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Tensile and Compressive Properties of Unidirectional *Arenga Pinnata* Fibre Reinforced Epoxy Composite

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ABSTRACT

This paper presents a study on the effect of *Arenga Pinnata* fibre volume fraction on the tensile and compressive properties of *Arenga Pinnata* fibre reinforced epoxy composite (APREC). The composites were produced using four different *Arenga Pinnata* fibre volume contents, which were 10vol%, 15vol%, 20vol%, and 25vol%, in unidirectional (UD) fibre alignment. Tensile and compression tests were performed on all APREC specimens in order to investigate the effect of fibre volume fraction on modulus of elasticity, strength and strain to failure. The morphological structure of fractured specimens was observed using scanning electron microscopy (SEM) in order to evaluate the fracture mechanisms involved when the specimens were subjected to tensile or compressive loading. The results indicated that the higher the amount of *Arenga Pinnata* fibres, the higher the stiffness of the composites. This is shown by the increment of tensile and compressive modulus of the specimens when the fibre volume content was increased. Tensile modulus increased up to 180% when 25vol% *Arenga Pinnata* fibre was used in APREC compared to Pure Epoxy specimen. It can also be observed that the tensile strength of the specimens increased 28% from 53.820 MPa (for Pure Epoxy) to 68.692 MPa (for Epoxy with 25vol% APREC addition). Meanwhile, compressive modulus and strength increased up to 3.24% and 9.17%, respectively. These results suggest that the addition of *Arenga Pinnata* fibres significantly improved the tensile and compressive properties of APREC.

Keywords: Arenga Pinnata, compressive, tensile, fibre volume fraction, unidirectional fibre alignment

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INTRODUCTION

Natural fibres have been used in various applications since the ancient time. With modern technology, synthetic fibres such as glass fibre, carbon fibre, and Kevlar have been developed as substitutes. Even though synthetic fibres are better in terms of their mechanical properties when compared to natural fibres, there are still some drawbacks, for example, glass fibres are expensive and harmful to human body as well as the environment. Using latest technology, the mechanical properties of natural fibres can now be improved and tailored to suit certain applications as replacement to synthetic fibres, rendering them suitable in the aerospace (Jawaid, Abdul Khalil, Hassan, Dungani, & Hadiyane, 2013; Ku, Wang, Pattarachaiyakoop, & Trada, 2011; Saba, Tahir & Jawaid, 2014), automotive (Dicker et al., 2014; Koronis, Silva, & Fontul, 2013; Sanyang, Sapuan, Jawaid, Ishak, & Sahari, 2016; Ticoalu, Aravinthan, & Cardona, 2010) and construction (Alamri, Low, & Alothman, 2012; Dicker et al., 2014; Dittenber & Gangarao, 2012; Sahari, Sapuan, Zainudin, & Maleque, 2012) sectors. Utilisation of natural fibres from plants to produce natural fibre reinforced polymer composite (NFRP) is among the most popular research topics today (Bakar, Mei Hyie, Ramlan, Hassan, & Jumahat, 2013; Manap, Jumahat, & Sapiai, 2015; Sapiai, Jumahat, & Mahmud, 2015). Natural fibres are preferred because of their attractive characteristics such as its natural availability, environment friendliness, abundance of sources and bio-degradability property (Bachtiar, Sapuan, Khalina, Zainudin, & Dahlan, 2012; Khalid & Abdullah, 2013).

Plant-based natural fibres like kenaf, hemp, sisal, jute, flax and ramie are well-known natural fibres used with either thermoplastic or thermosetting polymers in producing composite materials. The selection of natural fibre to be studied also depends on geographical availability. For example, in Europe, the focus is on flax fibre, whereas jute, kenaf, coir and sisal are more popular in Asia (Pickering, Efendy, & Le, 2016). In this present study, *Arenga Pinnata* fibre was selected to be used as reinforcement for epoxy matrix polymer. This selection is not only because of the fibre's availability in Malaysia but also due to its high durability and resistance to sea water (Ishak et al., 2013). This type of fibre has multipurpose applications such in road constructions for soil stabilisation as a substitute for geotextile fibreglass reinforcement (Ishak et al., 2013) and it is also the main component in daily items such as ropes, brushes, filters, brooms, and shelter for fish breeding (Mogea, Seibert, & Smits, 1991). *Arenga Pinnata* was found to have great potential to be used as reinforcement in polymer matrixes (Misri, Leman, Sapuan, & Ishak, 2010) like polyester and epoxy.

Researchers have been studying ways to improve the mechanical properties of natural fibre composites in order to increase their capabilities and applications (Singha & Thakur, 2008). These natural fibre reinforced polymer (NFRP) composites offer a number of advantages over synthetic fibre such as glass fibre (Faruk, Bledzki, Fink, & Sain, 2014) as mention before. The widely expanding usage of NFRP composite materials for highly loaded structures has encouraged the need for a continuous revision of mechanical testing. Tensile and compression tests are some of the various assessments performed on natural fibre reinforced polymer (Dittenber & Gangarao, 2012; Ishak et al., 2013; Jumahat, Soutis, Mahmud, & Ahmad, 2012; Sanyang et al., 2016; Uddin & Sun, 2008) to study the composite mechanical properties in structural applications such as bridges and drain covers. Difficulties that have been identified in the testing of NFRP composites include the variability of the geometrical, physical, and mechanical properties of natural fibre in the NFRP composites.

This study aims to investigate the effect of *Arenga Pinnata* fibre content on tensile and compressive properties of *Arenga Pinnata* fibre reinforced epoxy composite (APREC). Fibre content of 10vol%, 15vol%, 20vol%, and 25vol% were used to produce APREC and subjected to tensile and compressive load test. After the test, the failure surface of the specimens was observed using scanning electron microscope (SEM) to examine the failure mechanism of the composites.

MATERIALS AND METHOD

Natural fibre, *Arenga Pinnata* was used as a reinforcement for epoxy matrix in order to produce *Arenga Pinnata* fibre reinforced epoxy composite (APREC). *Arenga Pinnata* fibre was harvested from Kuala Pilah, Negeri Sembilan, Malaysia. Epoxy resin, Miracast 1517 was supplied by Miracon (M) Sdn. Bhd, Selangor, Malaysia. Generally, APREC specimens were produced with volume fraction of 10vol%, 15vol%, 20vol%, and 25vol% *Arenga Pinnata* fibre content. The composites were fabricated using hand lay-up process and then placed on cold press machine and pressed at constant pressure to flatten the composite. Unidirectional (UD) fibre alignment was chosen as the fibre orientation in producing the composite. The specimens were then subjected to tensile and compressive load until they failed, and observed under SEM to study the failure mechanism of the specimens.

For tensile test, APREC specimens were prepared using square shape mould with dimension of 250 mm length × 25 mm width × 3 mm thickness according to ASTM D3039 while for compression test, the dimension of the specimens was 110 mm length × 9.8 mm width × 4 mm thickness according to ASTM D3410. However, the procedure to fabricate the composites were similar for both tensile and compression test. Firstly, epoxy resin, hardener and *Arenga Pinnata* fibres were weighted according to mass needed for each volume percentages of the composites (10vol%, 15vol%, 20vol%, and 25vol%). The weighted *Arenga Pinnata* fibres were aligned in the prepared mould in UD alignment, then a mixture of epoxy and hardener with ratio of 100 (epoxy resin): 30 (hardener) was poured into the mould on top of the fibres. The mould was then left for 5 to 10 minutes to let epoxy resin flow in between fibres and to remove air bubbles. After that, a plastic sheet and a steel plate were placed on top of the mould before moving it into the cold press machine. The mould was set to a constant pressure of 105 kg/cm^2 (10,000 kPa) for 24 hours to flatten the specimen's surface and to acquire desired specimen thickness (to obtain mould volume needed). Following a curing process of 24 hours the specimens were removed from the mould, and then filed and polished to make it smooth. Figure 1 shows example of cured APREC inside mould.

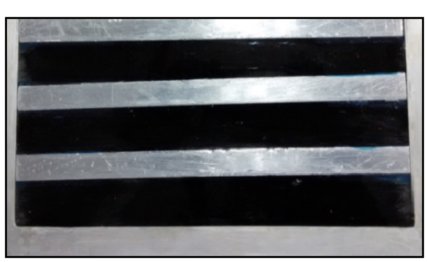

Figure 1. Example of cured APREC specimen moulding

Tensile and compression tests were conducted on all prepared specimens using Instron Universal Testing Machine. The experimental setups are shown in Figure 2 and Figure 3. For tensile test, the gauge length of the specimens was set at 150 mm and the test was performed at crosshead speed of 2 mm/min, based on ASTM D3039 standard.

Figure 2. Tensile test setup using Instron 3382 Universal Testing Machine

One the other hand, for compression test, the test was performed according to ASTM D3410, using crosshead speed of 1 mm/min.

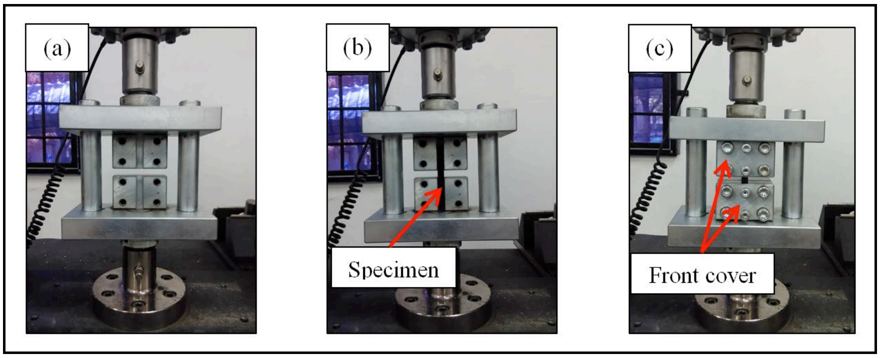

Figure 3. Compressive test jig configuration: (a) without specimen; (b) with specimen; and (c) with specimen and front cover

Bluehill 2 testing software was used to record the applied load and elongation data. These data were used to calculate the tensile and compressive properties (stress, strain, and modulus) of all specimens to investigate the effect of *Arenga Pinnata* fibre loading in APREC.

RESULTS AND DISCUSSION

Figure 4 illustrates the typical stress-strain curve of Pure Epoxy (as reference), 10vol% APREC, 15vol% APREC, 20vol% APREC, and 25vol% APREC. From the figure below, Pure Epoxy has the lowest slope gradient followed by 10vol% APREC, 15vol% APREC, 20vol% APREC, and 25vol% APREC with the highest gradient of the slope.

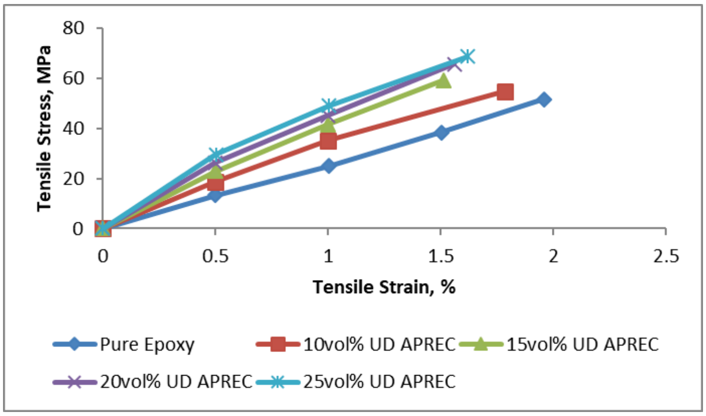

Figure 4. Typical tensile stress-train curve for Pure Epoxy, 10vol% UD APREC, 15vol% UD APREC, 20vol% UD APREC, and 25vol% UD APREC

Stress-strain curve pattern in Figure 4 shows initial linear elastic region before the stress reached around 10 MPa for APREC specimens for all volume percentage, but Pure Epoxy stress-strain curve shows almost linear line all the way until failure occurred. After the curves for APREC specimens passed the linear elastic region, they start to bend a little, indicating transformation to plastic region. Similar tensile stress-strain curve pattern had been reported by Ticoalu, Aravinthan and Cardona (2013) on untreated, 5% NaOH treatment, and 10% NaOH treatment of *Arenga Pinnata* fibres.

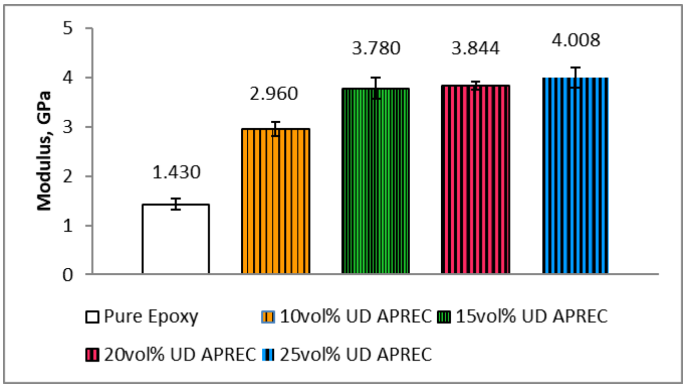

Figure 5. Tensile modulus of Pure Epoxy, 10vol% APREC, 15vol% APREC, 20vol% APREC, and 25vol% APREC

From the calculated tensile modulus shown in Figure 5, pure Epoxy acts as the reference, displayed the lowest stiffness of all specimens with 1.430 GPa. 10vol% APREC shows increment of 2.960 GPa (increased by 106.99%), 15vol% APREC with 3.780 GPa (increased by 164.34%), 20vol% APREC with 3.884 GPa (increased by 168.81%), and 25vol% APREC with 4.008 GPa (increased by 180.28%).

Tensile modulus increased with the increment of *Arenga Pinnata* fibre volume in APREC, suggested that *Arenga Pinnata* fibres had enhanced the composites' stiffness.

Table 1
Tensile strength and tensile strain of Pure Epoxy and APREC

Materials	Tensile Strength, MPa	Tensile Strain, %
Pure Epoxy	53.820 ± 0.971	1.959 ± 0.113
10vol% APREC	54.830 ± 1.533	1.787 ± 0.181
15vol% APREC	59.257 ± 0.724	1.515 ± 0.167
20vol% APREC	65.686 ± 1.368	1.562 ± 0.125
25vol% APREC	68.692 ± 1.110	1.619 ± 0.073

Tensile strength and strain of Pure Epoxy and APREC are shown in Table 1. The tensile strength result shows significant increment from Pure Epoxy which exhibited the lowest value of 53.820 MPa, followed by 10vol% APREC 54.830 MPa (1.88% increment), 15vol% APREC 59.257 MPa (10.10% increment), 20vol% APREC with 65.686 MPa (22.05% increment), and 25vol% APREC with 68.692 MPa (27.63% increment). However, tensile strain of all UD APREC specimens was slightly lower than Pure Epoxy as shown in Figure 3 where the curves of APREC specimens stopped earlier than Pure Epoxy due to premature failure caused by poor interfacial bonding between *Arenga Pinnata* fibres and epoxy matrix. This was verified by SEM images in Figure 6 showing debonding of *Arenga Pinnata* fibres from epoxy matrix and fibre pull-out.

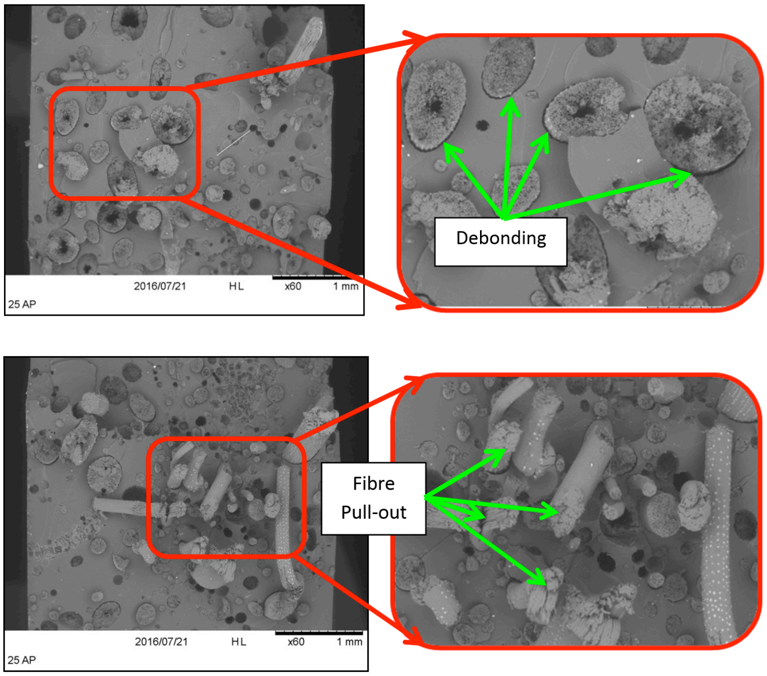

Figure 6. SEM images of UD APREC tensile failure surface

Figure 7 indicates a similar trend with tensile stress-strain curve where Pure Epoxy has the lowest gradient of the slope, followed by 10vol% APREC, 15vol% APREC, 20vol% APREC, and 25vol% APREC for the first 15% compressive strain. This implies that addition of *Arenga Pinnata* fibres increased the resistivity of the material to deform when subjected to tensile and compression. As shown in Figure 7, all specimens collapsed at around 20% compressive strain, but their compressive strength varies around 88 MPa to 100 MPa.

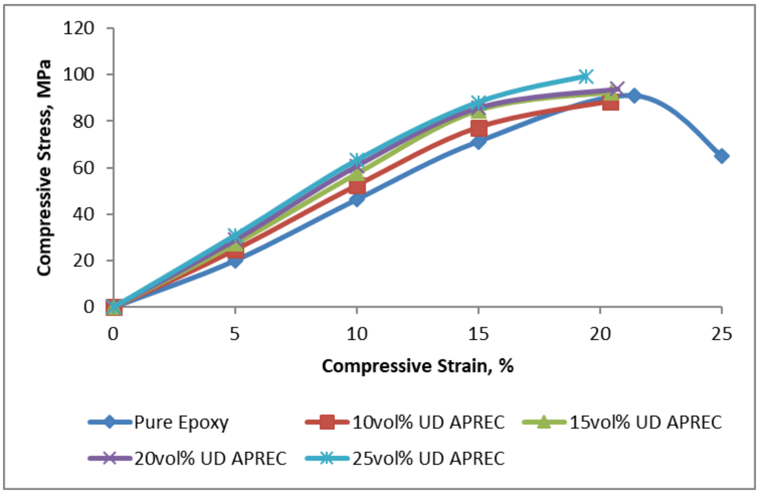

Figure 7. Typical Compressive stress-train curve for Pure Epoxy, 10vol% APREC, 15vol% APREC, 20vol% APREC, and 25vol% APREC

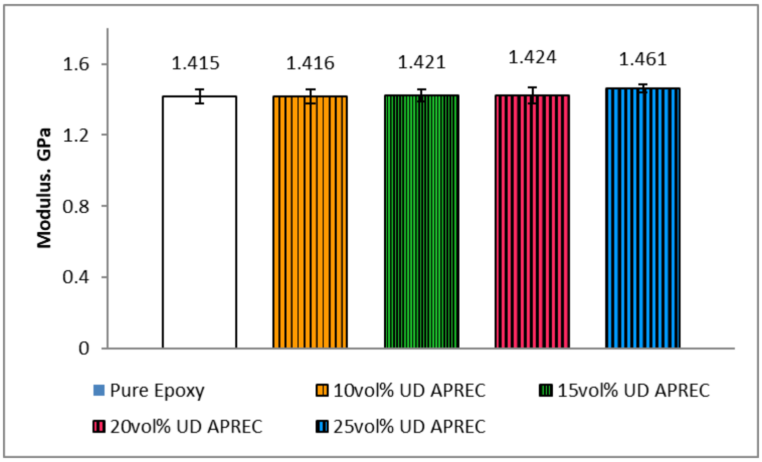

Figure 8. Compressive modulus of Pure Epoxy, 10vol% APREC, 15vol% APREC, 20vol% APREC, and 25vol% APREC

Compressive modulus of APREC specimens shows similar improvement compared to Pure Epoxy as in Figure 8 but the increments are not as much as tensile modulus. For 10vol% APREC, compressive modulus only increased by 0.06%, 15vol%, 20vol%, and 25vol% APREC had increased by 0.42%, 0.63%, and 3.24% respectively.

Table 2
Compressive strength and compressive strain of Pure Epoxy and APREC

Materials	Compressive Strength, MPa	Compressive Strain, %
Pure Epoxy	90.980 ± 5.453	21.403 ± 1.532
10vol% APREC	88.518 ± 0.188	20.409 ± 2.024
15vol% APREC	92.459 ± 3.184	20.469 ± 3.389
20vol% APREC	93.995 ± 0.642	20.730 ± 3.020
25vol% APREC	99.327 ± 2.492	19.426 ± 1.615

The addition of *Arenga Pinnata* fibres into epoxy matrix increased the compressive strength as shown in Table 2. Even though there was a slight drop in compressive strength displayed at 10vol% APREC, the compressive strength values had increased by 1.63% (15vol% APREC), 3.31% (20vol% APREC), and 9.17% (25vol% APREC) compared to Pure Epoxy. Compressive strains for all APREC specimens were just a bit lower than Pure Epoxy though the values were almost the same.

Figure 9 demonstrates the SEM image of APREC compressive failure section showing that the failure was initiated by the matrix failure. The *Arenga Pinnata* fibres surfaces were still intact after the compression test, proves that the untreated *Arenga Pinnata* fibres and epoxy matrix had poor interfacial bonding.

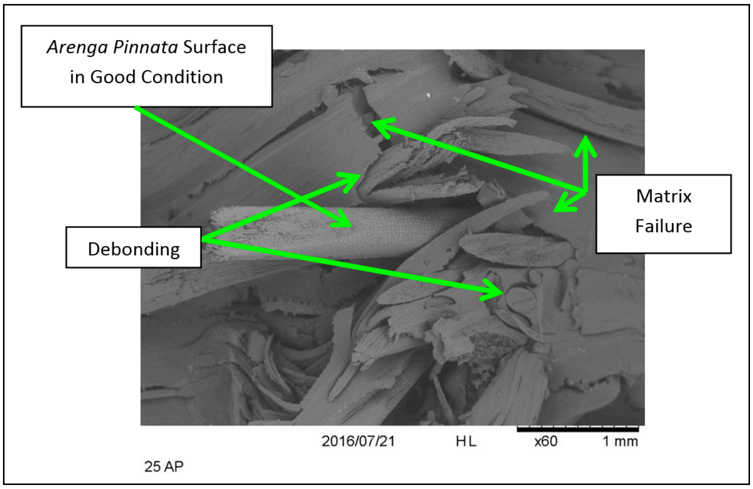

Figure 9. SEM image of UD APREC compressive failure section

CONCLUSION

Tensile and compression test were successfully carried out on 10vol %, 15vol%, 20vol%, and 25vol% APREC. Tensile modulus, tensile strength, compressive modulus and compressive strength results indicate that the addition of *Arenga Pinnata* fibre into epoxy matrix had improved the tensile and compressive properties of the epoxy. Furthermore, addition of fibre volume percentage in APREC had improved the tensile and compressive properties of the composites. Increment in modulus is the evidence that *Arenga Pinnata* plays an important role in improving the rigidity of epoxy matrix. Despite the successful improvement in mechanical properties, further enhancements are required to improve the interfacial bonding of *Arenga Pinnata* fibre and epoxy resin to improve the mechanical properties of APREC.

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