Tensile properties of interwoven hemp/PET (Polyethylene Terephthalate) epoxy hybrid composites

M A A Ahmad, M S A Majid, M J M Ridzuan, A Z A Firdaus and N A M Amin
School of Mechatronic Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600, Arau, Perlis, Malaysia.

shukry@unimap.edu.my

Abstract. This paper describes the experimental investigation of the tensile properties of interwoven Hemp/PET hybrid composites. The effect of hybridization of hemp (warp) with PET fibres (weft) on tensile properties was of interest. Hemp and PET fibres were selected as the reinforcing material while epoxy resin was chosen as the matrix. The interwoven Hemp/PET fabric was used to produce hybrid composite using a vacuum infusion process. The tensile test was conducted using Universal Testing Machine in accordance to the ASTM D638. The tensile properties of the interwoven Hemp/PET hybrid composite were then compared with the neat woven hemp/epoxy composite. The results show that the strength of hemp/PET with the warp direction was increased by 8% compared to the neat woven hemp composite. This enhancement of tensile strength was due to the improved interlocking structure of interwoven Hemp/PET hybrid fabric.

1. Introduction
The increasing environmental issues due to the used of petroleum based product and fuels lead to the development of natural fibre composite. Fibre reinforced composite are low cost, easier to handle and have good mechanical properties. Fibre can be easily obtained from the natural environment or readily available such as hemp, wood, carbon fibre, and fibre glass[1]. Iqbal et. al provides an explanation on how to utilise textile materials and fabrics manufacturing methods such as weaving, knitting and braiding[2]. The mechanical properties of the fibre reinforced composite depend on the fibre geometry, hybridization, and weaving architecture. These parameters will increase their performance of high strength application. Besides, a knitted or woven fibre provides equally distributed strength through the transverse direction and longitudinal direction [3].

Woven are made by interlacing fibre bundles (yarn) to form a fabric layer [4]. It gives high packing density and excellent dimensional stability. Further studied have been done to improve more on the strength of composite by producing woven and hybrid composite. Hybrid composite refers to more than one reinforcing material used in a polymer matrix, develop to achieve properties that cannot be made by a single fibre[3]. The hybrid will make each fibre improve the weakness of their properties, thus strengthen the structure of composite. Review by Swollfs shows that hybridization is a method to increase the toughness of fibre reinforced composite and three leading hybrid
configurations to combine the fibres are interlayer or layer-by-layer configuration, intralayer or yarn-by-yarn and intra-yarn or fibre-by-fibre [5].

An experimental study involving interwoven of kenaf/PET reinforced POM by Dan-Mallam showed that the high resistance to water uptake due to the interlacing of the hydrophobic PET fibre in the interwoven increased the composite strength [3]. Venkateshwaran et. al [6] indicates that the addition of sisal fibre to banana/epoxy composite will bring the hybrid effect that eventually improves the mechanical properties of the composite. Other than that, the similar result is shown by Yahaya et. al [7] in his investigation of tensile, flexural, and impact properties of woven kenaf/Kevlar reinforced epoxy composite. The primary objective of this paper is to investigate the effect of hybridization of interwoven Hemp/PET hybrid composite on their tensile properties.

2. Experimental Methods

2.1 Woven Fabric
Hemp and PET yarn were used as reinforcement material that supplied by Innovative Pultrusion Sdn. Bhd. The fabric was weaved using a locally constructed wooden frame with a size of 400×400 mm. It consists of sets of warp yarn guider at the both sides of the wood. The weaving process starts with the arranging warp yarn along the nail. Then the weft yarn was arranged passing over and underneath the warp yarn until the fabric was produced [8]. Figure 1 shows the weaving process and fabric.

![Weaving process and fabric](image)

Figure 1. (a) weaving process, (b) fabric.

2.2 Composite Fabrication
The composite was produced by the vacuum infusion process as shown in Figure 2. The vacuum infusion machine consists of the vacuum pump, pressure gauge, suction hose, and container for residual resin collection. Firstly, the fabric was placed on top of the transparent glass table. Peel ply was used to cover on top of it for the removal after curing. Netting was used to disperse the resin thoroughly on the fabrics during the suction process. Then vacuum bagging was used on the top of the sample. The resin flows through the hose by evacuating the mould of fabric into the residual resin container[9].

EpoxeAmite was mixed with a slow hardener in a weight ratio of 100g epoxy: 28.4g hardener according to the manufacturer suggestion. The infused composite was removed from the mould and
cured for a complete 12 hour at room temperature (23ºC). The vacuum pump was running about 6 hours before switch off. This is to ensure that the resin will disperse and filled thoroughly on the fabric during the curing process. H/H composite and H/P hybrid composite were prepared in this experiment. Abbreviations representing the composites types are listed in Table 1.

**Table 1.** Symbol used to represent different types of composite prepared.

| Type of composite | Abbreviation |
|-------------------|--------------|
| Woven hemp        | H/H          |
| Interwoven Hemp/PET along hemp direction | P/H |
| Interwoven Hemp/PET along PET direction | H/P |

**Figure 2.** Vacuum infusion process.

2.3 Tensile Testing

The tensile test samples were cut with a Dremel 4000 tool according to the ASTM D638 [10]. Fifteen samples were used in this experiment which are five samples for H/H composites and ten samples for the H/P composite with two different directions of fibre. Universal Testing Machine with a crosshead speed 1mm/min and 100kN strength was used for the tensile test. The extensometer was used to measure the strain as shown in Figure 3.
3. Results and Discussion

The results show that the maximum tensile strength and modulus elasticity of P/H hybrid, H/H, and H/P composites as shown in Figure 4 and 5. The tensile strength of P/H hybrid composite increased by 4% compared to the H/H composite which was recorded about 47 MPa and 51 MPa respectively. However, the strength showed by H/P hybrid composite is the lowest strength about 35 MPa. This leads to the significant of the hybridization to increase the strength of fibre in the composite.

The modulus of elasticity of the composite shows similar responses to their tensile strength. The P/H hybrid composite give the highest modulus of elasticity recorded about 2.3 GPa compared to the H/H and H/P composite with 2 GPa and 1.8 GPa respectively. The modulus is said to link with the stretching behaviour between the fibre and matrix in the composite. This is because the break and stretch of PET fibre when it approaches the breaking stress. Eventually, the sound characteristic PET fibre will help to enhance the strength of fibre and composite[8].

In addition, a better interfacial adhesion during the vacuum infusion process was lead to improving the strength of the composite. The P/H hybrid composite exhibit higher strength and elasticity modulus because of the fibre arrangement. Other than that, the stable network structure of interwoven hemp and PET fibres will improve the interlocking between fibre and matrix of the composite. Thus, it will prevent for fibre pull out while conducting the test.
4. Conclusion
The mechanical properties of H/H, H/P and P/H hybrid composites were investigated through the tensile test. The results showed the tensile strength and elastic modulus of P/H hybrid composite were higher than H/H composite. The interfacial adhesion was improved with a combination of hemp and PET fibres, thus prevent for the fibre pull out during the test. Thus, the higher load is needed to break the composites structure.
5. Acknowledgement
The authors would like to express gratitude and special thanks to University Malaysia Perlis (UniMAP) in providing researching platform well as providing the equipment and financial assistance for this project. Besides, the authors are also thankful to all fellows for providing their valuable suggestions and guidance during this investigation.

6. References
[1] E. Charlton, “Basics-Of-Composite-Materials,” about money.com, 2016. [Online]. Available: http://composite.about.com/od/aboutcompositesplastics/u/Basics-Of-Composite-Materials.htm.
[2] M. Iqbal, M. Islam, J. Ananda, and K. Lau, “Potentiality of utilising natural textile materials for engineering composites applications,” J. Mater., vol. 59, pp. 359–368, 2014.
[3] Yakubu Dan-mallam, TanWei Hong, and Moh Shukry AbdulMajid, “Mechanical Characterization and Water Absorption Behaviour of Interwoven Kenaf / PET Fibre Reinforced Epoxy Hybrid Composite,” Int. J. Polym. Sci. vol. 2015 (2015), Article ID 371958.
[4] F. C. Suhad D. Salman, Mohaimin J. Sharba, Z. Leman, M.T.H. Sultan, M.R. Ishak, “Physical, Mechanical, and Morphological Properties of Woven Kenaf / Polymer Composites Produced Using a Vacuum Infusion,” Int. J. Polym. Sci., vol. 2015, (2015), Article ID 894565.
[5] Y. Swolfs, L. Gorbatikh, and I. Verpoest, “Composites : Part A Fibre hybridisation in polymer composites : A review,” Compos. PART A, vol. 67, pp. 181–200, 2014.
[6] N. Venkateshwaran, a. ElayaPerumal, a. Alavudeen, and M. Thiruchitrambalam, “Mechanical and water absorption behaviour of banana/sisal reinforced hybrid composites,” Mater. Des., vol. 32, no. 7, pp. 4017–4021, 2011.
[7] R. Yahaya, S. Sapuan, M. Jawaid, Z. Leman, and E. Zainudin, “Mechanical performance of woven kenaf-Kevlar hybrid composites,” J. Reinf. Plast. Compos., vol. 33, no. 24, pp. 2242–2254, 2014.
[8] Y. Dan-Mallam, M. Z. Abdullah, and P. S. M. M. Yusoff, “The effect of hybridization on mechanical properties of woven kenaf fiber reinforced polyoxymethylene composite,” Polym. Compos., vol. 35, no. 10, pp. 1900–1910, Oct. 2014.
[9] A. B. Maslinda, M. S. A. Majid, M. J. M. Ridzuan, M. Afendi, and A. G. Gibson, “Effect of water absorption on the mechanical properties of hybrid interwoven cellulosic-cellulosic fibre reinforced epoxy composites,” Compos. Struct., vol. 167, pp. 227–237, 2017.
[10] A. D638-10, “Standard Test Method for Tensile Properties of Plastics 1,” no. ASTM International, pp. 1–16, 2012.