Gait Analysis of Lower Limb Prosthesis with Socket Made from Rattan Fiber Reinforced Epoxy Composites

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ABSTRACT— ***Rattan fiber is one of the natural fibers that has good potential to be developed into biocomposite. In this study, we have developed Rattan Fiber Reinforced Epoxy Composites (RFREC) materials. Composite materials have been developed, used to produce a prototype of lower limb prosthesis, especially in the socket component. In research and development of lower limb prosthetic socket by using RFREC materials, has implemented three tests that the compressive load test refers to ISO 10328, gait analysis by using Six Minute Walk Test Method (6MWT), and psychophysical analysis by measuring the pulse rate of the respondents before and after gait analysis done. The test results showed that maximum compressive load of socket: (5.54 ± 0.3) kN. Such as besides, gait analysis results showed that walking speed: (0.6 ± 0.01) m/s, cadence: (86.3 ± 0.33) steps/min, step width: (20.8 ± 0.84) cm, stride length: (84.4 ± 1.14) cm, stride total: (259 ± 1.00) cycles, and walking length total: (218.6 ± 3.41) m. Furthermore, the result of measurement of pulse rate before test: (84.6 ± 0.83) pulse/min and after test: (88.9 ± 0.92) pulse/min. Therefore RFREC materials can be further developed as prosthesis socket materials with good level in safety and comfort. It can be analyzed from the results of the compressive load test, the results of gait analysis and the results of physiological analysis, as described in this paper.***

Keywords— Rattan fiber, composites, compressive strength, prosthesis socket, gait analysis

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1. INTRODUCTION

In general, the current material technology developed to biomaterial based on natural fiber composite because it is more environmentally friendly, inexpensive, availability of abundant, and can be recycled. Natural fibers composite also have the high strength to density ratio so that makes it lighter. Although not fully replace synthetic fibers, using the eco-friendly natural fibers is a good step to protect the environment [1-6].

Research about natural fibers especially rattan fiber is very important to do because can increase the added value, the availability of abundant and can be recycled. Potential of natural fibers can be developed to create alternative products like above knee prosthesis socket. This product can increase the economic value and social welfare [7-9].

Prosthesis is a component of the human body replacement. One of the most used prosthesis is lower limb prosthesis**.** The main problem in the design of above knee prosthesis is compatibility between the size of the stump and the socket. This is especially necessary at the time used to walk so it can function properly and user feels comfortable [10-11].

Before this research, we have conducted the manufacture and testing of rattan fiber reinforced epoxy composites materials, which is projected to be used as above knee prosthesis socket materials. It based on the results of tests that have been conducted mechanical characteristic of rattan fiber reinforced epoxy composites materials in Vf 40%, showed in Table 1.

Table 1: Mechanical characteristic of rattan fiber reinforced epoxy composites materials [7]

Mechanical Characteristic	Result
Tensile strength	65.25 ± 0.81 MPa
Compressive strength	35.23 ± 3.8 MPa
Flexural strength	79.25 ± 3.51 MPa
Impact strength	46.35 ± 0.69 kJ/m^2

In this study, we have produced lower limb prosthesis socket prototype made from Rattan Fiber Reinforced Epoxy Composites (RFREC). The prosthetic socket prototype was made with anthropometric data of Indonesia people (Javanese) that have been taken direct measurement from the respondent. We produce prosthesis refer customized method to obtain the prosthesis in accordance with anthropometric data of user. The process of making customized prosthesis with the method is that all sizes, data, and the fabrication process only for the patient concerned [12-14].

This research aimed to obtain the characteristics of the prosthesis socket prototype made from RFREC materials included compressive failure test and gait analysis on respondents with above knee amputation due to traffic accident. Compressive failure test was conducted to determine the maximum strength of socket when loaded. After the mechanical characteristics obtained, we produce lower limb prosthesis prototype with socket component made from RFREC. Then we carry out test on respondent with above knee amputation to determine the level of ease and comfort of prosthesis prototype produced. We do gait analysis to obtain measurable parameters that can be compared with the data of normal walking and walking by using the lower limb prosthesis. Gait analysis is a pattern of activities to observe the way for patients who use the prosthesis, aiming to obtain information relating to balance, comfort, ease of use and possible abnormalities experienced by these patients during normal walking and walking using a prosthesis [14-18]. Important parameters are usually a concern at the time the gait analysis includes: walking speed, steps/min = cadence, step time, step length, stride length (Fig. 1), walking length total per minute, energy consumption is required and abnormalities that may be experienced by respondents [11, 14, and 19]. Gait analysis results can be used to determine comfort level of prosthesis during use by the patient.

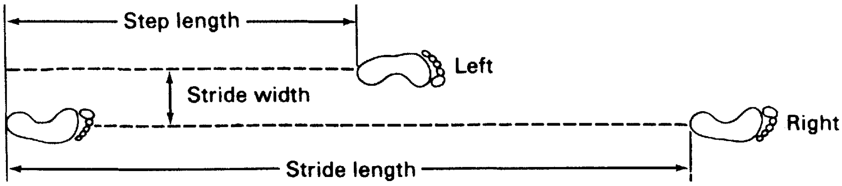

Figure 1: Measurement of walking steps [20]

2. MATERIAL AND METHOD

Prosthesis socket prototype manufactured by using continuous fiber composite materials of rattan and epoxy resin matrix ® Bakelite EPR 174 with V-140 epoxy hardener. Mixture ratio between the epoxy matrix and hardener is 1:1, so we can obtain that mixture of resin and hardener are good and balanced to produce of strength. Production process of socket is using mat lamination method with pressure and vacuum processes (- 50 bar) to eliminate voids [7-9]. Mat lamination method is a method of the production process of composite materials. The production process is done by making the arrangement of fibers in the form of mat, then coated with a mixture of epoxy resin and hardener.

Table 2: Fiber characteristics

Fiber	Dimension	Treatment	Fiber Orientation
Rattan (continuous)	Thickness 0.2 ± 0.05 mm Width 2.5 mm ± 0.5 mm	Soaked in 90% alcohol for 10 min, then dried	$0^0/90^0$

Socket prosthesis manufacturing process consists of anthropometric data measurements, negative mold, positive mold, preparation process of lamination, lamination process, finishing process, and fitting of prosthesis socket products. Maximum compressive strength testing was conducted to determine the maximum load that can be accepted by prosthesis socket until damaged. This testing is according to ISO 10328 for load level A 100, Loading Condition II [21-23].

After testing the mechanical characteristics, then we produce the prosthesis prototype with socket made of RFREC materials. Prosthesis prototype then tested to walking by the respondent. We use the method of gait analysis to analyze the ability of the prosthesis when used for walking. Gait analysis of the lower limb prosthesis prototype is using Six Minute Walk Test Method (6MWT). The 6-minute walk test requires a subject to walk as far as he or she can in 6 minutes, with rests as needed. This test is particularly appealing for clinicians, because it is relatively quick and easy to implement and can be completed by many patients [24]**.** The 6MWT is the distance walked in a period of 6 minutes. This test was initially considered an endurance measure but more recently has been considered a broader measure of mobility and function [18]. Respondent walks using prosthesis for six minutes without stopping on the track and environmental conditions in accordance with the day-to-day activities of the respondent [14-18]. The 6MWT is a practical test performed in clinic to assess exercise capacity of responden that use lower limb prosthesis.

In this study we have carried out the physiological analysis to measure the pulse rate of the respondent by using pulsemeter before and after walking for six minutes. This analysis aims to obtain data of respondent comfort level when using the prosthesis [12-14]. If people feel comfortable in walking, then the pulses per minute is low. The comfort level refers to the number of pulse rate of respondent after walking activities is low level (75-100) pulses/min and moderate level (100-125) pulses/min [12-13].

3. RESULT AND DISCUSSION

3.1 Compressive Load Testing

Compressive load testing need to be done to obtain data on the maximum load that can be accepted by the prosthesis socket prototype. This test is according to ISO 10328, standard for load level A 100, Loading Condition II, by using compression machine ADR 3000 kN. Based on the results of tests that have been done, the maximum compressive load of socket made from RFREC materials can be obtained as shown in Table 1.

Table 3: Results of compressive load testing

No. Sample	Max Load (kN)
1	5.25
2	5.24
3	5.52
4	5.96
5	5.82
6	5.46
Max	5.96
Min	5.24
Average	5.54
Standard Dev	0.30

Compressive load of prosthesis socket prototype that can cause total failure of the socket by on average load obtained for 5.54 ± 0.30 kN. Referring to the ISO 10328 for load level A 100, Loading Condition II, the minimum load carried on a load of 1000 N. Socket prosthesis prototype must be in good condition and safe to accept the load 1000 N.

In this study, we provide safety factor (SF): 3, so the socket must be able to receive the load up to 3000 N. Safety factor is given to anticipate the dynamic load of the respondents at the time of walking. We obtained data that failure to compressive the socket began of 4000 N, with deflection average to 1 mm. Based on the maximum compressive load that can be accepted by the socket such as Table 1, and the damage began at 4000 N load, then the socket with composite materials can receive the load safely. Compressive load socket made from RFREC materials obtained exceed load of the weight of respondents. When compared with the compressive load of ramie fiber reinforced epoxy composite material of 4.51 kN [7,9], then RFREC materials better in receiving compressive load. This result is quite good, so RFREC materials can be used to develop prosthesis socket prototype.

3.2 Gait Analysis

Based on compressive load test result as shown Figure 1 and results of testing the mechanical characteristics has been done before [7], we made a complete prosthesis prototype with socket made from RFREC as shown in Figure 2. We have been using local components to produce the prosthesis prototype. The respondent for gait analysis is below knee amputees patient, a man 37 years old and has been used lower limb prosthesis for more than five years. He amputated due to traffic accidents.

Figure 2: Prosthesis prototype [14]

Gait Analysis is an activity to observe the pattern of the way for the patient when using a lower limb prosthesis. The purpose of gait analysis is to obtain information related to balance, comfort, ease of use and the possibility of abnormalities experienced by the patient when walking by using the lower limb prosthesis. In general, walking cycle can be described as the Fig. 3. There are two main parts: the Stance Phase and Swing Phase. If it is assumed when walking start from the right foot first step, then the stance phase consists of: right initial contact, midstance right, right terminal stance, right preswing, followed part swing phase consisted of initial swing right, right midswing, right terminal swing.

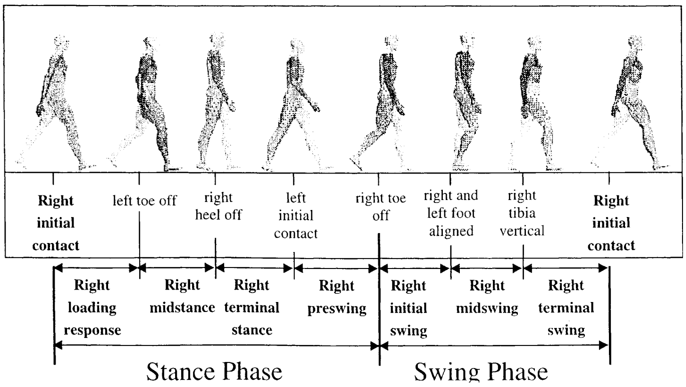

Figure 3: Walking cycle [11]

Gait analysis procedure refers to the Six Minute Walk Test Method (6MWT) were modified and developed by researchers, adapted to the needs of research and research facilities are available. Gait analysis is done in a public place and open, so that respondents can feel the atmosphere like during daily activities. Gait analysis carried out by walking slowly for six minutes using lower limb prosthesis on a flat road with a quiet atmosphere. Before and after walking, heart rate of respondent was measured with a pulse meter. Among the walk cycle for six minutes, the respondent rest for 20 minutes.

Figure 4: Gait analysis process [14]

Table 4: Gait analysis result

Gait Parameters	Result
Steps total per 6 minute	518 ± 2.00
Cadence (steps/min)	86.3 ± 0.33
Step time (s)	0.7 ± 0.01
Right step length (cm)	40.6 ± 0.89
Left step length (cm)	43.8 ± 0.84
Step width (cm)	20.8 ± 0.84
Stride length (cm)	84.4 ± 1.14
Stride total per 6 minute (cycle)	259 ± 1.00
Walking length total per 6 minute (m)	218.6 ± 3.41
Walking length total per minute (m)	36.4 ± 0.57
Walking speed (m/s)	0.6 ± 0.01

Based on the results of gait analysis has been done (Figure 4), the average walking speed is (0.6 ± 0.01) m/s (Table 4). When compared with some of the research, it appears that the results walking speed is quite good. According to Tommy [15], walking speed range for men (30-39) years old with normal speed range: (0.486 to 1.28) m/s. According to Farahmand, et al., 2006, walking speed from patient normal walking: (0.6 ± 0.01) m/s. The results are still within range (0.486 to 1.28) m/s [15].

In general, the number of steps per min at normal walking: (70-90) steps/min. In this range, the patient walks normal and comfort. Medium speed group with the number of steps: 95 steps/min. High speed group with the number of steps: 120 steps/min [20]. According to Verne et. al. [10], the number of steps between: (70-130) steps/min. Based on gait analysis results obtained by the average number of steps (86.3 ± 0.33) steps/min. These results are within range of normal step group. It can be concluded that patient using prosthesis socket made from RFREC material can walk well in normal condition.

In the study of ergonomics, one method to measure level of fatigue by using physiological criteria. If people feel comfortable in walking, then the pulses per minute is low. The comfort level refers to the number of pulse rate of respondent after walking activities is low level (75-100) pulses/min and moderate level (100-125) pulses/min. This method is done by measuring the pulse rate per min before and after gait analysis [12-14].

Table 5: Heart rate reference [13]

Assessment of Work Load	Heart Rate (pulses/min)
	Reference
Very low (resting)	60-70
Low	75-100
Moderate	100-125
High	125-150
Very high	150-175
Extremely high (eq. Sport)	> 175

According to Table 5, load of activity can be measured using pulse rate when people do activities. Pulse rate can also be used to estimate the physical conditions or the degree of physical healthy as well as measure the fatigue that occurs.

Based on the pulse rate measurement before gait analysis: (84.6 ± 0.83) pulse/min and after gait analysis: (88.9 ± 0.92) pulse/min. If these results are converted to Table 5, it can be concluded that the patient worked in areas of low to moderate. Patient did not feel significant fatigue. The patient's condition remained healthy and comfortable. It can be concluded that the condition of the patient still good condition and did not experience fatigue after walking for 6 minutes continuously use of the lower limb prosthesis that has been developed.

Table 6: Heart rate of respondent before and after gait analysis

Assessment of Work Load	Heart Rate (pulses/min)		
	Reference	Before	After
Very low (resting)	60-70	-	-
Low	75-100	84.6 ± 0.83	88.9 ± 0.92

4. CONCLUSION

We have developed a product of lower limb prosthesis using RFREC materials. The products that we have developed is based on the utilization of natural fibers are good strength, abundant in Indonesia and has not been used optimally. The results showed that the rattan fiber composites can be used to develop manufacturing products in the field of health. This result can be used as a reference for the development and further research in the field of lower limb prosthesis, especially the use of natural fibers as composite materials.

Based on the results, prosthesis socket prototype made from RFREC materials can be an alternative product that may be used by the respondent with safe and comfortable, as well as a positive impact on the use of natural materials that are environmentally friendly and can be recycled. RFREC materials can be further developed as prosthesis socket materials with good level in safety and comfort. It can be analyzed from the results of the compressive load test, the results of gait analysis and the results of physiological analysis. These results when compared with the reference value is in the range of values.

5. ACKNOWLEDGEMENTS

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