Epoxy-Coated of Bamboo Fibre Reinforced Polymer Composite for Uncemented Total Hip Replacement (THR) Application

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ABSTRACT

Uncemented total hip replacements (THR) have become increasingly prevalent in relieving pain related to human hip. However, this replacement is prone towards aseptic loosening due to stress-shielding phenomenon. This phenomenon occurs due to the usage of metallic implant which has higher stiffness compared to femoral bone. This study aims to create a new natural based material which has mechanical properties closer to femoral bone. Semantan (Gigantochloa Scortechinii) type of bamboo was used and subjected to a chemical treatment called epoxy coating prior to the fabrication of the composite as to increase the mechanical properties of the fibre. The mechanical and morphological characteristics of the bamboo fibre were studied. The result obtained shows that epoxy coating has increased the fibre-matrix adhesion and the stiffness was 3.66% closer to the femoral cortical bone.

Keywords: *Uncemented total hip replacement (THR); aseptic loosening; stress-shielding; bamboo fibre; epoxy coating.*

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Introduction

Total hip replacement (THR) has become a great procedure in relieving thigh pain. People who suffer with osteoarthritis are often associated with hip replacement [1], [2]. The symptoms of hip arthritis like thigh pain has limited the human daily activities such as standing, walking, stair climbing or even jumping. THR is a procedure where diseased or damaged femoral head is removed and replaced with artificial implant [3]. THR may be divided into two types which are cemented and uncemented THR. Uncemented THR has been introduced later due to some drawbacks of cemented THR [4]. Uncemented THR was performed using press-fit technique. Typically, the artificial implant was associated to be used in a long period; however, most of the patients that went through THR will undergo revision after 15 years utilizing their new hip due to some cases. The most reported case in uncemented THR was aseptic loosening [5]. Stress shielding is the major factor that leads to aseptic loosening [6], [7]. This phenomenon occurs when metal implants are used in joint replacement. The femoral bone will resorp (bone resorption) due to high stiffness of implant properties [8]-[10]. Stress shielding can be reduced by decreasing the stiffness of the implant properties [11], [12]. Due to this limitation, it is essential to develop a new orthopedic material-like composite that has material properties closer to the natural bone.

Recently, composite materials have become a trend in replacing the metal materials in various engineering applications in many industries which include transportation, aerospace and more due to its promising benefits. The benefits of using natural fibre may include low cost, lightweight, renewable resource, biodegradability and relatively high tensile and flexural modulus [13]-[15]. Furthermore, medical implant is one of the fields that has growing interest in the utilization of composite materials as it gives lots of benefits to them [16]. Among the various natural fibres, bamboo fibre is a good candidate to be used as natural fibre in composite material [17]-[19]. The properties of bamboo are quite similar to wood, but it is easier to form, and bend compared to wood [20]. Hence, Semantan (Gigantochloa Scortechinii) type of bamboo was selected to be used in this current study due to its abundant availability in Malaysia particularly. Since the bamboo has a naturally high amount of hydroxyl side (-OH), it will exhibit high moisture content absorbed into its structure. The problem arises when this untreated bamboo is fabricated into a composite structure as it will cause incompatibility factor especially between the bamboo surfaces and matrix. It can be seen with the formation of ‘gaps’ or ‘voids’ formed inside the composite’s structure that give low surface interaction that is able to reduce the composite’s properties. Hence, a surface treatment is required to reduce this effect to the composite’s end properties. Thus, the suggested surface treatment is by employing the simple and cost-effective epoxy treatment that by far few researches have conducted [21], [22].

Materials and Methods

Materials

Raw Semantan bamboo (Gigantochloa Scortechinii species) were used as the reinforcement supplied by Terra Techno Sdn. Bhd. (TTE), Malaysia. Figure 1 illustrates the anatomy of bamboo culm where its full length was labelled at the node and internode part. The internode part of the bamboo culm was taken and processed into strips form with specific dimensions (length= 500mm, width= 10mm and thickness= 2mm) by using splitting machine while the node part was removed.

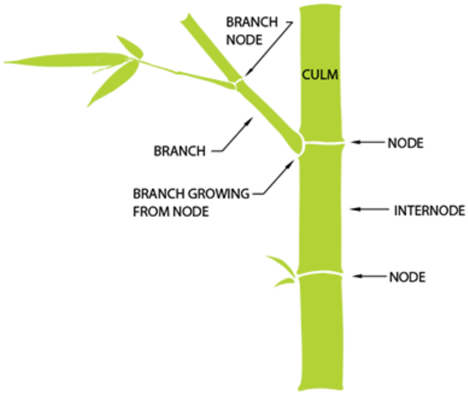


Figure 1: Anatomy of bamboo culm

As for the treatment matrix, the epoxy resin and hardener code name CP 362 obtained from Vistec Technology Sdn. Bhd were used. Table 1 shows the physical characteristics of both epoxy and hardener used in the current study. Meanwhile the acetone, with chemical formula CH3O2 was supplied by Polyscientific Enterprise Sdn. Bhd.

Table 1: The physical characteristics of CP 362 epoxy resin adapted from [23]

Part	Code	Chemical Type	Viscosity (cps)	Color	Gel Time (25°C)	Post Cure (25°C)	Final *vis (cps)
Epoxy	CP 362	Epoxy DGEBA	13,000	trans.	35 Mins	9.5 Hours	8500
Hardener		Modified Polyamine	400	trans.			

+trans. → transparent
*vis → Viscosity

Chemical Treatment

Figure 2 illustrates the details of processing flow for the uncoated and epoxy-coated/treated bamboo strips. The chemical treatment started by preparing the chemical solution. The epoxy and hardener were mixed (within gel time) with suggested ratio of 2:1 by weight prior diluted using acetone with 1:5 ratio. Next, the bamboo strips were immersed into the epoxy dilution with the immersion time of 5 minutes at room temperature. During this process, the bamboo strips were treated where all the impurities were removed and simultaneously giving a thin layer of epoxy coating to the bamboo strips in order to improve the mechanical properties. The epoxy coated of bamboo strips were finally taken out and oven-dried for 24h with temperature of 80 degree Celsius.

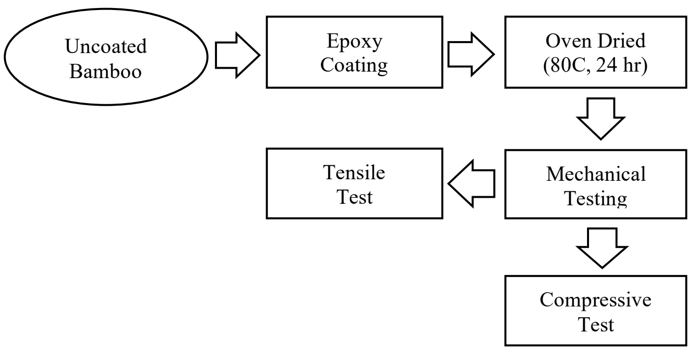


Figure 2: Processing flow chart of coated bamboo strips

Sample Preparation

Five test specimens were prepared for each uncoated and epoxy-coated/treated bamboo strips. For tensile test, the specimens were prepared as ASTM D638-10. The samples was set to be having 80 mm of edge length, 70 mm of grip length; 35 mm on the both end of sample, width of 10 mm and thickness of 2 mm. For compressive test, the dimensions of the sample specimens were: length= 75 mm, width= 10 mm and thickness= 2mm as per ASTM standard D695.

Mechanical Testing

Five specimens for both uncoated and epoxy-coated/treated bamboo strips were tested in order to evaluate their tensile strength and compressive strength. Moreover, tensile test was carried out to obtain the other mechanical properties of the bamboo strips such as modulus of elasticity and also Poisson ratio. Tensile and compressive tests were conducted by using SHIMADZU Universal Testing Machine (AGX-20 kN) as referred to ASTM D 638 and ASTM 790. For tensile test, the specimens were positioned vertically centre of the crosshead grip. The Poisson ratio jig was then attached at the edge length of specimen. The load cell was set to stop at the 8 mm length to avoid the Poisson jig from breaking. For compressive test, the specimen was attached tightly between the compression plates and placed on the machine's platform. During the compression process, the attached sample was compressed by upper compression plate within 3 mm length range where it will stop automatically to avoid the compression jig being compressed. Table 2 shows the process used to evaluate the mechanical properties.

Table 2: Process used to evaluate the mechanical properties of bamboo strips

Mechanical Properties	Machine	Cross head Speed (mm/min)
Tensile strength	SHIMADZU Universal Testing Machine	5mm/min
Modulus of elasticity	SHIMADZU Universal Testing Machine	5mm/min
Poisson ratio	SHIMADZU Universal Testing Machine	5mm/min
Compressive strength	SHIMADZU Universal Testing Machine	1.3mm/min

Scanning Electron Microscope (SEM)

Hitachi Scanning Electron Microscope (SU3500) was used to examine the fractured surface of the bamboo strips after subjected to the mechanical testing. The fractured specimens with dimension of length= 20 mm and width= 10 mm were prepared for the observation. The specimens were then coated with a thin layer coating of platinum using sputter coater. The specimens were observed at an accelerating voltage of 3kV with magnification range of 20x to 150x.

Results and Discussion

Table 3 shows the mechanical properties obtained from the tensile and compressive test for uncoated and epoxy-coated bamboo strip. The uncoated bamboo strip has 12.58 GPa, 277.19MPa, 72.71 MPa and 0.16 for young's modulus, tensile strength, compressive strength and Poisson ratio, respectively. For the epoxy-coated bamboo strip, the mechanical properties obtained were 14.74 GPa, 228.07 MPa, 102.58 MPa and 0.17 for young's modulus, tensile strength, compressive strength and Poisson ratio, respectively. The tensile strength of the bamboo strip slightly decreased after subjected to the epoxy treatment indicating fibre degradation [21], [22]. The chemical treatment has removed some of the hemicellulose of the bamboo fibre. However, the compressive strength for the epoxy-coated bamboo strip was higher than the uncoated bamboo strip. The major factor on the increasing of compressive strength was the presence of thin epoxy. It is important to have higher compressive strength as the major load at the human lower limb was compression in vertical direction/ orientation.

Table 3: Mechanical properties values of the uncoated and epoxy-coated/treated bamboo strips

Mechanical Properties	Uncoated	Coated
Young's Modulus (GPa)	12.58	14.74
Tensile Strength (MPa)	277.19	228.07
Compressive Strength (MPa)	72.71	102.58
Poisson Ratio	0.16	0.17

Figure 3 shows the fractured specimens after tensile test for uncoated and epoxy-coated bamboo strip. As seen in figure 3(a), the uncoated bamboo strip was completely damaged after being pulled. The fibers were also dispersed and separated indicating weak fiber bonding. In contrast, the failure behavior involved for epoxy-coated bamboo strip was fiber breakage in vertical orientation. The bamboo fiber only slid after being pulled. There was no fiber separation can be seen. This indicates the epoxy coating has protected the fiber structure from being damaged.

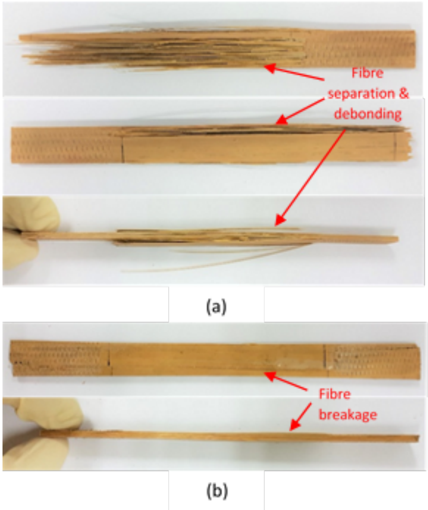
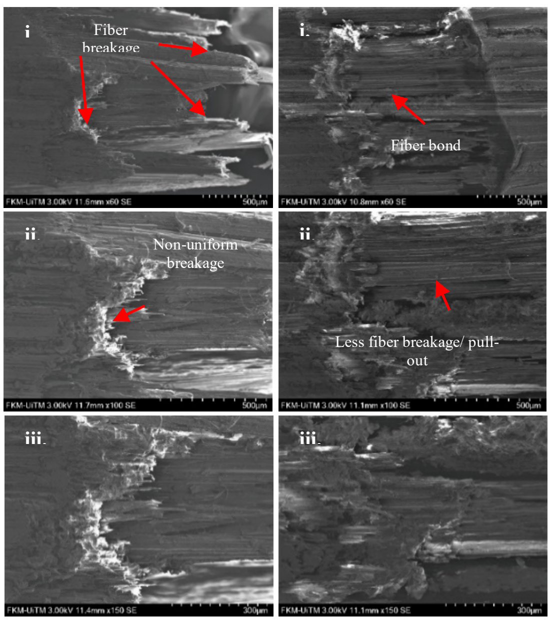


Figure 3: Fractured specimens after tensile test for (a) uncoated bamboo strip (b) epoxy-coated bamboo strip

Figure 4 shows the SEM images captured for (a) uncoated single bamboo strip and (b) Epoxy-coated/treated single bamboo strip after tensile test with magnification of 60x, 100x, and 150x, respectively. Based on the micrograph in Fig. 4(a), it strongly showed the evidence of fibre pull-out and breakage, which indicated poor bonding among the fibre itself that led to low fibre-epoxy adhesion. Besides that, the fibre breakage occurred was also rough and non-uniform. Conversely, the Epoxy-coated/treated single strip showed strong evidence that the bamboo fibre did not completely pull-out and break after being pulled under tensile test which indicated strong bonding between the fibres itself (Fig. 4(b)). The epoxy treatment has given a thin layer of coating which protected the fibre structure. Besides, the epoxy treatment has also increased the fibre-epoxy adhesion and consequently increased the strength and bonding of the fibre.



(a) (b)

Figure 4: SEM images of fracture after tensile test for (a) uncoated single strip bamboo (b) Epoxy-coated/treated single strip with magnification of 60x, 100x and 150x

Figure 5 provides the SEM micrographs of (a) untreated single strip bamboo fibre and (b) Epoxy-coated/treated single strip bamboo fibre after compressive test with magnification of 20x, 60x, and 100x, respectively. As can be seen in Figure 5(a), fibre delamination occurred after being compressed and it was ununiformed in the event that the bamboo fibre structure was not protected. Besides, the texture of fractured bamboo fibre was rough. On the other hand, there was surface separation of the bamboo fibre and fibre debonding for the Epoxy-coated/treated of single bamboo strip (Figure 5(b)). However, the fibre debonding was uniform compared to the untreated bamboo fibre indicating the epoxy coating has added "plastic" properties to the composite system which consequently increased the compressive strength.

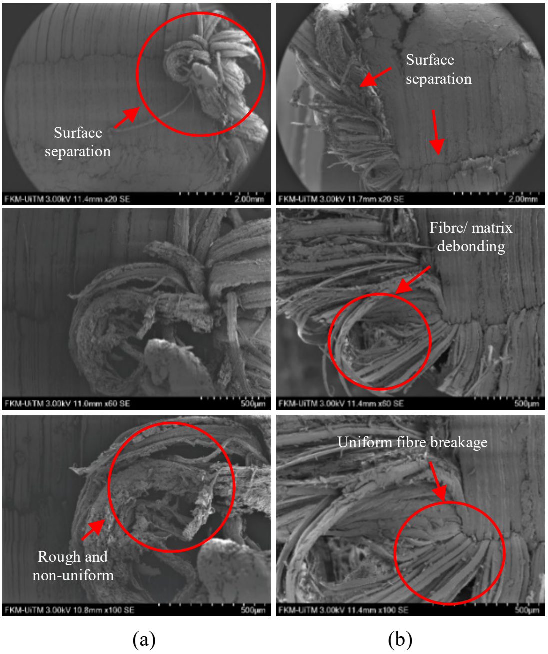


Figure 5: SEM images after compressive test of (a) uncoated single strip bamboo (b) Epoxy-coated/treated single strip bamboo with magnification of 20, 60x and 100x

Conclusion

The following findings can be highlighted from the results of the present study:

- The modulus of elasticity for the epoxy-coated bamboo strip was 14.74 GPa. Meanwhile the modulus of elasticity of cortical bone was 14.20 GPa. Thus, the percentage similar was about 3.66%.

- Although the mechanical properties of the bamboo strip decreased compared to the uncoated bamboo strip, the epoxy coating has controlled the failure behaviour of the fibre.
- The epoxy treatment has successfully treated (prove by fibre degradation) and produced a thin layer of epoxy coating to the bamboo fibres (protect the fibre structure and increase the fibre bonding).

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References

[1] S. Shuib, N. F. Ismail, M. A. Yahaya, "Analysis of an improved hybrid stem design for total hip replacement (THR)," J. Mech. Eng., vol. 5(5), 2018, pp. 205–215.
[2] N. F. Ismail, S. Shuib, M. A. Yahaya, A. Z. Romli, A. A. Shokri, "Finite element analysis of uncemented total hip replacement: The effect of bone-implant interface," Int. J. Eng. Technol., vol. 7(4), 2018, pp. 230–234.
[3] K. Colic, A. Sedmak, A. Grbovic, U. Tatic, S. Sedmak, and B. Djordjevic, "Finite element modeling of hip implant static loading," Procedia Eng., vol. 149, 2016, pp. 257–262.
[4] M. T. Bah et al., "Inter-subject variability effects on the primary stability of a short cementless femoral stem," J. Biomech., vol. 48(6), 2015, pp. 1032–1042.
[5] A. Halim Abdullah, N. M. Mohsien, M. Syahmi Yusof, N. Aznan, and S. Hisyam Marwan, "Effects of stem malalignment in cementless hip arthroplasty: A computational study," int. j. eng. technol., vol. 7(4.27), 2018, pp. 137.
[6] G. Green, M. Khan and F. Haddad, "Why do total hip replacements fail ?," Orthop. Trauma, vol. 29(2), 2014, pp. 79–85.
[7] D. L. Millis, "Responses of musculoskeletal tissues to disuse and remobilization," Canine Rehabil. Phys. Ther., 2014, pp. 92–153.
[8] M. I. Z. Ridzwan, S. Shuib, A. Y. Hassan, A. A. Shokri, and M. N. Mohammad Ibrahim, "Problem of stress shielding and improvement to the hip implant designs: A review," Journal of Medical Sciences, vol.7(3), 2007, pp. 460–467.
[9] H. Kawaji, T. Uematsu, R. Oba, N. Hoshikawa, H. Watanabe, and S. Takai, "Influence of femoral implant alignment in uncemented total hip

replacement arthroplasty: Varus insertion and stress shielding," vol. 83(6), 2016, pp. 223–227.
[10] S. Shuib, N. Faiqa Ismail, M. Nazif Nazri, and A. Zafir Romli, "Bamboo and glass fibre hybrid laminated composites as locking compression plate (LCP) for tibia fracture treatment," J. Phys. Conf. Ser., vol. 1150 (1), 2019.
[11] D. R. Sumner, "Long-term implant fixation and stress-shielding in total hip replacement," J. Biomech., vol. 48(5), 2005, pp. 797–800.
[12] M. N. Ahmad, S. Shuib, A. Y. Hassan, A. A. Shokri, M. I. Z. Ridzwan, and M. N. M. Ibrahim, "Application of multi criteria optimization method in implant design to reduce stress shielding," Journal of Applied Sciences, vol. 7(3), 2007, pp. 349–355.
[13] Y. Xie, C. A. S. Hill, Z. Xiao, H. Militz, and C. Mai, "Silane coupling agents used for natural fiber/polymer composites: A review," Compos. Part A Appl. Sci. Manuf., vol. 41(7), 2010, pp. 806–819.
[14] D. Liu, J. Song, D. P. Anderson, P. R. Chang, and Y. Hua, "Bamboo fiber and its reinforced composites: Structure and properties," Cellulose, vol. 19(5), 2012, pp. 1449–1480.
[15] P. Wongsriraksa, K. Togashi, A. Nakai, H. Hamada, "Continuous natural fiber reinforced thermoplastic composites by fiber surface modification," Adv. Mech. Eng., 2013, Article ID 685104.
[16] M. S. Scholz et. al., "The use of composite materials in modern orthopaedic medicine and prosthetic devices: A review," Compos. Sci. Technol., vol. 71(16), 2011, pp. 1791–1803.
[17] C. A. Fuentes, G. Brughmans, L. Q. N. Tran, C. Dupont-gillain, I. Verpoest, and A. W. Van Vuure, "Mechanical behaviour and practical adhesion at a bamboo composite interface : Physical adhesion and mechanical interlocking," Compos. Sci. Technol., vol. 109, 2015, pp. 40–47.
[18] S. A. Bahari, M. Ahmad, K. Nordin, and M. A. Jamaludin, "Analysis on strength behaviour of malaysian bamboo species," AIP Conference Proceeding, vol. 2007, 2010, pp. 462–467.
[19] J. Atanda, "Environmental impacts of bamboo as a substitute constructional material in Nigeria," Case Studies in Construction Materials, vol. 3, 2015, pp. 33–39.
[20] N. Z. Jusoh, M. Ahmad, A. Ibrahim, "Study on compressive strength of semantan bamboo culm (Gigantochloa scortechinii)," 330, 2013, pp. 96–100.
[21] M. M. Owen, U. S. Ishiaku, A. Danladi, B. M. Dauda, A. Z. Romli, "The effect of surface coating and fibre loading on thermo-mechanical properties of recycled polyethylene terephthalate (RPET)/ epoxy-coated kenaf fibre composites," AIP Conference Proceeding, vol. 1985, 2018, pp. 030002.
[22] M. M. Owen, U. S. Ishiaku, A. Danladi, B. M. Dauda, A. Z. Romli,

"Mechanical properties of epoxy-coated sodium hydroxide and silane treated kenaf/recycled polyethylene tereph-thalate (RPET) composites: Effect of chemical treatment," AIP Conference Proceeding, vol. 1985, 2018, pp. 030001.
[23] Epoxy resins [Online]. http://www.orientaloption.com/epoxy.htm. (Accessed 04.10.18).