Bamboo and Glass Fibre Hybrid Laminated Composites as Locking Compression Plate (LCP) for Tibia Fracture Treatment

Solehuddin Shuib¹, *Nur Faiqa Ismail¹, Muhammad Nazif Nazri¹, Ahmad Zafir Romli²
¹Faculty of Mechanical Engineering, Universiti Teknologi MARA, Selangor 40450, Malaysia
²Institute of Science, Universiti Teknologi MARA, Selangor 40450, Malaysia

*Corresponding author: nfaiqa.ismail@gmail.com

Abstract. Metallic implants have been used widely in orthopaedic field of area. Materials such as titanium, ceramic, stainless steel, and other metal alloys are commonly used to be attached on bones. Those material have higher stiffness than cortical bone significantly in reducing compression at the fracture site and cause the “stress-shielding” phenomenon. The materials can lead to subsequent bone loss upon healing. Besides, these materials also have limitations involving corrosion and release of ions. This study aimed to investigate the bamboo and glass fibre hybrid laminated composite for orthopaedic applications for tibia fracture fixation. This study involve the uses of bamboo and glass fibre hybrid laminas and cold pressed using epoxy resin to produce layered bamboo epoxy composite laminates with glass fibre. The mechanical properties of layered bamboo epoxy composite laminates including tensile strength and flexural strength are evaluated by using ASTM D3039 and ASTM D790 standard method. Mode of failure is identified at microscopic level using stereo zoom microscope of fractured surfaces under different types of tests. The new material will improve the utilization of locking compression plate (LCP) as the material properties was 66% closer to the cortical bone; hence, stress shielding phenomenon can be minimized. The development of a new material of locking compression plate (LCP) for tibia fracture treatment will be successfully decreased the “stress-shielding”; thus, improved the bone healing process of tibia fracture.

Keywords: Bamboo, fibre glass, hybrid laminates, stress shielding.

1. Introduction

The utilization of compression plate began from the late nineteenth century with their subsequent popularization by Danis [1] and the Arbeitsgemeinschaft fur Osteosynthesefragen (AO) group in the 1960s. Conventional non-locked plates had been proven to successfully stabilize numerous types of fractures and osteotomy sites. However, locking compression plate (LCP) must resist physiological loads in order to allow the occurrence of fracture union. Titanium, ceramics, medical grade titanium and other metal alloys were placed in large bones functioning as artificial joints.

Plates and bars were also attached to bones in order to assist the healing of fractured bones. However, these metal plates had disadvantages such as corrosion, where the released ions could cause clinical issues. Due to the limitation, there is need to find a new orthopaedic materials like composite that have closer Young Modulus to the natural bone. Composite materials replaced metallic materials in various engineering applications in many industries including transportation aerospace, pressure vessel
and others. Medical implants is one of the field that has growing interest in the utilization of composite materials [2]. An effective fixation device must have mechanical properties almost alike to the bone plate. This is because it enable some levels of axial movements between the fracture ends while preserve the fracture site by reducing the unfavourable fragment’s motions [3].

There are many types of renewable resources where natural fibre is one of them. It is a new generation reinforcements and supplements for polymer based materials. The evolution of the natural fibre composite materials or also known as environmental friendly composites has become a hot topic recently. A typical composite material consisted of a bonding material called matrix, and one more or more reinforcing materials called fibres [4].

Natural fibre is an effective material in replacing the synthetic materials where the main goal is to minimize the weight of the product and also the energy conservation applications. The aircraft and automotive industries have been actively developed different kinds of natural fibres, mainly on hemp, flax and sisal bioreinforced systems for their interior components. The benefits of using natural fibre such as follows: (i) low weight, (ii) cost reducing, (iii) less damage to processing equipment, (iv) good relative mechanical properties, (v) improved surface finish of moulded part composites, and (vi) abundant and renewable resources [5].

Fixation of long bone fractures with clinically available metal plates may be a limitation due to the mismatch between stiffness of the metal plate and the bone. This mismatch can result in “stress shielding”, which leads to more load transfer to the plate instead of the bone. Thus, it results in bone resorption and eventual implant loosening [6].

In order to minimize the negative effect of “stress shielding”, it is essential to design a bone plate which having a mechanical properties closer to the human bone [7]. In this interest, it has been suggested to create a composite material with mechanical properties closer to the human bone to replace the conventional bone plate which made of metal. There are a few numbers of study used hybrid composites for the bone fracture plate applications [8, 9]. Hence, this study propose to develop a new material of locking compression plate (LCP) for tibia fracture treatment which made of bamboo and glass fibre hybrid laminated composites.

2. Materials and Method

2.1. Materials Preparation

2.1.1. Bamboo Strip
A bamboo strip was obtained from a bamboo-processing factory. The bamboo culms were converted into slivers, strips or laths by flattening, cutting and further processed. Bamboo’s grain can be split into strips by simple tool as thin as several microns. The process started by removing the bamboo bark followed by peeling of the culm’s cylindrical part in order to obtain the bamboo strips.

2.1.2. Glass Fibre
There is a great choice of composite reinforcement materials on the market, particularly fibreglass cloth and glass fibre fabric. A wide range of fibreglass cloth used for aerospace, defence, automotive and marine applications amongst others. Furthermore, a glass fibre can be made of woven roving, woven, unidirectional and even multiaxial. Interestingly, a glass fibre that made of interweaving direct roving resulting a uniform tension. It is used for high performance reinforcement applications with aims for high dimensional stability and easy handling. Traditional woven fibre products are limited to two angles; 0degree and 90deg (perpendicular). Therefore, fibre glass woven was used in this study. The fibre was cut into several part with dimension 30cm x 30cm.
2.1.3. Composite Preparation

Epoxy resin (BJC-39) and hardener (BJC-39) was measured with ratio 2:1 of their weight respectively. Hardener (BJC-39) acts as the curing agent, was added to the epoxy resin. The whole solution then be stirred manually or with the help of mechanical stirrer and then poured on the specimens, bamboo sheet and glass sheet, layer by layer, using hand lay-up technique. It began with bottom surface of bamboo strips. It was brushed in one direction to ensure the fully enclosed of the strips. Then, other laminas were placed on the first laminate to make another layer of laminate. In this current study, up to three layers of laminate/ply were stacked together in order to form one sample of unidirectional of bamboo strips laminate. Finally, the sample was closed with another plastic sheet with load to ensure the sample of laminated stick closely.

2.2. Test Pieces Preparation

Before fabricating the composite laminate, ply stacking sequences of laminated hybrid composite structure was designed. In this study, a bamboo strip was designed into two different plies with two different angles; 0 deg and 30deg. Starting with the first layer of bamboo fibre, the bamboo strip was arranged closely to make a square shape. It came with load to prevent gaps between the bamboo strips during the combination process. PVA glue was used to make strong bonding between the bamboo strips. Next, matrix epoxy resin with hardener was poured and swiped on the first layer bamboo fibre. Then, a glass fibre was placed on the first layer bamboo fibre to bind them together. Next, the second layer of bamboo fibre was placed on the glass fibre so that the composite material consisted of composition such bamboo fibre: glass fibre: bamboo fibre. The processes were repeated for ten (10) samples using different ply and sequence of bamboo fibre with 0deg and 30deg. Laminates were made by stacking layers (also called plies or laminate and usually unidirectional) in a specified sequence. A laminate may have up to three layers and the fibre orientation may change from layer to layer in a regular manner through the thickness of the laminate. This study focus on composites fabricated from many laminates which are sequentially stacked in a designed angles and orientations. Finally, bamboo strips and glass fibres reinforced epoxy hybrid composite were fabricated. Composite materials can be prepared by different methods. However, in this study, only hand lay-up technique was utilized due to some factors; (i) part size and shape, (ii) cost, (iii) familiarity with the technique, and (iv) availability of tools.

2.3. Composite Plies and Laminate Designed

Bamboo laminates were formed by arranging different laminated layers. Moreover, due to the customizability of the composite material, a composite plate with similar geometry to conventional plates can be optimized by manipulating fibre orientation or the stacking sequence of plies to yield desired stiffness and strength in different direction10. Table 1 shows the different orientation of fibre in degree of stacking sequences.

| Sample | No. of Bamboo Layer | Thickness (mm) | Orientation Fibre in Degree (°) of Stacking Sequences |
|--------|---------------------|----------------|------------------------------------------------------|
| 1      | 1                   | 1              | Glass                                                |
| 2      | 1                   | 1              | [0°]                                                  |
| 3      | 2                   | 3              | [0°/glass/0°]                                         |
| 4      | 2                   | 3              | [0°/glass/30°]                                        |
2.4. Mechanical Test

Tensile test and flexural test were performed using INSTRON 3382 Universal Testing Machine (UTM) according to ASTM D3039 and ASTM D790 with cross head speed of 2 and 3mm/ min respectively. The dimensions for tensile samples were; length= 220mm, width= 20mm, and thick= 1mm until 4mm. The three point bending test pieces dimensions were; length= 170mm, span length= 128mm, width= 20mm, and thick= 1mm until 4mm. The tensile properties of the bamboo fibre filled with epoxy resin composite material were determined by universal testing machine at a fixed strain rate of 2mm/ min under displacement of control mode. When the material was stressed in tension test, it had tendency to elongate. Thus, the bond between bamboo fibres and epoxy resin weakened and lead to the loosening of bamboo fibres and fracture of material. Flexural strength, also known as modulus of rupture, or bend strength, or transverse rupture strength is a material property, defined as the stress in a material just before it yields in a flexural test. Its properties were determined by universal testing machine at a fixed strain rate of 3mm/ min under displacement control mode. The tensile strength and elastic modulus were then recorded.

3. Results and Discussion

The characterizations of the composites revealed the effect of the thickness and orientation on the mechanical properties of composites. The properties of the composites with different thickness and orientations were investigated by tensile and bending test. The effect of laminate thickness and orientation on the tensile and flexural of the material was tabulated. The comparison between the different bamboo plies and the orientation for tensile test has been made and illustrated in the Figure 1.

|   |   |   |                |
|---|---|---|----------------|
|5  |2  |3  |[30°/glass/30°]|
|6  |3  |5  |[0°/glass/0°/glass/0°]|
|7  |3  |5  |[0°/glass/0°/glass/30°]|
|8  |3  |5  |[0°/glass/30°/glass/0°]|
|9  |3  |5  |[0°/glass/30°/glass/30°]|
|10 |3  |5  |[30°/glass/30°/glass/30°]|

|   |   |   |                |
|---|---|---|----------------|
|5  |2  |3  |[30°/glass/30°]|
|6  |3  |5  |[0°/glass/0°/glass/0°]|
|7  |3  |5  |[0°/glass/0°/glass/30°]|
|8  |3  |5  |[0°/glass/30°/glass/0°]|
|9  |3  |5  |[0°/glass/30°/glass/30°]|
|10 |3  |5  |[30°/glass/30°/glass/30°]|

2.4. Mechanical Test

Tensile test and flexural test were performed using INSTRON 3382 Universal Testing Machine (UTM) according to ASTM D3039 and ASTM D790 with cross head speed of 2 and 3mm/ min respectively. The dimensions for tensile samples were; length= 220mm, width= 20mm, and thick= 1mm until 4mm. The three point bending test pieces dimensions were; length= 170mm, span length= 128mm, width= 20mm, and thick= 1mm until 4mm. The tensile properties of the bamboo fibre filled with epoxy resin composite material were determined by universal testing machine at a fixed strain rate of 2mm/ min under displacement of control mode. When the material was stressed in tension test, it had tendency to elongate. Thus, the bond between bamboo fibres and epoxy resin weakened and lead to the loosening of bamboo fibres and fracture of material. Flexural strength, also known as modulus of rupture, or bend strength, or transverse rupture strength is a material property, defined as the stress in a material just before it yields in a flexural test. Its properties were determined by universal testing machine at a fixed strain rate of 3mm/ min under displacement control mode. The tensile strength and elastic modulus were then recorded.

3. Results and Discussion

The characterizations of the composites revealed the effect of the thickness and orientation on the mechanical properties of composites. The properties of the composites with different thickness and orientations were investigated by tensile and bending test. The effect of laminate thickness and orientation on the tensile and flexural of the material was tabulated. The comparison between the different bamboo plies and the orientation for tensile test has been made and illustrated in the Figure 1.
As can be seen in the Figure 1, the lowest tensile strength and tensile modulus for sample 1 (fibre glass alone composite) was 99.91 MPa and 10.70 GPa, respectively. Next, the highest tensile strength and tensile modulus was 840.12 MPa and 29.41 GPa for sample 6 [0°/ glass/ 0°/ glass/ 0°]. From the result obtained, we can observe that as the laminated layer increases, the tensile strength and tensile modulus also increases. Conversely, there is a clear trend of different orientation of the bamboo strips decrease the tensile strength and tensile modulus where it can be witness on sample 3 [0°/ glass/ 0°], sample 4 [0°/ glass/ 30°], and also sample 5 [30°/ glass/ 30°]. Hence, the tensile strength and tensile modulus has reduced as the angle of orientation of fibre increasing from 0° to 30°.

Figure 1. Comparison of different bamboo plies and orientation in tensile test

Figure 2. Comparison of bamboo plies and orientation on flexural test
Figure 2 compares the variations of flexural stress and flexural modulus with different angle orientation laminate layers. From the graph above we can observe that the minimum value of the flexural strength was 6.74 MPa while for the maximum of flexural strength was 588.97 MPa. The bending fracture concentrated near the middle of the test specimen where load was applied. The maximum and minimum flexural modulus were 0.19 GPa and 116.09 GPa respectively. Interestingly, the sample 6 \([0^\circ/\text{glass}/0^\circ/\text{glass}/0^\circ]\) was observed as the best in tensile strength, tensile modulus, flexural strength and flexural modulus for both test.

Material like stainless steel and titanium alloys promote stress shielding and reduce fracture healing due to high axial stiffness of these materials. Thus, it is essential to design a locking compression plate with lower axial stiffness in order to achieve better fracture healing. This is to allow the underlying bone carries a considerable amount of the applied load, while having sufficient bending stiffness to prevent gross motion at the fracture site.

Based on the result gained, the bamboo and glass fibre hybrid laminated composite have tensile modulus of elasticity of 13.31 GPa, 14.97 GPa, 16.91 GPa, 19.79 GPa, 20.10 GPa, 26.01 GPa and 29.41 GPa. As mentioned before, the bamboo and glass fibre hybrid laminated composite need to achieve an optimal LCP design that have modulus of elasticity closer to the human cortical bone. According to Zahra S. Bagheri, a goal may match the Young’s modulus of implants and bone with the latter for compact bone ranges between 10-30 GPa [8]. One layer bamboo and one layer glass fibre give the young modulus 24.67 GPa and 10.70 GPa respectively. It can observe that all the specimens show good result which the values are within the range of the human cortical bone. The bone plate with low stiffness material presents much less stress shielding to the bone, supplying greater compressive stresses at the fractured interface to set off accelerated restoration in comparison with metal alloy bone plate.

Table 2 shows the comparison of mechanical properties such as tensile strength, bending strength, Young modulus and flexural modulus between different materials. The material of this current study was compared with the existing material in the literature such as carbon fibre epoxy, banana and roselle hybrid, stainless steel and cortical bone. The results of the current study were within the range reported in the literature. The results of glass fibre was good in Young Modulus which close to the cortical bone. However, the tensile and bending strength was very low. Besides, one layer bamboo fibre also give a good result in tensile strength with range carbon fibre epoxy and higher than cortical bone but lower in bending strength compared to the carbon fibre epoxy. By comparing with the cortical bone, current hybrid composite matches the elastic modulus of the cortical bone and two to three times stronger in tensile strength. However, bamboo and glass fibre laminated composite was less stiff but strong when compared to stainless steel. Therefore, the bone plate with low stiffness material may be recommended for the long bone fracture treatment.

| Material                                      | Tensile Strength (MPa) | Bending Strength (MPa) | Young Modulus (MPa) | Flexural Modulus (MPa) |
|-----------------------------------------------|------------------------|------------------------|---------------------|-----------------------|
| Glass Fibre                                  | 99.91                  | 6.74                   | 10,700              | 190                   |
| Bamboo (1 Layer)                              | 290.08                 | 28.84                  | 24,670              | 1,630                 |
| Bamboo and Glass Fibre Hybrid Laminated Composite (2 to 3 layers) | 201.29-840.42         | 48.05-568.97          | 13,320-29,410       | 3,810-116,050         |
| Carbon Fibre Epoxy [3]                        | 46.94-377.49           | 60.62-240.19          | 6,000-21,000        | -                     |
Finally, other most important aspect that need to be consider is the biocompatibility of the new material to the human bone. The new material for the Locking Compression Plate (LCP) will be coated with the Epoxy where the biocompatibility test of the Epoxy has been conducted by Bagheri et. al. (2015) on CF/Flax/epoxy specimens which include cytotoxicity and osteogenesis tests. Findings obtained from the experiments shows approximately similar cell viability with no cytotoxicity at all incubation times to that of medical grade stainless steel. Furthermore, CF/Flax/Epoxy osteogenesis bone formation genes’ expression levels were enhanced compared to those induced by the control which indicates the hybrid structure potential to facilitate bone growth. To conclude the finding, this new material for the LCP is safe to be used for Tibia Fracture Treatment.

4. Conclusion
This study verifies that the developed bamboo and glass hybrid laminated composites showed that the enhanced mechanical (the improvement of the structure by adding the layers of the bamboo fibre) was successful. From the study above, we can conclude that bamboo and glass fibre laminated composite is an ideal candidate for design of a plate for fracture fixation system as the material properties 66% closer to the human cortical bone. This new material with low stiffness material than stainless steel offers less stress-shielding; thus provide faster healing of tibia fracture.

5. Acknowledgement
The authors would like to thank the Research Management Institute (RMI) of Universiti Teknologi MARA (UiTM) and Ministry of Education, Malaysia for financial support and facilitating this project support to this study through Research MITRA GRANT awards 600-IRMI/MYRA 5/3 (001/2017)-1.

6. References
[1] E. N. Kubiak, The Evolution of Locked Plates, *J. Bone Joint Surgery*, **Vol. 88**, No. 4, 2006, Page 189.
[2] M. S. Scholz et al., The use of composite materials in modern orthopaedic medicine and prosthetic devices: A review, *Composites Science and Technology*, **Vol. 71**, No. 16, 2011, Pages 1791-1803.
[3] R. M. Deshmukh and P. S. S. Kulkarni, Experimental investigation and prediction of mechanical properties of a composite material for bone plate application, *Int. J. Curr. Eng. Technol.*, **Vol. 4**, No. 16, 2015, Pages 4-8.
[4] P. Niemeyer and N. P. Sudkamp, Principles and clinical application of the locking compression plate (LCP), *Acta. Chir. Orthop. Traumatol Cech.*, **Vol. 73**, No. 4, 2006, Pages 221–228.
[5] D. L. Miller and T. Goswami, A review of locking compression plate biomechanics and their advantages as internal fixators in fracture healing, *Clinical Biomechanics*, **Vol. 22**, No. 10, 2007, Pages 1049-1062.
[6] Shuib, S., Ridzwan, M. I. Z., Mohammad Ibrahim, M. N., & Tan, C. T., Analysis of orthopedic screws for bone fracture fixations with finite element method. *Journal of Applied Sciences, Vol. 7*, No.13, 2007, 1748–1754.
[7] Z. M. Huang and K. Fujihara, Stiffness and strength design of composite bone plates, *Compos. Sci. Technol.*, **Vol. 65**, No. 1, 2005, Pages 73-85.
[8] Z.S. Bagheri, I. El Sawi, E.H. Schemitsch, R. Zdero, H. Bougherara, Biomechanical properties of an advanced new carbon/flax/epoxy composite material for bone plate applications, *J. Mech. Behav. Biomed. Mater.*, **Vol. 20**, 2013, Pages 398-406.
[9] M Sayer, NB Bektaş, O Sayman, An experimental investigation on the impact behaviour of hybrid composites plates, \textit{Compos. Struct.}, Vol. 92, 2010, Pages 1256-1262.

[10] A. M. Ballo, E. A. Akca, T. Ozen, L. Lassila, P. K. Vallittu, T. O. Närhi, Bone tissue responses to glass fiber-reinforced composite implants- a histomorphometric study, \textit{Clin. Oral Implants Res.}, Vol. 20, No. 6, 2009, Pages 608-615.

[11] M. Saranya, M. Suganya, R. Lalithadevi, and P. P. Selvam, Development of bone plate for fracture fixation, \textit{Vol. 3}, No. 3, 2014, Pages 53-56.

[12] R. M. Deshmukh and S. S. Kulkarni, A review on biomaterials in orthopaedic bone plate application, \textit{Int. J. Curr. Eng. Technol.}, \textit{Vol. 55}, No. 44, 2015, Pages 2587-2591.

[13] Z.S. Bagheri, E. Giles, I. El Sawi, E.H. Schemitsch, R. Zdero, H. Bougherara, Osteogenesis and cytotoxicity of a new Carbon Fiber/Flax/Epoxy composite material for bone fracture plate applications, \textit{Journal of Materials Science and Engineering}, \textit{Vol. 46}, 2015, Pages 435-442.