber were supplied by Innovative Pultrusion Sdn. Bhd.

2.2. Equipment
A hot-press machine and a rectangular mild steel mould were used to produce hybrid composites. A universal material testing machine of model Shimadzu AG-IS Ms 250kN was used to conduct flexural tests on the specimens from the composite. Besides that, a wooden frame was used for weaving of hemp/ PET fabric. In addition, a rope making equipment was used to twist PET fibre into yarn.

2.3. Production of yarn and Interwoven Hemp/ PET Fabric
Twisted yarn of PET fibre was produced using the same method as in rope making. The PET yarn was made by twisting 3 strings that consist of 10 filaments. The yarns were used in producing interwoven hemp/ PET fabric where hemp was used as warp yarn and PET as weft yarn. The diameter for both PET and Hemp yarn is 2mm. Hemp yarn was tied on the nails of wooden frame before PET yarn was woven over and under across the hemp yarn as shown in Figure 1.

2.4. Production of POM layers
Mould release agent was sprayed onto the mould to ease removal of POM layers. The mould was preheated for 20 minutes at 180°C as shown in Figure 2. POM in pellets form was weighted and placed into the heated mould. Two layers of POM were produced simultaneously by using a metal sheet as separator. It was then put into the hot-press machine and hot-press for 20 minutes at 180°C with 5000psi pressure. After 20 minutes, the mould was naturally cooled to room temperature before the POM layers were removed. Figure 3 shows a sample of POM layer.
2.5. Production of Interwoven Hemp/ PET Fibre Reinforced POM Hybrid Composite using different methods.

The mould was preheated for 20 minutes at 180°C in the hot-press before 2 POM layers were placed into the mould with interwoven hemp/ PET fabric put in between the POM layers. The entire assembly was the placed into the hot-press for 20 minutes at 180°C with 5000psi pressure. The mould was then let to cool naturally to room temperature before removing the hybrid composite. In the second method POM pellets of equal amount as used to produce the POM layer were used directly by placing the pellets into the bottom of the mould cavity before placing the hemp/PET fabric. Then another equal amount of POM pellets were placed on top of the hemp/PET fabric. Thus producing sandwiched layers of pellets/fabric/pellets. The entire assembly moulding was hot-pressed for 20 minutes at 180°C with 5000psi pressure. The composite was removed after cooling naturally to room temperature. **Figure 4** shows a sample of interwoven hemp/ PET fibre reinforced POM hybrid composite.

![Figure 4](image)

Figure 4 (a) Top side Hybrid composite (b) Bottom side

2.6. Specimen Cutting

According to ASTM D790, 90mm length with 40mm overhand length at supports, 13mm width and 5mm thick were used as the dimension of specimen in this research. X-axis of the specimen was hemp fiber and y axis was PET fiber as shown in **Figure 5**. **Figure 6** shows samples of specimens.

![Figure 5](image)

Figure 5 Specimens dimension as drawn on composite.  
Figure 6 Specimens cut to ASTM D790.

2.7. Flexural Test

Flexural test was conduct to evaluate the force needed to bend a beam under three point loading conditions by using a universal testing machine (UTM) according to the ASTM D790 standard as shown in **Figure 7**[5]. A speed rate of 1mm/ min and a load cell of 100kN were used. When the
specimen breaks, the test was stopped. In order to obtain a satisfactory result, five specimens from each composite were tested.

2.8. Experimental flowchart.
The experimental flowchart is given in Figure 8. The experiment is started with the preparation of interwoven fabrics and production of POM layers. Then the production of Hemp/PET/POM hybrid composite is performed. Finally three point bending test in accordance to ASTM D790 is carried out.

![Figure 7 Experimental setup of flexural test.](image1)

![Figure 8 Flow chart of complete experiment](image2)

3. Results and Discussion
The statistical analysis of 5 specimens each for the two different production methods is as shown in Table 1. The result in the three point bending test from Table 1 indicates that using POM layer in the production of hybrid composite gave higher values. Figure 9 and Table 2 show that composite produced by using POM layers has higher flexural strength compared to POM pellets which is 37.38±4.24MPa and 34.79±4.05MPa; respectively. The difference between the two types is 6.4%. Similarly in Table 2, the flexural strain for composite using POM layers and POM pellets was determined to be 0.016±0.005mm/mm and 0.013±0.004mm/mm respectively. The difference between the two types was 17.6%. This higher values could have been contribute from the fact that the composite produced using POM pellets have higher void as shown in Figure 11.
Table 1 T-test results of flexural test on composite using POM Layer and POM Pellets.

|                     | POM Layer |                   | POM Layer |                   | POM Pellets |                   | POM Pellets |                   |
|---------------------|-----------|-------------------|-----------|-------------------|-------------|-------------------|-------------|-------------------|
|                     | Max. Force| Max. Displacement| Max. Stress| Max. Displacement| Max. Force| Max. Displacement| Max. Stress| Max. Displacement|
|                     | N         | mm                | MPa       | mm                | mm          | mm                | MPa         | mm                |
| n =5                |           |                   |           |                   |            |                   |            |                   |
| Average             | 90.00     | 4.436             | 37.38     | 0.016             | 83.75       | 3.587             | 34.79       | 0.013             |
| Standard Deviation  | 10.22     | 1.442             | 4.24      | 0.005             | 9.74        | 1.189             | 4.05        | 0.004             |
| Standard Error of the Mean | 4.57 | 0.645 | 1.90 | 0.002 | 4.35 | 0.532 | 1.81 | 0.002 |
| 95% Confidence Level| 9         | 1.3               | 3.7       | 0.004             | 8.5         | 1                 | 3.5         | 0.004             |

As shown in Figure 10 and Figure 11, both composites contained bubbles/air gaps which were caused by trap air bubbles or insufficient of amount POM. The production method of using POM pellets gave a more severe defect. This high porosity in the composite produced contributed to lower flexural strength.

Figure 9 (a) Maximum Stress and (b) maximum strain with error bar.

Figure 10 Defects in composite produced with POM layers.

Figure 11 Defects in composite produced with POM pellets.
Furthermore, both composites show similar trend of stress-strain graph as shown in Figure 12. Modulus of elasticity for composite using POM layers was obtained at 2.24GPa and the specimen produced with POM pellets was 2.15GPa. A difference of 4.2% between these results was considered relatively small and insignificant. Hence heating of POM pellets to create POM layers and later reheating the POM layers in the production of composite in this study does not alter the Modulus of elasticity of POM as most commercially available POM has a modulus of elasticity of 2.58GPa-2.85GPa [6-8]. As POM is thermoplastic, it can be reversibly melted by heating and re-solidified without significant changing in mechanical and chemical properties [9, 10]. Thus, the production methods by using POM layers or POM pellets have insignificant effect to the production of hybrid composite using POM as matrix as POM can be reheated and re-solidified with minimal changes to the Modulus of Elasticity.

| Method of Production | Maximum Stress (MPa) | Maximum Strain (mm/mm) | Modulus of Elasticity (GPa) |
|----------------------|----------------------|------------------------|----------------------------|
| POM Layers           | 37.38±4.24           | 0.016±0.005            | 2.24                       |
| POM Pellets          | 34.79±4.05           | 0.013±0.004            | 2.15                       |

Figure 12 Stress-Strain Curve of Hybrid Composite from different production method.

4. Conclusion
From this study, the production methods of using pre-made POM layers and using POM pellets directly shows that the thermoplastic characteristics of POM is able to give similar result without significant differences. Therefore, by using POM pellets directly can decrease the time and energy consumed during the hybrid composite production.

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