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TENSILE AND FLEXURAL STRENGTH OF RAMIE FIBER REINFORCED EPOXY COMPOSITES FOR SOCKET PROSTHESIS APPLICATION

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ABSTRACT

The aim of this study is to develop a socket prosthesis made from natural fibers, especially ramie fiber reinforced epoxy composite (RE). Development of socket prosthesis with RE was carried out as an attempt to substitute socket prosthesis with fiberglass polyester composites (FGP). The process of socket prosthesis production was conducted by using filament winding method. In this study tensile and flexural tests were applied to a specimen chopped from the prototype of socket prosthesis. As a comparison, separate tests applied to each socket prosthesis made of ramie polyester composites (RP) and FGP were conducted. The results showed that socket prosthesis made of RE has highest tensile and flexural strengths when compared to RP and FGP composite materials. The tensile strength and Young's Modulus of RE composite materials are 86 ± 6.07 MPa and 9.56 GPa. The flexural strength of RE composite materials is 103 ± 15.62 MPa. RE composite material have the potential to be further developed as an alternative material of socket prosthesis particularly for tensile and flexural properties which locally available, bio mechanically appropriate, can be designed as lightweight as possible, comfortable to be used and psychosocially acceptable.

Keywords*:* Ramie fiber, epoxy, socket prosthesis, tensile strength, flexural strength.

1. INTRODUCTION

Indonesia is one of the countries producing natural fibers. Various types of natural fibers such as ramie fiber, banana fiber, coconut fiber, rice fiber kenaf bast, bamboo fiber, sisal fiber, pineapple fiber can be found in large numbers (Jamasri, 2008). Natural Fiber Composites (NACO) is a potential material to be developed and used as alternative substitute materials of conventional materials such as metals and synthetic fibers composites. Natural fiber is a material that can be recycled, more environmentally friendly, potentially abundant, less costly than synthetic fibers and green composites (Lina et al., 2008; Rashdi et al., 2010). As such, it can support the concept of go green and back to nature (Sastra et al., 2005; Kaczmar et al., 2007; Ratna et al., 2009). One type of natural fiber with the potential to be developed is ramie fiber. Ramie fiber is one of natural fibers which have good mechanical properties. There are some advantages of using ramie fiber as biomaterial such as a good specific strength, light, readily available (local genius), renewable, environmentally friendly (green composite), low cost, healthy, skin-irritation free, comfortable, and good at interfacial with resin (Torres et al., 2004; Maya et al., 2006; He et al., 2008). In this study, ramie fiber composites were developed as an alternative material for the socket prosthesis. Currently in Indonesia, the socket prosthesis made of fiberglass composite material. Some of the weaknesses of fiberglass among others less elastic, expensive, not good for health, not environmentally friendly, imported products, poor resistance to solvents, poor bonding to resins (Agustinus et al., 2009; Daniel et al., 2001). Disadvantages of fiberglass as a prosthesis socket material can be improved by ramie fiber. In the development of a prosthetic foot, according to John Craig (2005), prosthetists worldwide generally must consider the psychosocial impact of replacing the human foot with an artificial one of acceptable cost and function. In most low income countries, there may be only one, or at best a few, option from which to choose. Use of ramie fiber is one attempt to provide an alternative for patients to choose the socket prosthesis according to his needs and low prices. This is in line with the recommendations from Poonekar (1992) regarding ideal criteria for appliance to be appropriate technology in developing countries: low cost, locally available, capable of manual fabrication, considering local climate and working conditions (barefoot or sandal wear including rice farming in wetted fields), durable, simple to repair, simple to process using local production capability, reproducible by local personnel, technically functional, bio mechanically appropriate, as lightweight as possible, adequately cosmetic, and psychosocially acceptable.

Based on the recommendation in above (John Craig, 2005; Poonekar, 1992), this research was conducted. The goal of this research was to develop socket prosthesis made from ramie fiber reinforced epoxy composites (RE). RE will be used as alternative materials to substitute the Fiberglass reinforced Polyester (FGP). FGP is a prosthesis socket material used in several hospitals in Indonesia. Comparison materials were FGP and ramie fiber reinforced polyester composite (RP). The study was conducted by comparing the tensile and flexural strength of RE, RP and FGP. The socket prosthesis material must have both high tensile and flexural strength. These properties are needed, to ensure socket prosthesis durability under a dynamic load, usage safety, damage possibility (Sam et al., 2005). Besides to compare the tensile and flexural strength, a test was needed, so that a better alternative material of socket prosthesis can be obtained.

2. MATERIAL AND METHOD

2.1 Ramie Fiber Preparation

Ramie fiber used in this study is a continuous ramie fiber in the form of 100 % ramie threads produced by a manufacturer in Tangerang, Indonesia. Ramie fibers were immersed in 5% NaOH solution for 2 hours at room temperature by manufacturer. After the alkaline treatment, ramie fibers were thoroughly washed by immersion in water tanks, followed by running water. To reduce the decay, the manufacturer has conducted treatment using silane (amino-ethyl-propyl amino silane trimetoxy), so the fiber is stronger and more durable.

2.2 Fabrication of Laminate Composites

RE and RP composite laminates (socket prosthesis prototype) were produced in a filament winding process with dry winding (fiber to matrix ratio 40:60 by weight) in room temperatures (25-30C^0) by adding a pressure and vacuum process during lamination to reduce void. The socket prosthesis prototype (RE) produced with six layers, a symmetrical fiber orientation, thickness (t) : 4 mm. The epoxy and hardener were then mixed in the ratio 1:1. The socket prosthesis prototype (RP) produced with six layers, a symmetrical fiber orientation, thickness (t) : 4 mm. The polyester mixed 2% (v/v) hardener. FGP composite laminates were produced in a hand lay up process (mat lamination process) with thickness (t) : 4 mm in room temperatures (25-30C^0) by adding a pressure and vacuum process during lamination to reduce void.

2.3 Specimen Test Preparation

Samples test was produced by cutting the socket prosthesis prototype (RE, RP and FGP). All samples test was produced conforming to the ASTM D 3039 for tensile testing and ASTM 790-03 for flexural testing (ASTM, 2002). Before the test was conducted, all test samples were conditioned in accordance with room temperatures of 23 ± 2^0C with relative humidity 50 ± 5% during 24 hours.

2.4 Tensile Testing

Tensile testing is referred to the ASTM D 3039 standard by using the Universal Testing Machine Shimadzu AGS-10k NG, room temperature 23^0C, relative humidity of 61%. The cross-head speed for tensile testing was 2 mm/min. The dimensions of the specimens for tensile testing were 250 x 25 x 4 mm (length x width x thickness). Six samples were tested for tensile testing. The average values were reported including standard deviations. The position of the samples and the process of tensile testing as shown in Figure 1. Each sample was loaded to failure. Based on tensile testing will be obtained for tensile strength and Young's Modulus of the socket prosthesis material. (ASTM, 2002).

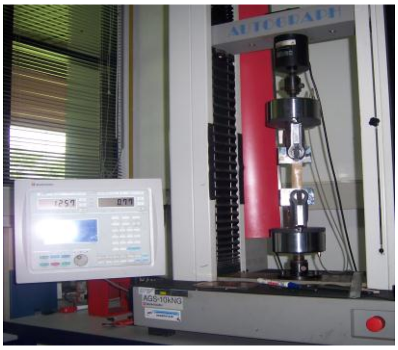

Figure 1 Tensile specimen test

2.5 Flexural Testing

Flexural testing is referred to ASTM D 790-03 standard by using the Universal Testing Machine Shimadzu AGS-10kNG, testing room temperature 23.7^0C, relative humidity of 62%. The load was applied midway between the supports with a crosshead speed of 1.7 mm/min (Figure 2). Each sample was loaded to failure. The dimensions of the specimens for flexural testing were 120 x 10 x 4 mm (length x width x thickness). Six samples were tested for flexural testing. The average values were reported including standard deviations. (ASTM, 2002).

Figure 2 Flexural specimen test

2.6 SEM Analysis

Fracture surface of composite samples were observed on a scanning electron microscope (SEM). The SEM was operated at an accelerating voltage of 10 kV.

2.7 Static Comfort Testing

Each socket prosthesis prototype was tested to determine socket comfort level of the static test. Respondents were asked to use socket prosthesis and evaluate the comfortability of each socket prosthesis. Test results were compared between RE, RP and FGP composite materials.

3. RESULT AND DISCUSSION

3.1 Tensile Strength

Table 1 represent the result obtained from tensile testing of the specimens. RE composite presented a tensile strength of 86 ± 6.07 MPa, RP of 67 ± 5.11 MPa and FGP of 62 + 4.20 MPa. It is shown that the tensile strength which is resulted from RE is highest than that of RP (28.36%) and FGP (38.71%). Several factors can greatly effect the strength and performance of composite materials. The adhesion at interface between the resin and fiber, and the mechanical properties of the resin and fiber, greatly effect composite performance. The fiber length, orientation and ratio of the fiber to resin, and processing techniques used to fabricate the composite also effect composite performance (Douglas *et al*., 1992). In case of RE composite material, several factors that led to better tensile strength of RP and FGP materials: good interface between the resin and fiber (Maya *et al*., 2006), a combination of ramie fiber and epoxy matrix results in a stronger bounding, so that it is less damageable with a large load. The increases of fiber length and fiber content can improve the tensile strength and flexural strength (He *et al*., 2008).

Ramie fiber used in this study is a continuous fiber. Ramie fibers were immersed in 5% NaOH solution for 2 hours at room temperature. Alkali treatment of composites resulted in higher storage modulus values due to increased crosslinking and formation of a strong fiber/matrix interface (Maya *et al*., 2006). Another thing that causes a bigger tensile strength of RE is the process of manufacturing by filament winding. The filament winding process produces the bond ramie fiber and epoxy matrix stronger (Autar, 2006). RE produces an Young's Modulus of 9.56 GPa highest compared to RP (7.45 GPa) and FGP (6,49 GPa). High Young's Modulus will result in a total contact socket and produces a better comfort level for patients. This condition should be considered in selecting of socket materials. Traditional sockets are usually made from rigid materials although some prefer a flexible socket (high Young's Modulus) supported by rigid frame as it provides better comfort during walking and sitting (Campbell, 2002).

Compared to Sam *et al*. (2005) findings related to laminate composites used as Prosthetics and Orthotics, RE composite material can be included in the middle group which has a maximum tensile strength of 67-109 MPa and an elasticity modulus of 5.0 – 17.3 GPa (Table 2). Based on tensile strength and Young's Modulus, RE composite material have the potential to be developed as socket prosthesis material substitute FGP composite material.

Table 1 Tensile strength and Young's Modulus of socket materials

Socket Materials	Tensile Strength (MPa)	Std. Dev	Young's Modulus (GPa)	Std. Dev
RE	86	6.07	9.56	0.68
RP	67	5.11	7.45	0.57
FGP	62	4.20	6.89	0.47

Table 2 Plotting tensile strength and Young's Modulus of RE, RP and FGP in ultimate tensile strength group (Sam *et al*., 2005)

Strength Range	Fiber Types	UTS Range (MPa)	Young's Modulus (GPa)
Low	Perlon, nylon, cotton, nyglass, spectralon	18 – 42	1.8 – 5.1
Middle	Glass	67 – 109	5.0 – 17.3
	RE	86 ± 6.07	9.56 ± 0.68
	RP	67 ± 5.11	7.45 ± 0.57
	FGP	62 ± 4.20	6.89 ± 0.47
High	Carbon	236 – 249	20.6 – 25.5

3.2 Flexural Strength

The flexural strength of socket materials is presented in Table 3. The flexural strength of RE composite material is 103 ± 15.62 MPa. This result is highest compared to the RP composite material (84.8 ± 6.93 MPa) and FGP composite material (79.04 ± 0.134). A combination of natural fiber and epoxy matrix results in a better elasticity than that of RP and FGP composite materials. However, the property of polyester matrix, which tends to be hard and brittle when compared to epoxy matrix, results in a combination with flexural strength lower than RE composite material. Flexural strength from socket prosthesis is needed to support the body weight and the extreme movement, which may happen from the process of walking and other dynamic activities of the users (Winson *et al*., 2004).

Several factors can greatly effect the strength and performance of composite materials, especially in flexural strength. These results indicate that the combination of ramie fiber and epoxy that fabricate by filament winding process can produce a higher flexural strength (Autar, 2006). The filament winding process was produce the bond ramie fiber and epoxy matrix stronger and not easily damaged by flexural loads are acceptable. An improvement of the interfacial adhesion between the fibers and matrix will improve the mechanical properties of composites through an efficient load transfer between the fibers and the matrix (Al-Kaabi *et al*., 2005). This property is very suitable to the needs of the material was applied to the socket prosthesis materials. The material requirements for socket prosthesis are a material must be able to receive dynamic loads, strong, elastic and lightweight (Campbell, 2002). Based on flexural strength, RE composite material have the potential to be developed as socket prosthesis material substitute FGP composite material.

Table 3 Flexural strength of socket materials

Socket Materials	Flexural Strength (MPa)	Std. Dev
RE	103	15.62
RP	84.8	6.93
FGP	79.04	0.14

3.3 Morphological Analysis

To observe broken patterns, results from the lamination process and the possibility of void occurrence on RE, RP and FGP are morphologically analyzed by using Scanning Electron Microscope, SEM. From the SEM results of RE (Figure 3), it is shown that there is no presence of void because the RE laminate making process was done by giving the press and vacuum process. The broken fibers indicate that fibers will break after enduring a bigger tensile load and having fewer occurrences of fiber pull outs. This indicates that fibers have a bigger Young's Modulus and will be damaged after receiving a maximum load preceded by a length extension. This condition is in accord with what has been explained in the above tensile and flexural tests.

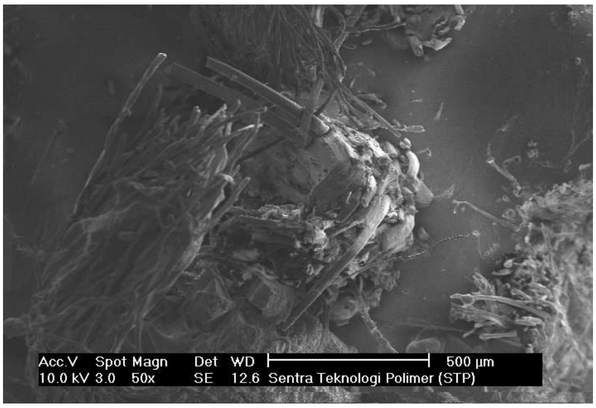

Figure 3 SEM micrographs of RE (50x)

Based on SEM results for RP composite material having fiber pull-out which indicates that the RP is a brittle material (Figure 4). FGP SEM results showed that composite materials have delamination and debonding which indicate that the bond between fiber and matrix is poor (Figure 5).

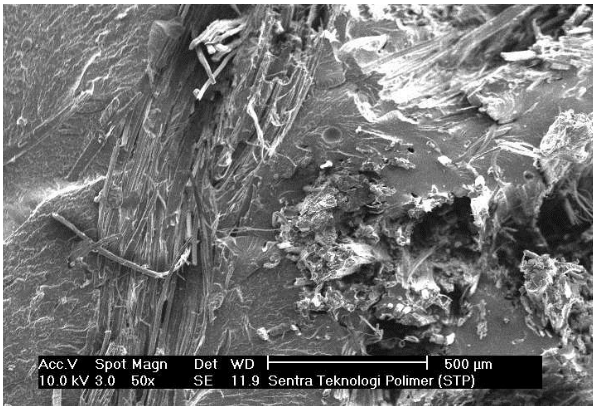

Figure 4 SEM micrographs of RP (50x)

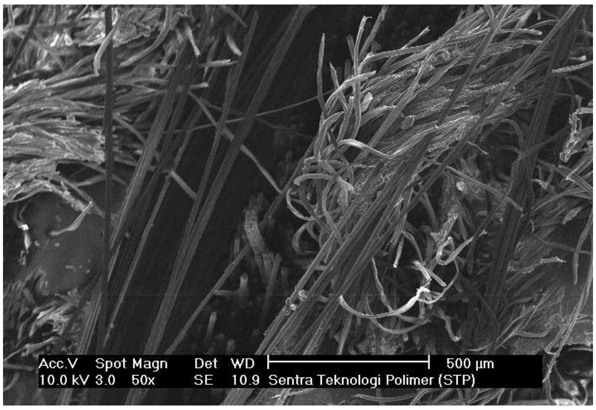

Figure 5 SEM micrographs of FGP (50x)

3.4 Static Comfort Testing

The socket prosthesis prototype of RE composite material was experimented to the patients (the respondents of this study) as shown in Figure 6. The experiment conducted showed that socket prosthesis of RE composite material is more comfortable to be used by the patients because it has a biggest elasticity than that of RP and FGP composite materials.

Figure 6 Static comfort test of socket prosthesis

Young's Modulus of materials and socket design greatly affect the total contact socket. With a total contact socket, the prosthesis users more easily in the move because of the weight transmitted to the socket with smooth and friction between the stump and the socket can be avoided. Patients feel more comfortable with a total contact socket, more confident and feel safer, so that a greater level of confidence in the use of prosthesis for walking activities. This conditions are supported by the tensile strength, Young's Modulus and flexural strength from RE composite material.

4. CONCLUSION

In this study, mechanical properties particularly for tensile and flexural properties of RE, RP and FGP composites materials for socket prosthesis materials are described. On the basis of the experimental evidence, the conclusions are as follows: The tensile strength and elasticity modulus of RE composite materials are 86 ± 6.07 MPa and 9.56 GPa has the highest value compared to RP and FGP composite materials. The flexural strength of RE composite materials is 103 ± 15.62 MPa has the highest value compared to RP and FGP composite materials. The result of present study have showed that RE composite material have the potential to be further developed as an alternative material of socket prosthesis substitute socket prosthesis with fiberglass polyester composites (FGP), which are locally available, bio mechanically appropriate, as lightweight as possible, comfort and psychosocially acceptable.

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