Water Hyacinth (Eceng Gondok) As Fibre Reinforcement Composite for Prosthetics Socket

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Abstract. Based on the study of water hyacinth fibres, the results of tensile tests and compressive flexural tests for water hyacinth fibre composites laminated with methyl methacrylate resin as reinforcing materials for the manufacture of trans femoral socket prosthesis, showed there is no significant difference in strength and flexibility between water hyacinth fibres and nylon glass fibre which is more often using in orthopaedics technology.

Objectives: This study aims to engineer water hyacinth fibre as reinforcing materials for fabricating trans femoral sockets and perform the structural testing.

Study Design: Experimental, bench research.

Result: The availability and renewable natural fibres has the potential to reduce hazards for those involved in manufacturing the artificial limb sockets, without reducing and compromising the strength of sockets and benefiting for the users. Wall thickness, fibre direction and fibre-matrix resin lamination played a significant role in socket strength.

Conclusions: From this limited study we conclude that the resin and water hyacinth fibre composite socket has the potential to replace the standard layup. Further mechanical and biocompatibility testing as well as a full economic analysis is required. Thus, the use of composites with water hyacinth fibres has the potential to be further developed as an alternative material for socket prosthesis in Indonesia.

1. Introduction

The World Health Organization (WHO) in 2011 estimated that around 15% of the world population (7 billion people) live with physical limitations where 2-4% of them experience difficulties in carrying out daily activities. According to the data of National Census Central Bureau of Statistics in Indonesia of 2003, the number of persons with disabilities in Indonesia is 0.7% of the population of 211.428.572 or as many as 1.480.000 people. Based on data from the Ministry of Health's Basic Health Research in 2018 of 11% there were people with disabilities in limbs \cite{1}.

In dealing with the stabilization required a prosthesis (motion assisted device) which serves to restore limb function and prevent further stabilization. In the manufacture of a prosthesis on the knee or called trans femoral socket is needed that is designed according to the foot butts left after amputation of the knee. The sockets needed are designed to follow the anatomical contours of each individual. Sockets are expected to be able to accommodate stumps in full contact in order to increase the biomechanical
feedback such as the circulatory system, nerves, and integument can be accommodated and there are 2 types of trans femoral socket prostheses, namely quadrilateral socket and ischial containment socket. Ischial containment sockets exhibit better ability, with a socket shape that follows the anatomic and stable contours for media lateral control and rotation [2].

The type of socket material experienced significant development from the 1950s to the present, ranging from wood, leather, aluminium to plastic. The development of plastic types is currently quite diverse from thermoplastic and thermosetting. Thermosetting can be made from a variety of reinforcing and composite materials. Composites in the worldwide continue to grow rapidly starting from fiberglass, nylon-glass, polyester to carbon fiber.

Based on data from the Indonesian Ministry of Health's Data and Information Center in 2017 that most medical devices are still imported from abroad, although since 2017 it has been reported that medical equipment production facilities have increased by 517 facilities, more than doubled, and for increasing the number of medical devices. 32 types. So that currently there are 719 production facilities capable of producing as many as 294 types of medical devices [1].

With the aforementioned capabilities, the Domestic Medical Devices Industry has been able to meet approximately 50% of the standard facilities for medical devices in hospital types A, B, C and D. However, especially the orthotics and prosthetics industry still experience limitations to produce domestically starting from manufacturing technology up to unavailability of materials that have the strength and ability to withstand dynamic loads. Reinforcing materials, especially the types of carbon fiber, fiberglass, nylon glass used in fabricating the assisted devices are still imported and quite expensive, which is above IDR. 1,000,000 / m2, with consequences the price of an assisted device as a whole is not affordable by all levels of society with the disability.

The needs for socket-fabricating reinforcement materials must be sought from materials in Indonesia. Indonesia with extraordinary natural potential has quite diverse natural resources, efforts to look for socket prosthesis materials that are from existing natural materials such as natural fibers that are widespread throughout Indonesia, for example water hyacinth fibers, bamboo fibers, pineapple fibers, Banana fiber, palm fiber, sugar cane fiber, rattan fiber etc. This material is currently widely used for furniture industries and other industries.

Present, the main environmental problem faced is plastic waste that cannot be degraded. Continuous production and utilization of plastic in every sector of our lives have expanded plastic waste on a large scale. With the increasing use of synthetic fiber materials, environmental problems such as waste disposal, garbage disposal services, and pollution from incineration are more important [3]. The use of natural fibers as a substitute for traditional synthetic fibers, such as glass and carbon, has recently received increasing attention in addressing these environmental problems.

Material engineering is growing faster and this is driven by the needs for materials that have certain desired characteristics. One of them is in the composite field. The ability to easily be formed encourages the use of composites as a substitute for metal and plastic materials on various products. Silva et al. Evaluated the toughness of bio composite cracks made from sisal fibers and castor oil in the polyurethane matrix. They found better fracture toughness characteristics for sisal fiber composites [4]. Composite fabrication also involves the role of heat. Idicula et al studied thermal transport characteristics of composites made from natural fibers with polyester matrices. Their study shows that natural fibers along with glass fibers show sufficient heat transport behavior for composites [5]. Natural fibers have advantages such as low prices and very light weights. Even some studies conducted on the use of natural fibers with glass fiber were also tried. Panthapulakkal et al. Have examined the mechanical and thermal qualities of bio composites made of hemp fiber and glass with a polypropylene matrix. They have found that composites increase the impact and bending characteristics. In addition, composites also show improved water resistance and thermal characteristics [6]. Thwe et al. Have studied the effect of composite ageing, which is made from bamboo fibers and glass with a polymer matrix. Their results show that the ageing phenomenon drastically reduces tensile characteristics [7]. This bio-composite material is intended to have a superior ecological effect than plastic to promote improvement in its mechanical properties, to suit the needs of modern technology.
Bio-composites with natural fibers from water hyacinth. Bharath et al. Conducted a study to make prosthetic sockets using bio composites with areca fiber, sisal fiber, banana fiber which were successfully reinforced with epoxy resin with a simple and inexpensive hand lay-up technique. The results of mechanical testing of bio-artificial composite prosthesis sockets show that the concept of using some natural fibers is feasible for socket prosthesis applications. However, there is scope to optimize the volume fraction of natural fibers as reinforcement to achieve enhanced mechanical properties of socket prostheses [8]. Ramie and banana fiber composites have the highest ultimate tensile strength among the natural fiber test pieces; hence, we chose to weave ramie thread into a stockinet material to fabricate the natural fiber and plant resin test socket. The carbon fiber composite samples show the highest Young’s modulus (8.8 GPa) and ultimate tensile strength (127.5 MPa). Bamboo fibers do not appear to have increased the ultimate tensile strength of the test pieces above the ultimate tensile strength of the plant oil [9].

In 2012 Andrew I Campbell have investigated the potential to replace the conventional acrylic and glass fiber composite materials currently used in prosthetic limb socket manufacture with a plant-based polycarbonate-polyurethane copolymer resin and plant fiber composite. The comparative tensile strength tests indicated that both banana and ramie plant fibers could produce a strong composite material. Four test sockets were constructed and tested to destruction by applying a loading at a rate of 100 Ns⁻¹ until failure. The socket constructed using the plant oil resin and ramie fibers failed at a higher loading than that of the conventional materials; both failed at a loading of about 25% higher than the loading required by the ISO 10328 standard. The wall of the socket was thicker than that of the conventional materials socket due to the thickness of the weave of the ramie stockinet. While wall thickness does contribute to the strength of the socket [9].

In this study, efforts will be made to make bio-matrix composites of methyl methacrylate polyester resin with water hyacinth fibers as reinforcing materials and to characterize mechanical performance to evaluate their suitability for socket prosthesis applications.

2. Method

2.1. Materials
We sourced a range of water hyacinth fibers from a local supplier in Cipondoh Tangerang. The fibers were supplied in the form of individual fibers; i.e. they were not spun into a thread. And then we order to the local craftsmen to create a water hyacinth mat. We purchased a methyl methacrylate based resin from a Germany supplier. The resin are excellent transparency, high-impact strength, and good chemical resistance. This is an exceptional combination of properties for an impact-modified thermoplastic.

2.2. Tensile Strength Testing
To eliminate unsuitable fiber resin combinations we conducted simple comparative tensile strength measurements on dumbbell-shaped test pieces. A Roland EGX 400 engraving machine was used to cut moulds to a depth of 4 mm from a 1.5 cm thick polypropylene sheet, with the dimensions given in Figure 1(a). We prepared ten test pieces for each of the fiber samples using a constant volume of 70% of fibers. For comparison, test pieces without fibers and containing glass fiber were also prepared. The resin and hardener solution were mixed according to the manufacturer’s instructions and a wooden spatula used to work the resin into the fibers as it was poured into the moulds, ensuring that the fibers were fully coated. The fibers were aligned parallel to the long axis of the mould and were not held under tension. A piece of armored glass was then placed on top of the moulds and clamped firmly into place. Excess resin expelled through the applied pressure was removed. The test pieces were left to cure in the moulds for about twenty four hours. A servopulser tensile test machine was used to determine the tensile strengths of the test pieces. They were clamped into the machine and the computer set to draw the clamps apart at a rate of 5 mm min⁻¹ until failure of the test piece. The computer recorded the load and extension during each run.
2.3. *Flexural Strength Testing*

Method to prepare the test pieces for flexural strength testing, engraving machine was used to cut moulds to a depth of 4 mm from a 1.5 cm thick polypropylene sheet and dimension as required in ASTM D790 is 2.5 cm width and 10 cm length. A Shimadzu AG IS 50kN universal testing machine was used to determine the flexural strengths of the test pieces. They were three points bending hold into the machine and the computer set to push the apart at a rate of 5 mm min⁻¹ until failure of the test piece. The computer recorded the load and extension during each run.

![Figure 2(a). Dimensions of the flexural strength test pieces.](image)
3. Result

The tensile strength test results for some of the water hyacinth fiber and nylon glass composite samples are plotted in Table 1.

Table 1. The water hyacinth fiber and direction angle combinations used for the test pieces and their loadings at tensile failure.

| Direction of weaving | Number of Specimen | Tensile strength (σ) Mpa | Average of tensile strength (σ) Mpa | Maximum Load (Kg)/mm² | Average maximum Load (Kg)/mm² |
|----------------------|--------------------|--------------------------|------------------------------------|-----------------------|-------------------------------|
| Fibre with angle of 0º | 1A                 | 42.4                     | 44.10                              | 122                   | 138.6                         |
|                      | 1B                 | 46.02                    |                                    | 157                   |                               |
|                      | 1C                 | 43.9                     |                                    | 137                   |                               |
| Fibre with angle of 45º | 2A                | 47.5                     | 47.19                              | 172                   | 168.6                         |
|                      | 2B                 | 46.02                    |                                    | 157                   |                               |
|                      | 2C                 | 48.06                    |                                    | 177                   |                               |
| Fibre with angle of 90º | 3A                | 46.02                    | 46.34                              | 157                   | 160.3                         |
|                      | 3B                 | 47.5                     |                                    | 172                   |                               |
|                      | 3C                 | 45.5                     |                                    | 152                   |                               |
| Nyglass fibre        | 4A                 | 43.9                     | 42.93                              | 137                   | 127.1                         |
|                      | 4B                 | 42.4                     |                                    | 122                   |                               |
|                      | 4C                 | 42.5                     |                                    | 122.5                 |                               |

Based on data the results of the tensile test on water hyacinth composites, the average tensile strength of 45.88 MPa was produced with a maximum load that could be held on average 155.88 Kg / mm² before the composite and matrix would be broken.

The tensile test results on water hyacinth composites with a 0º woven pattern produced an average tensile strength of 44.10 MPa with an average maximum load of 138.6 Kg / mm² before the composite and matrix would be broken.

The tensile test results on water hyacinth composites with 90º woven patterns produced an average tensile strength of 46.34 MPa with an average maximum load of 160.3 Kg / mm² before the composite and matrix would be broken.

The tensile test results produced by water hyacinth fibers with a 45º woven pattern get the best results by obtaining an average tensile strength of 47.19 MPa with a maximum load that can be held is 177 Kg / mm² this shows a 45º woven pattern gives a strong bond to resin and existing matrix.

While the tensile test on Nyglass which is commonly used in making socket prosthesis produces an average tensile strength of 42.93 MPa with a maximum load that can be held at 127.1 kg / mm² before the Nyglass fiber breaks.
The flexural strength test results for some of the water hyacinth fiber and nyglass composite samples are plotted in Table 2.

**Table 2.** The water hyacinth fibre and direction angle combinations used for the test pieces and their loadings at flexure failure.

| Direction of weaving | Number of Specimen | Maximum Strain Flexure (%) | Modulus of Rupture (MoR) / (N/mm²) | Maximum Force (N) |
|----------------------|--------------------|-----------------------------|-------------------------------------|-------------------|
| Fibre with angle of 45º | E 45 1             | 2.75653                     | 20.2013                             | 128.125           |
|                       | E 45 2             | 5.52325                     | 21.9643                             | 120.313           |
|                       | E 45 3             | 3.52984                     | 23.4091                             | 117.188           |
|                       | E 45 4             | 4.06293                     | 23.7069                             | 129.688           |
|                       | E 45 5             | 5.77104                     | 23.8955                             | 151.563           |
|                       | E 45 6             | 4.13012                     | 25.6649                             | 148.438           |
|                       | E 45 7             | 3.32711                     | 20.3639                             | 142.188           |
|                       | E 45 8             | 3.62162                     | 23.3749                             | 148.438           |
|                       | E 45 9             | 3.97362                     | 19.8024                             | 148.438           |
|                       | E 45 10            | 3.21202                     | 24.2178                             | 139.063           |
| Average               |                    | 3.99081                     | 22.6601                             | 137.344           |
| Fibre with angle of 90º | E 90 1             | 2.88274                     | 21.7535                             | 117.188           |
|                       | E 90 2             | 3.25121                     | 19.5664                             | 114.063           |
|                       | E 90 3             | 3.793                       | 23.7885                             | 121.875           |
|                       | E 90 4             | 2.89018                     | 21.1413                             | 128.125           |
|                       | E 90 5             | 2.84519                     | 25.2193                             | 126.563           |
|                       | E 90 6             | 2.55481                     | 22.9841                             | 121.875           |
|                       | E 90 7             | 5.81574                     | 23.4674                             | 117.188           |
|                       | E 90 8             | 3.63044                     | 20.2316                             | 109.375           |
|                       | E 90 9             | 3.3498                      | 15.7183                             | 85.9375           |
|                       | E 90 10            | 2.42153                     | 14.7059                             | 76.5625           |
| Average               |                    | 3.50734                     | 20.8576                             | 111.875           |
| Nyglass               | FG 1               | 3.41                        | 89.6201                             | 181.25            |
|                       | FG 2               | 3.02561                     | 90.8177                             | 176.563           |
|                       | FG 3               | 3.25587                     | 98.54                               | 203.125           |
|                       | FG 4               | 3.18317                     | 102.074                             | 200               |
|                       | FG 5               | 3.63841                     | 83.7222                             | 167.188           |
|                       | FG 6               | 3.99898                     | 96.1295                             | 192.188           |
|                       | FG 7               | 6.12306                     | 55.3496                             | 142.188           |
|                       | FG 8               | 4.02656                     | 55.5761                             | 160.938           |
|                       | FG 9               | 5.59671                     | 57.5969                             | 165.625           |
|                       | FG 10              | 3.1244                      | 97.554                              | 192.188           |
| Average               |                    | 3.93828                     | 82.698                              | 178.125           |

From the table above shows the test results with the maximum value of composite flexibility of water hyacinth with 45º with strain of 3.99%; The 90º fiber is 3.50% and the Nyglass composite is 3.93% which means there is no significant difference in the elasticity of the composite of water hyacinth and fiberglass composite and can be seen from graph in the Figure 3(a, b and c).
Figure 3(a). Loading failure of test pieces for 45º water hyacinth fiber.

Figure 3(b). Loading failure of test pieces for 90º water hyacinth fibre.

Figure 3(c). Loading failure of test pieces for nyglass fibre.

For comparison we have included tensile strength results for Nyglass and 80:20 acrylic resin test pieces. While the results indicate that the standard materials are not as stiff or strong, we note that the Nyglass weave results in many of the fibres being normal to the long axis of the test pieces. We would therefore, expect both the stiffness and the tensile strength to be higher than the measured values if all the Nyglass fibres were parallel to the long axis.
4. Discussion
From our tensile strength data the best performing combination of the resin and water hyacinth fibres was given by 45° of weaving direction. Kim and Netravali [10] found a similar ultimate strength for ramie fibres embedded in soy flour resin. However, they used a higher ramie fibre content of about 50 wt% (~37 vol%, ρ~1.5 g cm⁻³ for ramie fibres). They also found that increasing the protein content of the soy flour resin (without fibres) increased the tensile strength from about 13 MPa to about 36 MPa. A similar increase was seen for the Young’s modulus. The higher protein content soy flour resin is similar in tensile strength to that of our resin only samples (28 MPa). By including the ramie fibres the tensile strength of the high protein soy flour composite was increased to 104 MPa. It is likely that we would see a similar increase in composite strength if we were to increase the fibre concentration. We are currently conducting experiments to optimize the water hyacinth fibre concentration.

Table 3. Average (of five) ultimate tensile strength test results of the plant oil resin and natural fibre composite test pieces. For comparison, the data for test pieces made with the mineral fibres glass and carbon are included. Our results show that the combination of the plant oil resin with banana or ramie fibres gives the highest ultimate strength [9].

| Fibre   | Tensile strength (MPa) | Strain (%) | Young’s modulus (GPa) |
|---------|------------------------|------------|-----------------------|
| Banana  | 82.7 ± 5.0             | 3.1 ± 0.4  | 3.4 ± 0.005           |
| Ramie   | 80.8 ± 8.2             | 3.1 ± 0.7  | 4.0 ± 0.007           |
| Seacell | 66.1 ± 2.8             | 7.3 ± 0.6  | 2.5 ± 0.008           |
| Flax    | 59.5 ± 5.0             | 2.7 ± 0.3  | 2.8 ± 0.007           |
| Soya    | 55.8 ± 2.7             | 14.8 ± 1.2 | 1.7 ± 0.007           |
| Corn    | 38.9 ± 0.8             | 36.5 ± 5.0 | 1.5 ± 0.011           |
| Cotton  | 36.0 ± 4.1             | 3.8 ± 0.2  | 1.6 ± 0.002           |
| Bamboo  | 29.9 ± 3.4             | 10.9 ± 2.9 | 1.1 ± 0.002           |
| Carbon  | 127.5 ± 28.0           | 2.0 ± 0.2  | 8.8 ± 0.016           |
| Glass   | 56.8 ± 5.0             | 3.1 ± 0.1  | 2.4 ± 0.001           |
| None    | 28.4 ± 7.3             | 19.5 ± 18.0| 1.0 ± 0.001           |

5. Conclusion
We have investigated the potential to replace the conventional acrylic and glass fibre composite materials currently used in prosthetic limb socket manufacture with a water hyacinth fibre composite. Our comparative tensile strength tests indicated that water hyacinth fibres could produce a strong composite material.

6. Conflict of interest
The authors report no conflicts of interest.

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