The New Model of Lower Limb Prosthesis: Lower Limb Prosthesis Design Based on Indonesian Anthropometry

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Abstract.

There have been many different types of lower limb prosthesis offered today. in this paper, a new design has been created that aims to make a prosthesis without measuring the dimensions of the amputation patient's legs. The material used in this design is nylon filament and aluminum 6061. In designing the prosthesis, Indonesian anthropometry is used with ages above 12 years with the 95th percentile. The process of design and analysis using Autodesk Inventor software which uses the theory of finite element analysis. In the process, the analysis is carried out static loading test on the prosthesis and assumed the load is centered on the shank section. Static loading carried out on the prosthesis with nylon and aluminum material after testing showed that the maximum von mises value in the shank part is 0.83 MPa and the foot part is 0.76 MPa. The design of prosthesis using nylon filament and aluminum after analysis proved to be quite strong. However, in this design, the pressure testing that occurs in the socket section due to the load given is still unknown. In designing this prosthesis, it is also designed with three different sizes, considering the variation in the shape of the calves of each different amputation patient.

Keywords: Von mises, Prosthesis, filament, anthropometry

1 Introduction

Lower limb amputation mostly caused by complications of diabetes mellitus which according to the World Health Organization (WHO, 2014) the number of diabetic patients has increased from 180 million in 1980 to 420 million in 2014 **(Nakajima, Yamamoto, & Katsuhira, 2018)**, peripheral arterial disease or combination by diabetes mellitus and peripheral arterial disease **(Devinuwara, Dworak-Kula, & O'Connor, 2018)** or caused by accident **(Shuxian, Wanhua, & Bingheng, 2005)**.

Amputee patients who lived in low-income countries rather difficult to get a prosthetic leg because of the high price. Therefore, it needs material to reduce the high price of a prosthetic leg. We are using aluminum and nylon filament as the main materials of our prosthetic leg. Ultra nylon is material which suitable for automotive and it has high mechanical strength **("New nylon filaments for 3D printing," 2015)** and aluminum as the shank that aims to get a light material and adequate.

In this paper has discussed how to design and modeling prosthetic leg using finite element analysis. Finite Element Method (FEM) is a method to obtain approximate solutions of boundary value problems in engineering using computational technique **(Pradhan & Chakraverty, 2019)**.

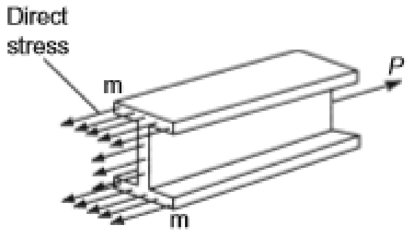
1.1 Material Strength

To make a product, we must know the type of material we use and the most important is the strength of the material. Failure of an engine element is one of the reasons for the occurrence of plastic deformation, however, failure caused does not make the entire engine stop functioning **(Herry Sonawan, 2010)**.

1.1.1 Stress and Strain

In a stress and strain theory, there is stress named direct stress (Megson, 2019). There is direct stress produced by an axial load. Here is an example of a picture of the material affected by the force distribution.

Figure 1: Force distribution



(Megson, 2019)

Based on the figure in figure 1, it can be seen that when the material is exposed to force (tensile or compressive forces), the overall surface of the material will be affected uniformly **(Megson, 2019)**. The stress can be symbolized as σ and to find the stress value in the material affected by the force, we can get from the formula as follows.

$$\sigma = \frac{\mathrm{p}}{\mathrm{A}} \tag{1}$$

Which (p) is compressive or tensile and (A) is a cross-sectional area.

1.1.2 Nylon

Nylon is often used in the industrial world, especially in mechanical properties, for example in the manufacture of gears, bearings, airbags, and others **(Setoodeh & Farahmand, 2018)**. Another advantage of nylon material is that it has good durability **(Setoodeh & Farahmand, 2018)** and also has high wear resistance **(Kumar & Panneerselvam, 2016)**.

Nylon material is a type of thermoplastic material **(Pan, Zhao, Xu, Hou, & Yang, 2016)**, which means this material will melt when exposed to hot temperatures or heated and will become solid when cooled. With the property of this thermoplastic, products made using this material when damaged or become waste can be reused or reproduced.

1.1.3 Aluminum 6061

As with nylon material, aluminum is also widely used in the industrial world. Aluminum is mainly used in aircraft, defense, automobiles, and marine applications because of its strength and availability as well as its corrosion properties **(Rao & Mallikarjuna Rao, 2018)**. Another function of aluminum is that besides this material is strong, aluminum is also a lightweight material **(Jirón-Lazos et al., 2018)**.

1.2 Prosthesis Design

There has been very much done by previous researchers in the design of prostheses especially lower limb prostheses. Therefore, on this occasion, the researcher can design a new prosthesis model based on studying previous designs. Next below is the design of the prosthesis that has been made by previous researchers.

Figure 2: Ankle Foot Prosthesis

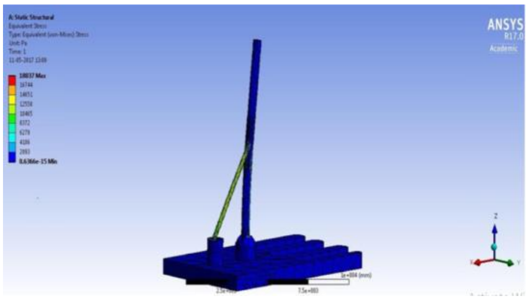
(Jin, He, & Shih, 2016)

Ankle-foot prosthesis (AFO) is a prosthesis made for patients who experience musculoskeletal or neuromuscular dysfunction, as in stroke patients, multiple sclerosis and others **(Jin et al., 2016)**. This product is intended to help with ankle movements due to unstable ankles which can also be caused by accidents or muscular imbalances. From the picture shown in figure 2 it also appears that a belt is used to reinforce the prosthesis when used. The AFO design made by the previous researchers contributed in the form of an idea to the researcher in making a new model of a lower limb prosthesis which will be discussed in this paper.

1.3 Stress Analysis

Stress analysis is conducted to find out whether a design that is made is strong enough to receive a load. The following is an example of a stress analysis image that was performed on the design of a foot prosthesis.

Figure 3: Stress analysis



(Debta & Kumar, 2018)

Design testing in the research seen in figure 3 uses ANSYS software, which shows several colors. Each color shows value to find out how significant the design is made when exposed to the load. This research was carried out with static loading. To determine whether the design is made safe or not, it can be determined by looking at the minimum and maximum values of von-mises **(Debta & Kumar, 2018)**.

1.4 Anthropometry

Anthropometry is handling design problems by collecting numerical data related to human physical characteristics such as size and shape **(Nurmianto, 1996)**. Some considerations that must be determined to get the data as thoroughly as possible can be:

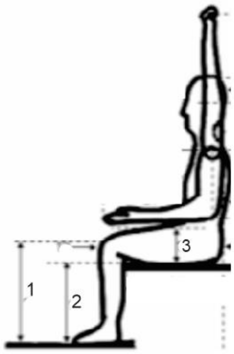
1. How large is the number of samples that must be measured
2. Whether the sample to be taken is limited to a particular community
3. When data is obtained, can the data be applied to other populations

The difference between one population and another population is determined by several factors, namely as follows **(Nurmianto, 1996)**.

1. Randomness or random
2. Gender
3. Ethnic groups
4. Age
5. Type of work
6. Clothes
7. Pregnancy factors in women
8. Physical disability

The following are data from anthropometry based on the dimensions of Indonesians with ages 12 and above, with the 95th percentile.

Figure 4: Indonesian anthropometry



(Hartono, 2018)

Table 1: Data of anthropometry

Number	Dimension	95th	SD
1	Knee height	20.2	3.2
2	Popliteal height	62.1	4.6
3	Thigh thickness	49.1	4.6

(Hartono, 2018)

Note: For the data above the sample is male and the size or dimensions in cm.

2 Methods

2.1. Phase of Research

The following is the design phase of the prosthesis that will be carried out.

1. Study of literature
2. Design process
3. Design testing
4. Evaluation

1. Study of literature

Literature studies are conducted to study previous studies and to study the theories needed to help design this prosthesis and also can help in solving problems in design.

2. Design process

The design starts with each part which will be divided into three parts, namely socket, shank, and foot. For the socket and foot parts use nylon material while the shank part uses aluminum 6061 material. The design process uses the Autodesk Inventor software.

3. Design testing

For design testing, software simulation was conducted which in this study also uses Autodesk Inventor. The design will be simulated in software with static testing or in this simulation called stress analysis.

2.2 Design Criteria

1. Robust

The prosthesis is able to withstand the load, which is in the literature studied the average maximum load of Indonesians over 12 years is 58.5 kg **(Hartono, 2018)**.

2. No corrosion

The material used is not easily corroded.

3. The prosthesis that is designed not too heavy but does not reduce in terms of material strength.

3 Result

The following are the parts of the prosthesis design using Autodesk Inventor software

1. Socket

As explained before, the socket part is made of nylon material and its dimensions are made in accordance with the anthropometry of the Indonesian people.

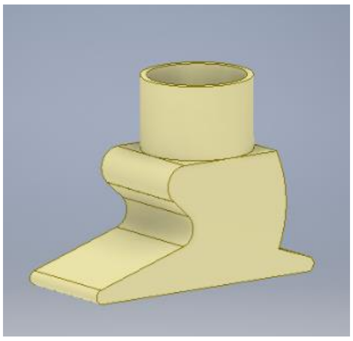
Figure 5: Socket part

The socket is designed to be able to adjust various variations of the shape of an Indonesian calf so that in the making there is no need to measure the dimensions of the amputee's calf patients.

2. Foot

As important as the shank part, the foot part also receives the same load, because in this study the load is assumed to be in line with the shank part and foot part.

Figure 6: Foot part



3. Shank

In making the shank, which is aluminum 6061 and cylindrical, it can use the following formula to determine the diameter of the shank to be able to withstand the load.

$$Strenth > \frac{\mathrm{p}}{\mathrm{A}} \tag{2}$$

From the formula above, shows that the value of material strength must be bigger than the load that works. Based on the specifications in Autodesk Inventor, the strength of the aluminum material is 31 MPa.

$$31\ MPa > \frac{573.7\ \mathrm{N\ x\ 15}}{\mathrm{A}} \tag{3}$$

$$A > \frac{8605.5\ \mathrm{N}}{31\ \mathrm{N/mm^{\wedge}2}}$$

$$A > 277.6\ \mathrm{mm^{\wedge}2}$$

Note: The value of p is taken from the average weight of Indonesian people **(Hartono, 2018)** and the value (15) is the maximum value of the safety factor according to Autodesk Inventor software specification.

From the results above, the diameter for the shank part can be determined.

$$A = \frac{\pi}{4} d\char`\^2 \quad (4)$$

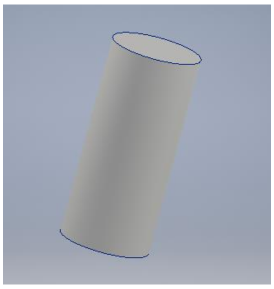
$$277.6\, mm^2 = \frac{\pi}{4} d\char`\^2$$

$$\mathrm{d}^2 = \frac{277.6\, mm^2}{0.8}$$

$$d = 19.33 \text{ mm}$$

Calculation of diameter shows that for the safety factor in the shank part, the shank diameter must be bigger than 19.33 mm. The following is a picture of the shank part. In this design, the shank diameter has been determined to be 36.5 mm.

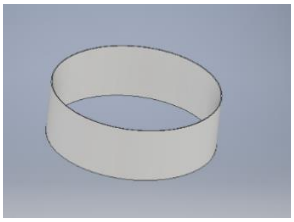
Figure 7: Shank part



4. Belt

Belt serves to strengthen or stabilize the socket when exposed to the load. The material used is polystyrene.

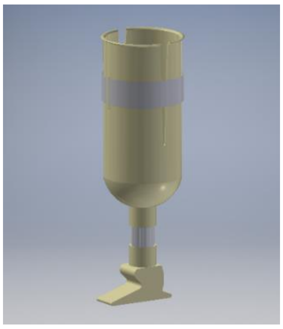
Figure 8: Belt part



3.1 Product Image

The following are the lower limb prosthetic parts that have been assembled.

Figure 9: Assembly parts



The total height of the lower limb prosthesis is 491 mm. with the height of the socket part is 250 mm, the shank part is 90 mm and the foot part is 51 mm.

3.2 Simulation

1. Von mises

The following is a static loading stress analysis simulation image that is equal to 573.7 N using Autodesk Inventor.

Figure 10: Von mises

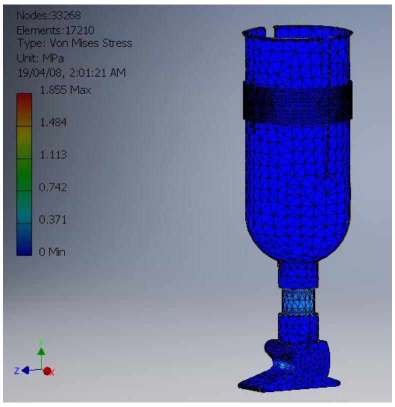
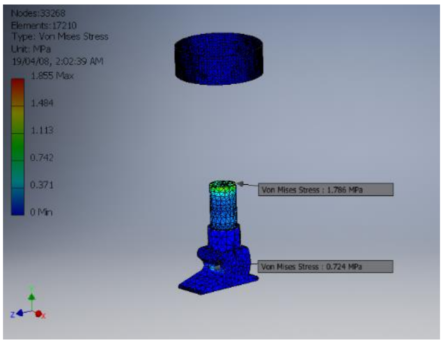


Figure 11: The part that is affected by the biggest load

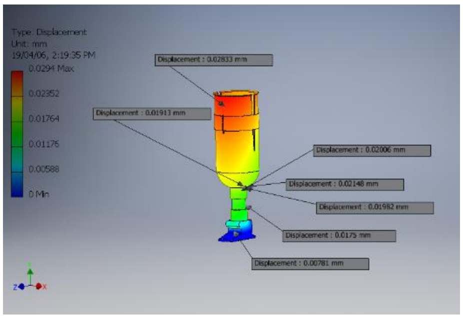


Based on the picture above, the part that is affected by the biggest load is in the shank and indentation in the foot. The maximum value of von Mises in the shank section is 1,786 and in the curve of the foot is 0.724. The unit used in this test is MPa.

2. Displacement

The following is a picture of displacement from the design of the lower limb prosthesis after being given a load.

Figure 12: Displacement



Based on the picture above, the simulation results show that the largest displacement value occurs in the socket section which is equal to 0.02833. Unit in mm.

4 Discussion and Conclusion

From the tests that have been conducted, the maximum values obtained have not exceeded the maximum limit of the von Mises value and the displacement value. however, based on the values obtained, the magnitude of the dimensions that have been designed are still not safe enough to accept the burden that is charged which is 573.7 N. Therefore, it is necessary to make improvements to the design, namely by improving or changing its dimensions. This improvement focuses on changing the shank part dimension and dimension on the foot part. The following are dimensions of the shank part and foot changes.

Figure 13: Foot part after repair

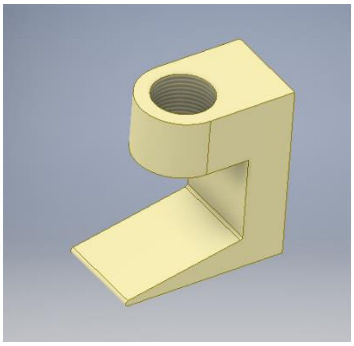
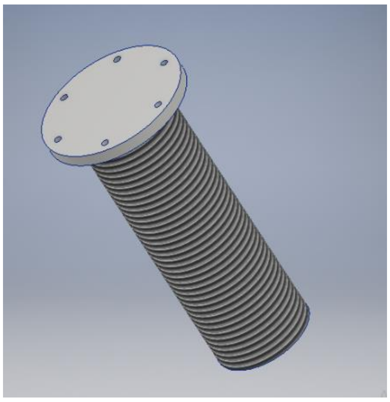


Figure 14: Shank part after repair



The diameter of the shank part has been raised to 40mm and reduces the curve slightly in the foot part. The following is a test result or static test re-simulation.

Figure 15: Von mises value on shank part

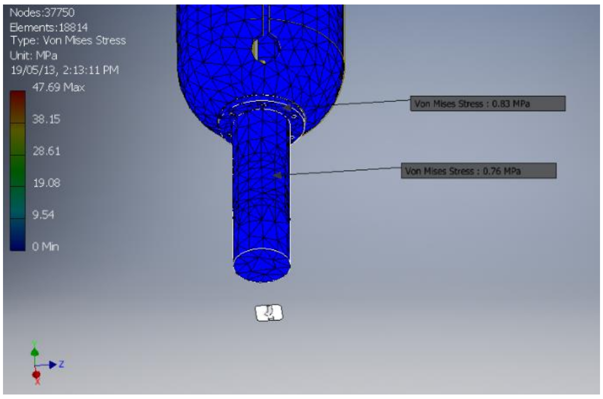


Figure 16: Von mises value on foot part

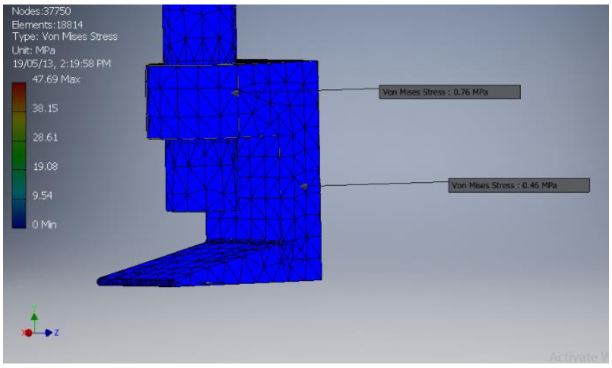
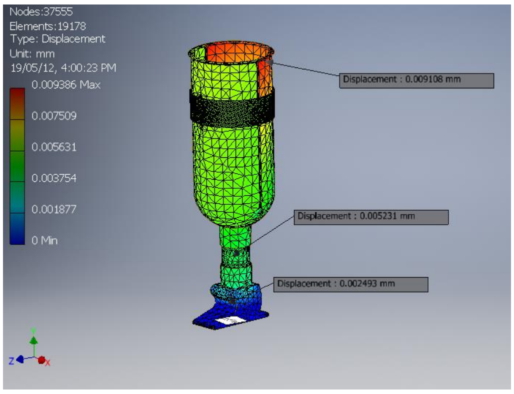


Figure 17: Displacement value after repair



After retesting, the maximum value of von Mises and also the maximum value of displacement has decreased. These values are also far from the maximum stress value indicated in the test in Autodesk Inventor Simulation. The maximum value in the shank section is 0.83 and on the foot section, the maximum value is 0.76 from the maximum value of von Mises shown is 47.96 (All unit in MPa).

From the above test after changing the design dimensions of the foot and shank parts, it can be concluded that in accepting loads of 573.7N, the design can be said to be safe. Although the value of the displacement is large enough, it can be neglected by looking at the von Mises value which indicates the design is strong enough to withstand the load.

In this study there are still many weaknesses, especially in the socket section, it is unknown how much pressure occurs in the socket when the load is given. The following is the final model of the lower limb prosthesis.

Figure 18: Final model of lower limb prosthesis

From this final model, additional function is added, the prosthesis can be adjusted in height.

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