Characterization of Continuous Gradient Functionally Graded Natural Fiber Reinforced Polymer Composites

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Abstract. In this study, cylindrical tubes of functionally graded natural fibre reinforced polymer (FGNF/epoxy) composite are fabricated using horizontal centrifugal casting method. Natural fibres (NF) used in this research are coconut coir and oil palm empty fruit bunch (OPEFB). Natural fibres are mixed with epoxy at four different compositions which is at 0%, 5%, 10% and 15%. The study aims to determine the mechanical properties and microstructure of the FGNF/Epoxy composites. In this method, a homogenous mixture of epoxy liquid and natural fibres is inserted into mould simultaneously. Then, the mould is rotated at a constant speed for 4 hours. Effect of this process, the natural fibres particles in epoxy liquid move radial during mould rotation. Hardness and compression test are carried out to characterize the FGNF/epoxy cylindrical tubes. The microstructures of the composites are observed using optical microscope (OM) and scanning electron microscope (SEM). From the microstructural observation, it is found that the natural fibres particles can be graded from inner to outer surfaces of the FGNF/epoxy cylindrical tubes. The hardness value of the outer part of the FGNF/epoxy fabricated is higher than the middle and inner parts. Besides, from the compression test it shows that epoxy reinforced NF give a better result in strength compared to specimen without reinforced NF. However, the strength value decrease when the fibres percentage increase more than 5%. FGNF/epoxy with 5% NF content gives a balanced composition to have high hardness value and strength.

1. Introduction

Nowadays, natural fibre reinforced polymer (NF/P) composites are increasingly being used for a wide range of applications due to many of their advantages such as in automotive and industrial sector. Natural fibres have the advantages of low density, low cost recyclability and biodegradability. This change is due to environmental and sustainability regulation in the last decades causes to considerable performance in green technology in the field of materials science through the development of bio...
composites. There are several reasons for this interchanging to occur. Synthetic materials-based products pose a high risk in most applications, both from direct exposure and also from secondary exposure through soil, water and air pollution. In aspect of health, synthetic materials in fabrics are highly toxic and are increasing the negative effects on our health. These synthetic fabrics also pose a serious threat to ecological balance [1].

In order to overcome the problem, synthetic material needs to be replaced by natural fibres. Some examples of natural fibre that usually used in industries are rice husks, coconuts, kenaf, jute, oil palm and pineapple leaves. In this study, coconut coir and oil palm empty fruit bunch will be used as the natural fibres. The benefits of these fibres compared to fiberglass is, they are more environmentally friendly because it can be degraded naturally and even cheaper in price than fiberglass. Plus, glass fibre also gives bad effect to human health when the material is reuse because it will release carbon monoxide gas and dust to surrounding.

There are several methods used to determine types of composite compositions. One of them is functionally graded material (FGM) concept. FGM is a material which is its composition changed towards volume [2]. Functionally graded material (FGM) is a new and advanced material in this engineering generation. This is because of its speciality in its gradient composition and has a different structure from the original materials. Its manufacturing process involves a mixture of several materials to form a new composite or to change the strength of the materials [3]. This concept has a potential to be used in many sectors such as engineering, nuclear energy and electronic [4].

There are several techniques in producing FGM such as powder metallurgy, vapour deposition, rapid prototyping and centrifugal technique [2]. In this research, only centrifugal technique will be used in FGM producing because this is the only techniques that can form a continuous structure whether in radial or altitude specimen [2]. Centrifugal casting method has a several advantages such as have a good behaviour, quality and dimensional flexibility. This is because centrifugal casting method produces smaller microstructure than static casting method. At the same time, centrifugal reaction can eliminate the foreign materials from the molten and can reduce the dimension of molten shrinkage. The advantages and disadvantages of these approaches in producing FGNF are still investigated [5 - 7]. In this work, the preliminary study to characterize FGNF/epoxy fabricated using centrifugal casting is investigated.

2. Methodology

2.1 Specimen Preparation
Firstly, all the raw natural fibres were treated with water for 7 days and NaOH solution for 24 hours at room temperature. Then, those fibres were rinsed and dried under sunlight for 24 hours. Drying process continued using high capacity oven for 24 hours at 50°C. After that, all the fibres were cut into small pieces between 5-10mm lengths using granulator machine. The fibres then were mixed with epoxy and hardener before fabricated using centrifugal casting method. Specimens were divided into four compositions of natural fibres which are 0%, 5%, 10% and 15%. After all the materials were stirred, the mixture was poured into a rotating mould before it was put on laboratory roll ball mill. The mould rotated for 3 hours at 600 rpm speed. When the specimens were fully hardened, they were tested in several methods to characterize their microstructure view and mechanical behaviours. The FGNF/epoxy fabricated shown in figure 1.
2.2 Density and porosity test
The density determined by exploiting the principle of Archimedes, which states that anybody immersed in a fluid becomes lighter by an amount equal to weight of the fluid that has displaced. Based on ASTM D792 standard, the density, $D$ and porosity, $P$ were calculated by (1) and (2), respectively. $W_s$, $W_d$ and $W_w$ are denotes mass of an immersed and suspended specimen in water, mass of air-dried specimen, and mass of wet specimen, respectively.

$$D = \frac{W_d}{W_d - W_s}$$  \hspace{1cm} (1)
$$P = \frac{W_w - W_d}{W_w - W_s} \times 100\%$$  \hspace{1cm} (2)

2.3 Microstructural observation
Microscopic examination was conducted to study the structure of the material under magnification. The properties of materials determine how well they will perform under a given application, and these properties are dependent on the material’s structure. Scanning Electron Microscopy (SEM) JEOL KSM-6380LA and Optical Microscopy (OM) were used to identify the failure fracture morphology of the composite specimen. Optical microscopy is an ideal method for general inspection purposes but scanning electron microscopy can provide the user with incredibly detailed topographical and compositional information.

2.4 Hardness test
Hardness test was run at room temperature according to ASTM D2240 standard. The tool that had been used in this test was shore durometer type D. This tool is usually used to test the hardness of polymer materials. Type D durometer was chosen to be used in this research because its function is to test a hard polymer material. The needle of the durometer will be pushed into the surfaces of the specimen radially starting from the inner, middle and outer part of the composite.

While, in longitudinal direction of the specimen were not been measured because it will have a uniform value of hardness along its height as it has a uniform distribution of fibres. Hardness value was recorded in one-minute reading. The specimen dimension needs to be 50mm height, 50mm width and 6mm thickness or more.

2.5 Compression test
The specimens were test at room temperature using Testometric Universal Testing Machine (UTM), modelled GOTECH 50KN. Force was set to 50 kN based on ASTM D695. The size of the specimen is 80 mm outer diameter, 5 mm thickness and 40 mm height. Actually, the size of the specimen was not following the testing standard size. However, the standard area ratio of the specimen
and the specification of the testing standard were still the same which is 0.5. Before the testing start, the bottom surfaces of the specimen were mechanically planar ground. This is to prevent the friction between the specimen and the surface of the testing machine plate while compressing process is running. Vertical force was given to the specimen with uniform speed, 1 mm/min until the specimen failed.

3. Results and discussions

3.1 Density and porosity

Table 1 tabulates the density and porosity of FGNF/epoxy fabricated. The lowest density recorded was at FGNF/epoxy composite specimen with 15% fibre content which was 1.1656 g/cm$^3$. The zero fibres content which was fully epoxy resin specimen was the highest density recorded followed by 5% and 10% fibre content. It can be concluded that increasing in fibre percentages will decrease the density of FGNF/epoxy composites.

Porosity measurement is important because it will show the critical imperfection of composite reinforced fibres. A higher percentage of porosity means many air gap or weak bonding between epoxy and fibres in the FGNF/epoxy fabricated. From table 1 can be seen that the increasing of percentage of natural fibres inside the specimens will caused the increasing of the porosity percentages. It is clearly showing that the existing of air gap or the separation between epoxy and fibres during centrifugal casting due to its different density where the higher density, epoxy, forced move to the mould outer periphery.

3.2 Microstructural observation

The microstructural observation is conducted to examine the fibres distribution and the bonding of fibres and epoxy matrix. It will determine the defect of these composites based on its fibres distribution through all the specimen, interface between matrix and fibres and its porosity.

Figures 2(a) show that the distribution of fibres (FGNF/epoxy with 5% fibre content) in all surfaces was balance. This was happened as the volume of the fibres was low and still can be flown by the epoxy resin smoothly while casting was running. Besides that, it shows that the middle and inner surfaces had the largest amount of porosity than outer surface of the specimen. This happened as the inner surface was exposed more to the air while casting than the outer surfaces, which was bounded by the inner mould surface.

Meanwhile for 10% fibre content, as shown in Figure 2(b), shows the moderate percentage of fibres. The figures show the appearance of fibres inside the FGNF/epoxy fabricated getting larger as the percentage was increased. This parameter also shows that the middle and the inner parts of the FGNF/epoxy fabricated have the largest amount of porosity. Porosity also might be happened while mixing and stirring activities were being performed.

Figure 2(c) shows the microstructure of the highest percentage of fibres content which was 15%. It shows the largest distribution of fibres inside the FGNF/epoxy fabricated especially at inner part of the
specimen followed by middle and outer part. The inner and middle also had bigger size of pores than the outer part. From physical observation, there were few fibres accumulated at some part of FGNF/epoxy fabricated. This caused the weak bonding between matrix and fibres.

Figure 2. Surfaces microstructure view of FGNF composite at various fibres content: (a) 5%, (b) 10% and (c) 15%.
3.3 *Hardness value*

Based on hardness value (HD) of FGNF/epoxy fabricated measured along radial direction as shown in figure 4, it shows that the FGNF/epoxy with 5% fibres content has the highest value of hardness followed by 10%, 15% and 0%. The outer parts of all FGNF/epoxy fabricated are the hardest followed by the middle and inner part. The hardest value obtained is at outer part of 5% fibres content which is 84HD. While the lowest hardness value is at inner part of 0% fibres content which is 66.25HD. It shows that fibres additions in matrix enhance the hardness value especially to the middle part of the specimen as shown in figure 4. Besides, the centrifugal force introduced during casting play an important role in distributing fibres along radial direction that contribute to the variation of hardness value along radial direction of FGNF/epoxy fabricated. The FGNF/epoxy composite with 5% fibres content was the most balanced mixture to have a good hardness composite.

![Figure 4. Hardness average (HD) versus specimen part graph](image)

3.4 *Compression strength*

Figure 5 plot the load-displacement curves of the FGNF/epoxy fabricated with different percentages of fibres tested. No fibres addition specimen which was 0% fibres content also been tested as baseline. Compression force graph of all FGNF/epoxy fabricated start by ascending toward displacement until it reaches the ultimate strength of the specimens and then drop until its failure. For FGNF/epoxy with 5% fibres content, its graph drops drastically after reach the ultimate strength. While the graph for FGNF/epoxy with 0%, 10% and 15% fibres content decrease gradually toward displacement. This shows that FGNF/epoxy with 5% fibres content more brittle. While, the other specimens occurred strength loss until they failed this which is called plastic region.
Based on Table 2, it shows that the strength of FGNF/epoxy shows an increasing value from 0% to 5% fibres content, but it starts decreasing when to percentage of fibres content more than 5%. The decreasing in strength happened because of accumulation of fibres inside the specimen that blocked the epoxy matrix from mixed with the fibres. The data shows that specimen with 5% fibres content had the highest value of maximum stress which is 33.631 MPa. While, the lowest value of maximum stress was at 15% fibres content obtained which is 5.246 MPa. It can be concluded that FGNF/epoxy with 5% fibres content is the strongest composition in compression than others.

![Figure 5. Load-displacement curve.](image)

**Table 2.** Compression test data.

| FGNF/epoxy | Max. Load (kN) | Max. Stress (MPa) |
|------------|----------------|------------------|
| 0%         | 17.690         | 15.016           |
| 5%         | 39.621         | 33.631           |
| 10%        | 22.577         | 19.164           |
| 15%        | 6.180          | 5.246            |

4. Conclusion

The cylindrical tube of functionally graded natural fibre reinforced polymer composite using centrifugal casting that have a better in strength was successfully fabricated. There were few differences between microstructure and mechanical behaviour of the composites as expected from the beginning of this research. The hardness and strength of FGNF/epoxy were increased with additional of natural fibres content from 0% to 5% but it was slightly decreased with additional of fibres content more than 5%.

However, the porosity is the main issue need to be reduced to enhance the composite. This may be contribute by the size of fibres. The smaller size of fibres may lead the good bonding of epoxy and fibres. This is happened when the size of the fibres is smaller, it will easily cover all the pores area inside the specimens. Thereby, porosity of samples can be decreased.
It can be determined that OPEFB and coconut coir are suitable to be used as polymer composite materials. It is one of new alternatives to replace synthetic fibre because they are environmentally friendly, not harmful to human, cheaper and easy to obtain.

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