Mechanical Characteristics of Rattan Reinforced Fiberglass and Epoxy Composites for Shank Prosthesis Application

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Mechanical Characteristics of Rattan Reinforced Fiberglass and Epoxy Composites for Shank Prosthesis Application

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***Abstract*—This research aims to develop a rattan laminated fiberglass epoxy resin materials (RLFERM) to increase of mechanical strength especially in tensile, compressive, impact and flexural strength. The RLFERM will be used as an alternative material for shank prosthesis endoskeletal type and another use in engineering design. This research is related to the utilization of the natural potential of Indonesia especially of rattan. The method used to produce the endoskeletal material by using laminated process of rattan with fiberglass and epoxy resin. The test conducted involves the tensile, compressive, impact and flexural strength. The result showed that there was an increase in strength of RLFERM compared with rattan without lamination (Natural Rattan, NR). Tensile strength of RLFERM (80.2 MPa) and E = 8.6 GPa increased by 67.8% when compared to the tensile strength of NR (47.8 MPa) and E = 6.4 GPa. Compressive strength of RLFERM increased 47.2%, from 31.8 MPa to 46.8 MPa, impact strength of RLFERM increased 64%, from 39 kJ/m^2 to 64 kJ/m^2, and flexural strength of RLFERM increased on average by 53% from 54.1 MPa to 82.3 MPa. Increasing strength of RLFERM is obtained from good interface between surface of rattan with fiberglass and epoxy resin as laminate. The first prototype of lower limb prosthesis with a shank prosthesis endoskeletal type of RLFERM, have been made with good results and tested for use by patient. The test results indicate that the lower limb prosthesis with a shank prosthesis components made from RLFERM can be used by patients to walk properly and has good strength. This result will be a reference for further research in the development of a shank prosthesis made from rattan and another use in engineering design.**

Keyword-Rattan, Laminated, Mechanical strength, Shank, Endoskeletal type

I. Introduction

Indonesia have many potential of natural materials such as rattan, bamboo, wood, and natural fiber [1]-[3]. This potential has not been fully used in the design and development of manufacturing products of high added value. In this study, we have developed an alternative materials for the product of shank prosthesis (lower limb prosthesis), specifically in endoskeletal type by using rattan material.

Lower limb prosthesis is divided into above knee and below knee prosthesis, performed by amputation [4]. Research and design of lower limb prosthesis continues to grow and has gained a new invention including materials, design, installation method, gait analysis and evaluation of the performance of the prosthesis after being used in a certain period of time by the patient. Stark [5] stated that the development of modern prosthetic should consider a few things such as functions, indications, and cost. Innovation prosthetic requires more knowledge in the field of foot physiologic function and more descriptive terminology. Five things that should be considered are load bearing, leverage, shock absorption, balance, and protection [5].

Campbell [6], Faulker *et al* [7], Khazraji *et al* [8] stated that a variety of materials have been used in the development of a prosthesis, such as metals, polymers, composites, and natural materials such as wood and leather. Material selection is not only concerned with functional requirements, but also the price, manufacturing processes, availability of materials and ease of repair and maintenance [9]. Irawan *et al* [1] has developed a socket made from ramie fiber reinforced epoxy composites. Sockets made from ramie fiber reinforced epoxy composites generate good strength and comfort for the patient. Socket component is also developed by using bamboo fiber composite, rattan fiber composite and banana composite materials [2], [10], [11]. Natural materials have the potential to develop as materials for lower limb prosthetic component.

An important component of the lower limb prosthesis is shank prosthesis. Some of the materials used to make the component of the shank are aluminum, titanium, mild steel, thermosetting plastic, stainless steel, and graphite. The development of the use of natural materials that are currently carried out in various fields by considering the ability of recycling and renewable, encourages research prosthesis using natural materials [9].

Similarly, the development of a prosthesis material also leads to the use of natural materials that are environmentally friendly. Shasmin *et al* [12] has developed a tube section (shank) with use of bamboo. Based on the results of these studies, the results are obtained that the tube made of bamboo has good strength and can be applied to the design of the prosthesis especially for shank component.

This research aims to develop alternative materials to produce the shank of endoskeletal type with rattan materials. Research of rattan as a material of the shank component is a very important. This is related to the utilization of the natural potential of Indonesia especially rattan. The results of various studies have been published which show that the rattan potential to be developed as biomaterials, especially to produce shank prosthesis endoskeletal type.

II. MATERIAL AND METHOD

A. Materials

Rattan laminated fiberglass epoxy resin materials (RLFERM) is made with a layer of material from the inside to the outside as follows: rattan diameter (30-40) mm with a surface made rough with depth of (0.5-1.5) mm, as much as two-ply stockinette layer with thickness of (0.5-1) mm as the inner reinforcement is placed on the surface of rattan, a layer of fiberglass shaped fiber mat (woven) as a single layer with a thickness of (1-2) mm, three layers of stockinette layer with thickness of (0.5-1) mm as outer reinforcement, and a protective outer plastic layer by one layer. The lamination process is done by pouring a mixture of epoxy resin and hardener to resin ratio of 1:1, by casting the channel. Lamination process is followed by the press and vacuum until -50 bar. The vacuum process aims to help accelerate the lamination process and eliminate void.

B. Method

Macrostructure test of a sample of rattan is to observe the pore structure of the rattan, so it can be determined the optimum surface area of rattan in the theoretical calculations. This is necessary because the rattan is a porous material that needs to be calculated solid surface that can be used in the calculation of the surface area [13]. Theoretical calculation of rattan strength uses the equations of mechanical strength by considering the porous surface area which is obtained from macrostructure test. Strength simulation and analysis of rattan uses computer software. The results of this simulation are used for comparative data on the results of testing the strength of rattan.

Mechanical strength testing included tensile, compressive, impact and flexural strength testing of Natural Rattan (without lamination, NR) and RLFERM. Tensile strength testing aims to determine the maximum tensile strength and elasticity modulus of rattan to be used as a shank material. Tensile strength testing uses a Universal Testing Machine. Compressive strength testing aims to determine the maximum compressive of rattan to be used as a shank material. Compressive strength is required by shank prosthesis material so as to receive a compressive load of the weight and the dynamic movement of the lower limb while walking [14]. Impact strength testing aims to determine the maximum impact of rattan to be used as a shank material, especially to provide a sense of safety when it is used for walking and when it receives impact loads from other objects [14]. Flexural strength testing aims to get the maximum bending strength of rattan. Bending strength is associated with flexural strength of rattan materials that is needed on the shank material with the purpose to provide comfort for the user.

After testing the mechanical strength, we developed a prototype prosthesis shank to be tested and used by the patient. Results of testing the prototype of this first level will be a reference for the development of next prototype.

III. RESULT AND DISCUSSIONS

A. Macrostructure Test of Rattan

Rattan is a material with a porous structure [15]. In the theoretical strength calculation, rattan surface area should be calculated by considering the pore surface area, so it can produce strength such as real strength [16], [17]. To obtain the pore surface data, the test is conducted with as many as 10 samples of rattan. Fig. 1 shows the result sample test of rattan surface with 7 times magnification.

The number of pores is counted and measured to obtain the surface area porous of rattan, so the surface area of solid rattan can be calculated as a reference to calculate the strength. Based on the macrostructure test results of 10 samples, a total solid surface area of 665 mm^2 is obtained. The ratio of the surface area of the solid area and the average total surface area is 0.84 (Table I). This ratio is used as the data to calculate theoretical strength of natural rattan.

TABLE I. Ratio of Surface Area of Rattan

	Diamater (mm)	Surface Area (mm^2)	Number of Pores	Diameter of Pores (mm^2)	Surface Area per Pores (mm^2)	Pores Area (mm^2)	Solid Area (mm^2)	Rasio
Max	32.5	829	1026	0.42	0.14	142	714	0.86
Min	29.5	683	1005	0.37	0.11	108	563	0.82
Av	32	787	1015	0.39	0.12	124	665	0.84
SD	0.88	42.81	7.44	0.01	0.01	8.91	41.57	0.01

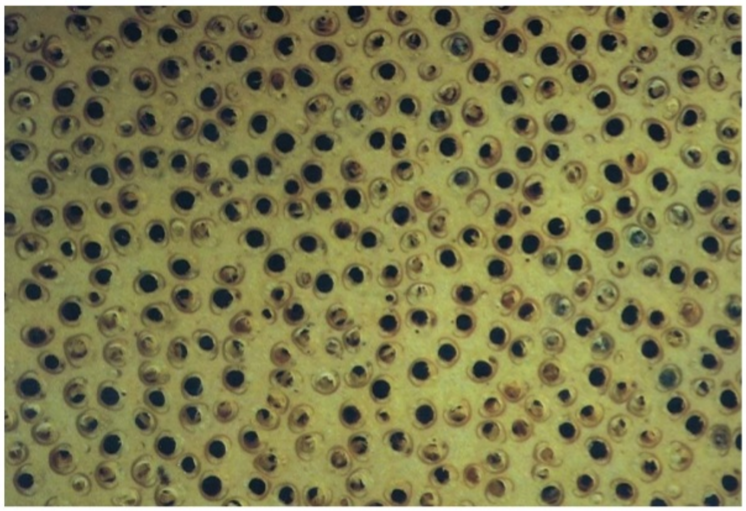


Fig. 1. Macrostructure test result

B. *Tensile Strength*

Fig. 2 shows an example of a RLFERM product that is produced by using lamination process with fiberglass and epoxy resin. The thickness of the outer layer of rattan with the lamination process is 3-5 mm. Lamination process produces a good interface between the surface of the rattan with fiberglass and epoxy resin.

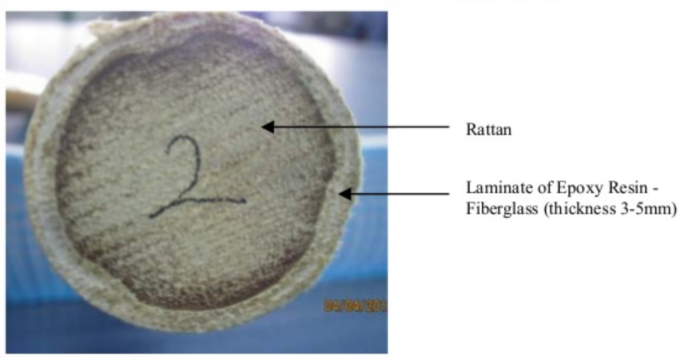
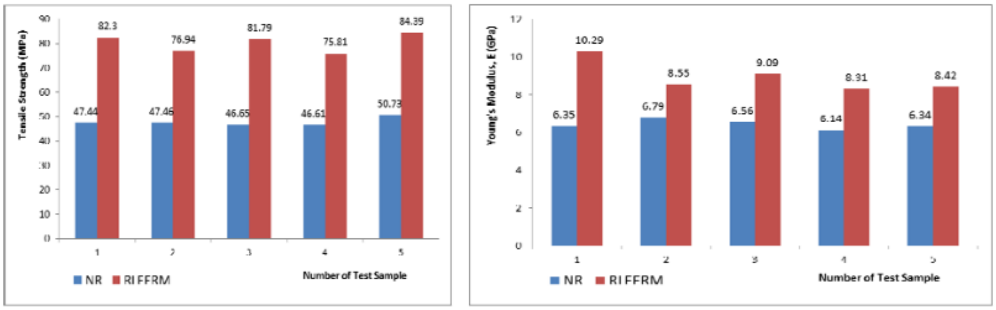


Fig. 2. Result of RLFERM manufacturing process

Tensile strength data used is the average tensile strength of 5 test samples. The results of comparison between the tensile strength and Young's Modulus of NR and RLFERM are shown in Fig. 3.



(a) (b)

Fig. 3. Tensile strength and Young's Modulus of NR and RLFERM

Fig. 3. (a) showed that the average tensile strength of RLFERM (80.2 MPa) with Young's Modulus 8.6 GPa, increased by 67.8% when compared to the tensile strength of NR (47.8 MPa) with Young's Modulus 6.4 GPa. Based on the results of tensile strength, it can be seen that the lamination process by using epoxy resin and fiberglass is proven to increase the tensile strength. This can be obtained due to the addition of fiberglass as reinforcement rattan surface in the lamination process. The increase of tensile strength is very good and is supported by a lamination process which has been developed in this study. Lamination processes using epoxy resin reinforced with fiberglass has managed to increase the tensile strength of rattan, which is projected as a shank prosthesis endoskeletal type, as an alternative material for replacing the materials used in the design of the shank prosthesis. Tensile test results also showed an increase in Young's Modulus of RLFERM when compared to NR (Fig. 3. (b)). Enhancement of 10% is very good, so the level elasticity of RLFERM will produce a level of comfort when used by the patient, but it is still strong enough to accept the burden of the patient's weight [14]. The tensile strength test results will be a reference in the development of shank prosthesis with use of natural materials, especially rattan.

We have been calculating the tensile strength of rattan by using theoretical method and simulation by using computer software. Comparison tensile strength results of theoretical calculations and simulation by taking into account the existing cavities in rattan amounted to 0.84; the results are as follows that theoretical tensile strength: 43.9 MPa, tensile strength results of simulation by using computer software: 42.5 MPa. The difference results from theoretical calculation, simulation and testing of NR, by 8.7%. These results are quite small, so it can be used to validate the results of tensile testing of NR.

When compared with some of the results of testing the tensile strength of rattan, the strength of RLFERM is very good, because it can increase the strength of NR obtained from the free market with a low to moderate quality, becomes rattan which has high strength. Bhat *et al* [18] shows the tensile strength of rattan class I (> 70 MPa), class II (45-70 MPa) and class III (< 45 MPa). Jasni *et al* [15] shows that the value of the strength of rattan ranges between (42-83) MPa. If it is compared with this range, the tensile strength of RLFERM is included in the class I [18].

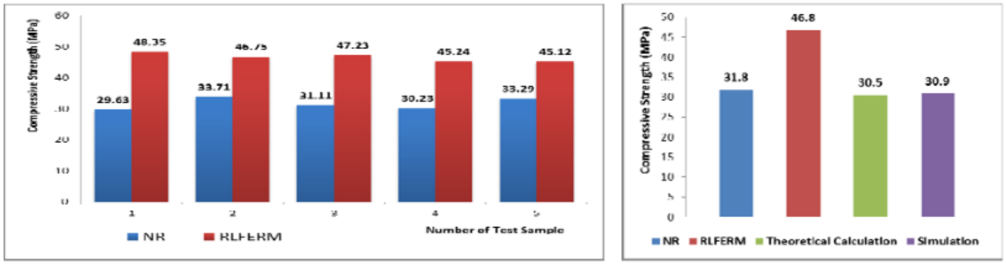
(a) NR (b) RLFERM

Fig. 4. Tensile Strength Sample Test of NR and RLFERM

Fig. 4 shows the difference from tensile testing result of NR and RLFERM. We can observe that NR has lower tensile strength when compared to RLFERM. It can be observed from the NR failure pattern and RLFERM due to tensile load receives. NR failure is greater than RLFERM, with a tensile load is smaller than RLFERM.

C. Compressive Strength

We have tested the compressive strength of the NR and RLFERM by using a Universal Testing Machine. Fig. 5. (b) shows that the compressive strength of the results of the simulation, theoretical calculations, and test results of NR, has acquired a very small difference. The difference is most influenced by the total surface area of the porous surface of the rattan, which was shown in Table I. The number of pores of rattan reduces the strength generated by the rattan.



(a) (b)

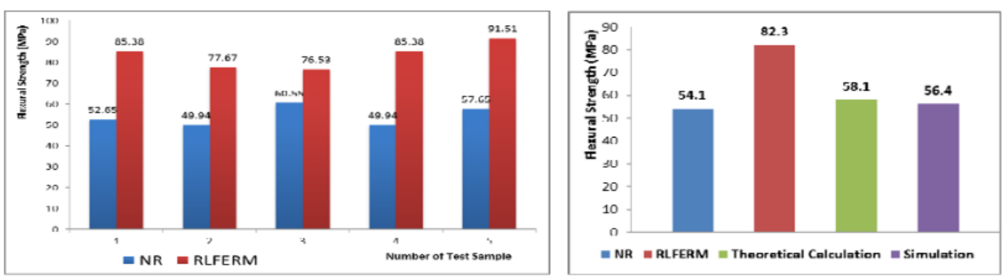
Fig. 5. Compressive Strength of NR and RLFERM

By using the theoretical reference compressive strength of 30.5 MPa, the average difference of the testing and simulation is 4.4%. The results of the compressive strength of both testing NR, the calculation of the theoretical strength and compressive strength simulation results are still in the range of research result (28.2-33.6) MPa [18], [19].

Results of the testing of compressive strength of RLFERM show an increase when compared to the compressive strength of NR (Fig. 5. (a)). With compressive strength of 46.8 MPa, it results an increase in the compressive strength of 47.2% if compare with NR (31.8 MPa). The increase in the compressive strength is greatly influenced by the surface layer of fiberglass as reinforcement rattan through the lamination process. When compared with the results of research [8], the compressive strength of rattan class I (33.6 MPa) and the compressive strength of rattan laminated epoxy resin reinforced with fiberglass, it can be obtained 39.3% greater strength. It can be concluded that the lamination process of rattan surface by using epoxy resin and reinforced with fiberglass can improve the compressive strength which is quite good when compared with NR.

D. Flexural Strength

Flexural strength is very important in the design of the prosthesis shank endoskeletal type. Good elasticity will provide a sense of comfort for the patient and the prosthesis shank is not quickly damaged due to compressive load and dynamic motion when the patient walks [1], [14]. Flexural strength is obtained from flexural testing by using a Universal Testing Machine. Fig. 6. (a) showed that flexural strength test result of RLFERM (82.3 MPa, average) is higher than the NR (54.1 MPa, average).



(a) (b)

Fig. 6. Flexural strength of NR and RLFERM

The comparison of flexural strength among NR with RLFERM, theoretical calculations and simulations by using computer software are shown in Fig. 6. (b). Differences of flexural strength among NR, theoretical calculation and simulation by using computer software are 5.8% (average). These results are quite good and can be used as a reference in further development. Flexural strength of RLFERM increased on average by 52% when compared with NR. These results can be obtained because the lamination process of rattan surface by using epoxy resin and fiberglass provides a surface layer tougher and stronger. These results indicate that the epoxy resin and fiberglass lamination process has improved flexural strength of rattan.

The increase of strength of RLFERM is obtained due to the strong of bonding between the surfaces of rattan with a layer of epoxy resin reinforced with fiberglass. Good interface can occur because the rattan surface is made rough, so that fiberglass can be attached. The stockinette layer on the inner surface associated with rattan that has been made rough and the exterior parts as a binder fiberglass also increased the strength of the case.

E. Impact Strength

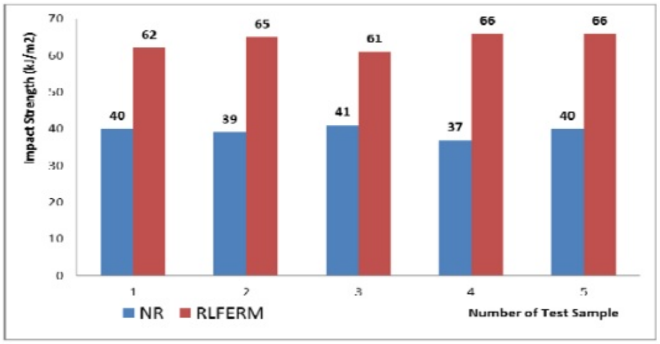


Fig. 7. Impact strength of NR and RLFERM

We have tested the strength of impact by using Charpy Impact Testing Machine. This test aims to determine the strength of rattan in receiving the impact load. Impact strength is required by the prosthesis shank material, so it can receive the load impact with other objects when used by patients [2]. The average impact strength of NR by 39 kJ/m^2 and RLFERM has increased very good by 64% to 64 kJ/m^2 (Fig. 7).

Improved impact strength is due rattan surfaces coated with an epoxy resin and fiberglass became harder and stiffer. This can be observed from the test sample which showed impact damage on the sample testing of NR is very different when compared with the results of RLFERM (Fig. 8). It can be concluded that the lamination process of rattan with epoxy resin and fiberglass, proven to improve the impact strength of rattan.

(a). NR (b). RLFERM

Fig. 8. Samples of compressive strength testing

F. Shank Prosthesis Prototype

To evaluate the strength of the RLFERM as an alternative material for produce shank prosthesis endoskeletal type, we have developed an initial prototype. Fig. 9. (b). shows that an initial prototype of shank prosthesis endoskeletal type made from RLFERM.

Socket, knee, shank and foot, assembled into a lower limb prosthesis as Fig. 9. (c), using a bolt connection. Bolt connection selected for ease of assembly and the replacement of components in case of damage. In general, when the prosthesis is used by the patient, the foot section will be damaged first. This happens because the part foot the main support at the time of prosthesis used to walk by the user [21]. Bolt connection will ease the process of repair or replacement in case of damage. Shank prosthesis made of RLFERM (Fig. 9. (b)), lighter than the shank prosthesis made from mild steel (Fig. 9. (a)). By using RLFERM, can be produced shank endoskeletal lighter, cheaper, Indonesia harness local potential and can be recycled. This is expected to positively impact the utilization of natural potential of Indonesia, especially rattan [10].

(a). Shank prosthesis of Mild Steel [20] (b). Shank prosthesis of RLFERM (c). Lower limb prosthesis prototype

Fig. 9. Shank prosthesis endoskeletal type

The first prototype of lower limb prosthesis with a shank prosthesis endoskeletal type of RLFERM, have been made with good results and tested for use by patient (Fig. 9. (c)). Shank prosthesis with RLFERM can be assembled easily to other components are socket, knee and foot. The first test results indicate that the lower limb prosthesis with a shank prosthesis components made of RLFERM can be used by patients to walk properly and has good strength. Strength and elasticity will impact on the level of safety and comfort experienced by the patient during walking using a lower limb prosthesis. It is very important to be a concern in the development of health products, especially lower limb prosthesis products [22], [23].

The results of this study can be used as a reference in the next research with increased strength and field testing process involving the patient, in order to obtain dynamic analysis to observe RLFERM strength and gait analysis when used for walking.

IV. Conclusion

We have developed of RLFERM as an alternative material to produce shank prosthesis endoskeletal type, by using rattan material. The use of rattan material due to the availability of abundant in Indonesia, has good strength, environmentally friendly and recyclable. The results of the macrostructure test of rattan show that solid surface area and porous parts with an average ratio of 0.84. Ratio obtained is used in the rattan strength calculation of the theoretical and simulation by using computer software. The ratio between the total surface area and pore surface area of the rattan should be taken because it affects the obtained total strength.

Manufacturing process produces a good interface between the epoxy resin, fiberglass and rattan surface. This result can be observed from the increased mechanical strength of RLFERM, including tensile strength, compressive strength, flexural strength and impact strength. The first prototype that we have developed shows that RLFERM has produced shank prosthesis endoskeletal types and can be used to walk by the patients well. The first prototype showed that patients can walk well and feel comfortable use shank prosthesis product made from RLFERM. The next study, we will observe the gait analysis and the strength of the shank prosthesis made from RLFERM when used for walking. This result will be a reference for further research in the development of a shank prosthesis made from rattan and another use in engineering design.

Acknowledgment

The Authors wish to thanks Research and Scientific Writing Department, Tarumanagara University for the financial support through Research University Grant.

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