Impact response performance of pineapple leaf fibre (PALF)/carbon reinforced hybrid composite

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Abstract. The number of fossil fuels is decreasing dramatically, whereas the amount of waste around the world is increasing due to the non-biodegradable petroleum-based product such as plastics. Therefore, impact response performance of pineapple leaf fibre/carbon reinforced hybrid epoxy composite was analysed with different layering sequences to replace non-biodegradable materials. The fibres laminates used for the hybrid composites were fabricated using interwoven between pineapple leaf fibre (PALF) and carbon fibre reinforced epoxy resin. The composites were made by using vacuum infusion method with a weight factor of 30% fibre and 70% epoxy resin. Other than the pure PALF reinforced epoxy composite, the PALF/carbon reinforced hybrid composites were using weight factor of 24% PALF and 6% carbon fibre. 5 types of layering sequences composites were fabricated that were, pure PALF, carbon/PALF/carbon, PALF/carbon/PALF, alternative PALF with carbon, and alternative carbon with PALF. Charpy impact test was used to obtain the impact strength of the hybrid composites. From the result obtained shows that layering sequences of PALF/carbon/PALF exhibited the highest impact strength that is around 100kJ/m² compare with others, followed by alternatively PALF with carbon, alternatively carbon with PALF, carbon/PALF/carbon and lastly pure PALF.

1. Introduction

This research project aims to study the impact response performance of pineapple leaf fibre with carbon reinforced epoxy composite. The increase of petroleum-based products, such as plastics causes many negative impacts on the environment [1], [2]. One of the solutions is using natural fibre as a substitute for synthetic fibres since they are eco-friendly and having excellent mechanical and physical properties. There are different types of fibres, for example, bast fibres, pineapple leaf fibres, core fibres, grass and reed fibres [3], [4]. Pineapple has become the 2nd important tropical fruits in the world in 2002, according to the Food Agricultural Organization of the United Nations. In 2018, there are about 24.8 million tons of pineapple fruits being produced annually in the whole world [5]. Among all the natural fibres, pineapple leaf fibre with epoxy composite shows a 40% better of mechanical properties such as impact, tensile and flexural strength compared to others. Therefore, pineapple leaf fibre composite can be a potential composite for further development and applicable for manufacture [6]. In recent year, hybrid composites are being used worldwide due to their low density, low price, unlimited or sustainable available, and most importantly, environment-friendly [7]–[10]. However, there are a few factors that affect the strength of a hybrid composite, such as properties of fibres, fibre to matrix interface bonding,
the arrangement of the fibres and the failure strain of each fibre. The ideal or best hybrid composite can be created when the fibres are having high strain compatible[11].

2. Materials and methods

2.1. Materials

The woven PALF and woven carbon fibre are purchased from a local supplier in Malaysia. The PALF and carbon fibre are used as a reinforcement material in the woven form with a dimension of 300 mm × 300 mm, as shown in Figure 1(a) and (b) respectively. The epoxy resin of EpoxAmite 100 series resin is being used as the polymer matrix for the composite together with a slow hardener, named Epoxamite 103 slow hardener. The epoxy resin is mixed with the slow hardener with a weight ratio of 100g: 28.4g according to the instruction of the supplier.

![Figure 1.](image)

**Figure 1.** (a) PALF and (b) carbon fibre dimension of 300mm x 300mm.

2.2. Composites Fabrication

The hybrid composites are prepared by using a PALF with a weight content of 24% ± 2% and carbon fibre weight content of 6% ± 2% having different types of layering sequence as listed in Table 1. Vacuum infusion method is used to fabricate the hybrid PALF/carbon fibre reinforced composites is illustrated in Figure 2.

| Type of layering sequences                        | Symbol  |
|--------------------------------------------------|---------|
| a. Pineapple leaf/carbon/pineapple leaf          | PCP     |
| b. Carbon/pineapple leaf/carbon                  | CPC     |
| c. Pineapple leaf/carbon/pineapple leaf/carbon   | PCPC    |
| d. Carbon/pineapple leaf/carbon/pineapple leaf   | CPCP    |
| e. Pure pineapple leaf                           | -       |
| f. Pure carbon                                   | -       |
Figure 2. (a) The infusion vacuum machine used for fabrication (b) shows the fabrication process of the composites.

2.3. Charpy impact test
LS-2206-50 Charpy Impact tester is used for testing the specimens’ impact strength. The specimens are placed in the Charpy Impact machine horizontally on the anvil for testing according to standard ASTM D6110. The pendulum is raised to an angle of 120° and lock to the height to prepare for impact testing. When all setup is ready, the handle is pulled as to release the impactor from the locking and knock on the specimens. After the specimens are broken, the angle of the impactor after impact is recorded, and the impact resistance is calculated.

3. Results and discussion
The impact resistance or absorbed impact energy per unit meter width of the composite is determined through the difference of potential energies before and after impact divided by the width of the composite. Table 2 shows the specimens before and after the impact with different layering sequences and the SEM image of each specimen.

From the result of figure 3, PCP has the highest average impact resistance. The PCP has the average impact resistance of 1.642kJ/m, which is 548% of pure PALF composites of 0.296kJ/m. For both the layering sequences of CPC and CPCP, the average impact strength of the hybrid composite doubled that of the pure PALF composite to around 0.5797kJ/m and 0.4891kJ/m respectively. Whereas for the layering sequences of PCPC, the average impact strength increased three times to 0.899kJ/m. Whereas for the impact strength of the composites shown in table 3 are determined from the difference of potential energies before and after the impact divided by the cross-sectional area of the composites’ impact surface. The performance of impact strength concerning to different layering sequences of composites is very alike to impact resistance, with layering sequence of PCP hybrid composite having the highest impact strength of 100.3 kJ/m². This is followed by PCPC hybrid composite with the impact strength of 61.09 kJ/m². The CPCP and CPC hybrid composites found to yield similar impact strength of 31.4 kJ/m² and 30.6 kJ/m², respectively. Neat PALF composite yields the lowest impact strength of 15.7436kJ/m².

From the research of N. Agarwal, it shows that 30% wt of carbon fibre reinforced epoxy composite has an impact strength of 12kJ/m² [12]. This shows that carbon fibre has a lower impact strength compared to PALF; having a superior impact, and energy absorption compared to other natural fibre, for example of Kenaf fibre [13]. Therefore when carbon fibre layer used as the skin of hybrid composite result in lower impact strength or energy absorption compared with hybrid composite with pineapple leaf fibre layer as skin [14]–[16].

From the SEM result for pure PALF composite, it shows that the debonding between PALF and the epoxy matrix and the fibre pullout from the epoxy matrix. This shows that there was a weak interface between fibre and matrix, causing weak adhesive bonding and created a concentrated deformation region [17], [18]. For CPC, the result shows there are potholes in the composite which caused by entrapped moisture molecules and also river markings oriented in a variety of angle across the fibre surface will lead to overexposure of fibre and localised microscopic areas of fracture. The large area of void in the
composite after the impact test observed is due to the pull out of fibres. This is mainly caused by the weak interface and adhesive bonding between fibre and matrix [17]. For the PCPC, the morphology suggests that the overall distribution of the epoxy matrix has fully covered the composite with little voids. The figures show that there is weak adhesive bonding among carbon fibre, PALF and epoxy with cause this layering sequence having the low impact response performance. This will cause the composite easily to debonds, and fibre easily pulls out from the matrix. For the CPCP, overall, there are quite some voids in the composites which are caused by the impurities and bursting moisture molecule.
Table 3. Average impact resistance and average impact strength of each layering sequences.

| Type of layering sequences | Average impact resistance, kJ/m | Average impact strength, kJ/m² |
|---------------------------|---------------------------------|-------------------------------|
| Pure PALF                 | 0.2960 ± 0.0685                 | 15.7436 ± 1.9407              |
| CPC                       | 0.5797 ± 0.264                  | 30.6439 ± 2.8693              |
| PCP                       | 1.6419 ± 0.1447                 | 100.2997 ± 5.4824             |
| PCPC                      | 0.8990 ± 0.0312                 | 61.0910 ± 9.2268              |
| CPCP                      | 0.4891 ± 0.0309                 | 31.3828 ± 1.6209              |

Figure 3. Graph of average impact resistance and average impact strength with different layering sequences.

Moreover, the interface of carbon fibre and the epoxy matrix is weak and cause a lot of the carbon fibre pulled out after the impact test process. All of these weak points decrease the impact strength of the composite and cause the composite fracture easily. Lastly, for PCP, the epoxy matrix is well filled across the composite, and the interface of fibres with the matrix is excellent, very little of fibres pull out after the impact process.

4. Conclusion
From the result obtained in this research, the impact properties of the hybrid composite are stronger than of PALF composites alone. The incorporation of carbon fibre in the hybrid composite increased the impact resistance and impact strength of the composite and made them stronger and better resistant to breaking. It shows that hybrid PALF/carbon fibre reinforced composite has the potential to replace most of the use of plastic products. This can help to preserve the number of fossil fuels and also to reduce the waste around the world as natural fibre composite is biodegradable. Other than that, this also creates a new method as to dispose of the residual of the pineapple plants by turning them into a more useful composite rather than bury them under the ground. Different layering sequences of fibres created composites with different impact properties. In conclusion, with the same weight factor of pineapple leaf fibre, carbon fibre and epoxy but different layering sequences, the one using natural fibre as the surface of the hybrid composite such as PCP layering sequence exhibit the best impact response performance of 100.3kJ/m² which is almost nine times stronger than of pure PALF. As from the result
of morphological analysis, the interface of fibres with matrix plays an essential role in impact response performance of a composite. The stronger the adhesive bonding of fibre with matrix and fibre with fibre, the more energy is needed to break the composite. In order to fabricate a stable hybrid composite, the weakness of bad interface of carbon with epoxy needs to be solved by using a chemical treatment to remove the impurities and the moisture molecules in fibres.

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