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Alternatif Design of Compliant Mechanism Based Ankle Foot Prosthesis

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Abstract. People with permanent disabilities such as transtibial amputees can be independent and lead normal lives through prosthetics. Foot prosthetics is currently a custom product that is adapted to the features of the amputated leg, so it is more expensive and time consuming. Artificial foot products in Indonesia are still dominated by imported products, so they have high prices and are difficult to reach for lower-middle class amputees. The purpose of this study was to create an alternative design of the ankle foot for users of below-knee prosthetics. The design was made using Solidwork software. Two types of alternative ankle foot designs were produced in this study. Both designs apply a compliant mechanism system to make it more flexible when used. The design is made to meet one of the specified criteria, namely light weight with a mass of less than 2.3883 kg. Three alternative materials are offered in both design alternatives, namely Acrylonitrile Butadiene Styrene (ABS), Poly Oxy Methylene (POM), and AISI 304. Based on the design, it is found that the lightest design is owned by an alternative ankle foot design 1 with ABS material that is equal to 62.69 gram.

1 Introduction

The number of subjects with amputations, especially in the lower extremities, is increasing due to several things such as the incidence of diabetes mellitus and accidents [1]–[3]. The prosthetic components for limb amputations have been designed in such a way but still have drawbacks. Some of these shortcomings include the presence of high energy consumption, asymmetry in the force applied to the lower limbs, and pain when walking [4][5]. For this asymmetry, prosthetic feet were developed utilizing elastic energy storage and return (ESAR) to assist walking such as body support, initiation of leg swing, forward propulsion normally performed by the plantar flexor of the foot in non-amputation [6]. Individuals with transtibial amputations using the ESAR type of foot showed greater peak prosthetic ankle power (push-off) when compared to solid ankle cushion heel feet. This ESAR feet also contributes to supporting the user's body thereby limiting the movement of the prosthetic leg [7].

The prosthesis is assembled from artificial components of the toe, sole, and socket. Artificial leg products are expected to be able to withstand the weight of the body when used for walking. In recent years, several types of technologically advanced prosthetic limbs have been released to the market with

a wide range of available devices. Eventhough, there are still difficulties for patients in choosing the most appropriate prosthetic limb. This is still a challenging because there are no generally accepted clinical guidelines based on objective data to obtain an optimal prosthetic limb for recovery from the rehabilitation process [8].

Most of the research on transtibial amputees discusses the comparison of gait in ESAR and Solid Ankle Cushioned Heel (SACH) foot users [9]. The ESAR type foot prosthetic used by transtibial amputees has been shown to have a better clinical effect than the SACH leg in terms of energy cost of walking [10], gait symmetry in ascending stairs [11], and biomechanical parameters such as power absorption in the period of increasing weight-bearing prosthetics and ankle range of motion (RoM) [12]. Rigney et. al [13] use finite element method as a method for standardizing the assessment of ESAR mechanical performance as it allows the control of variables such as bodyweight, friction and orientation. Fey et. al [14] The influence of prosthetic foot stiffness on muscle and foot function by developing forward dynamics simulations of below knee amputee walking with a range of foot stiffness level.

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Along with the development of manufacturing technology and advances in materials science, the prosthetic industry is also growing rapidly. So far, prosthetics are designed specifically for each person (custom products) with precise measurements to ensure proper fitting. This makes prosthetics expensive. The high cost is also caused by the selection of materials and machining process time. The foot prosthetic designed must have sufficient but light properties to be able to support the body without interfering with its normal function. This can be done by selecting the right material and design.

A prosthetic feet design with a type-compliant mechanism can be used to ensure proper movement during the gait cycle. This mechanism is elastic so it can help in terms of using the principle of energy storage and return. In addition, this mechanism is also able to reduce production costs because it is durable and easy to manufactured [15]. The compliant mechanism is suitable for use in the ankle foot because it is strong enough to withstand the load and the material used [16]–[19]. The compliant mechanism is designed in such a way as to imitate the actual movement of the foot so as to improve the quality of comfort for patients using foot prostheses, especially in transtibial amputee. Therefore, the design of a compliant mechanism-based ankle foot prosthesis is very suitable to be applied [20].

The aim of this research is to design a lightweight but strong of the ankle foot prosthesis for the transtibial amputee. To obtain these criteria, in this study, two alternative prosthetic designs for the ankle foot and several types of materials are provided. Based on the design results and testing of the material offered, the prosthetic weight data will be obtained, so that it can be taken into consideration in the production process.

2 Material and Method

Figures and tables, as originals of good quality and well contrasted, are to be in their final form, ready for reproduction, pasted in the appropriate place in the text. Try to ensure that the size of the text in your figures is approximately the same size as the main text (10 point). Try to ensure that lines are no thinner than 0.25 point.

The process of making the ankle foot design in this study begins with a literature study related to the designs that have been published. In addition, it is also observed about the products of the ankle foot that have been circulating in the market. Based on the results of the literature study and subsequent observations, the advantages and disadvantages are analyzed for further development. Some of the improvements made were related to the shape, weight, and size of the product [17]. There are two design results of ankle foot in the form of alternative design 1 and alternative design 2. Making alternative designs is done to get the best design by considering the criteria that have been determined. One of the criteria for this ankle foot design is light weight with less mass than the actual

foot. The maximum weight of the prosthesis mass is calculated according to the following formula:

$$\text{Maximum mass} = 5.7\% \times \text{lowest mass} \quad (1)$$

The mass calculation here follows from the anthropometry of the Indonesians, with the lowest average weight of 39.8 kg, so the mass of the prosthesis is less than 2.3883 kg. In cross-section, the ankle foot design is made mimic to the ankle foot original by considering its elasticity. The design process begins with measuring the geometry of the foot through scanning using the EinScan Pro 2X Plus. The scanning process is carried out to obtain the full contour of the ankle foot, so that it can be used as the basis for designing the ankle foot. The results of the foot scan are shown in Fig. 1. Furthermore, the ankle foot design is done using Solidwork software. The design results obtained from this study are shown in Fig. 2. To get an ankle foot design that fits the criteria, namely in terms of lightness, several types of materials are provided to be applied to the two alternative designs. Some of the materials and their properties that have been selected in this study can be seen in Table 1.

Tabel 1. Material Properties [19]

Material	Property	
	Young's Modulus (MPa)	Poisson's Ratio
ABS	2300-2750	0.37
POM	2900-3500	0.42
AISI 304	193000	0.29

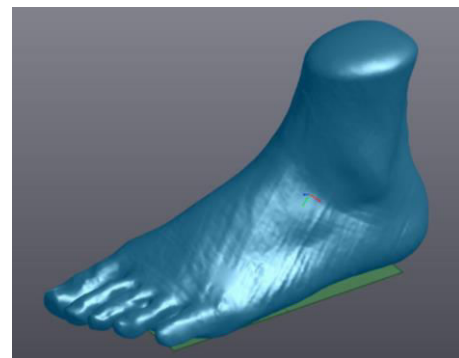


Fig. 1. Foot scan result using EinScan Pro 2X Plus



Fig. 2. Artificial Ankle Foot Design Alternative 1 (a) and Alternative 2 (b)

3 Result and Discussion

The ankle foot prosthesis in this study was designed to help below-knee disabilities to carry out daily activities, especially normal walking. The ankle foot prosthesis design is made by developing from the existing designs. This development is aimed at obtaining a more ergonomic and mass-produced product. That way, in addition to getting a product that is comfortable to use but also has an economical price, so that it can be reached by the lower middle class. Design development is carried out on the geometry and alternative materials used. The alternative designs obtained in this study were obtained by studying the anthropometry of the prosthesis user first, so that the design could truly mimic the original form. The anthropometry that is the basis for this research is the anthropometry of the Indonesian people with the largest average human weight being 89.5 kg and the lowest human weight being 39.8 kg [20]. This body weight is used as a reference in designing the foot prosthesis, because the prosthesis must be able to support the maximum weight of the user.

Based on predetermined criteria, the ankle foot prosthesis design must be able to withstand a human body weight of 100 kg. As for based on the calculations that have been done, the weight of the prosthesis that should be designed is less than 2.3883 kg. Furthermore, based on predetermined criteria, an alternative ankle foot prosthesis design was made using solidwork software. There are two alternative ankle foot designs made in this study. This is because to get the best design according to the criteria, ergonomic and economical product. The two alternative designs made apply the compliant mechanism system. This mechanism is located on the heel which is made to resemble the letter C with the aim of flexibility of movement.

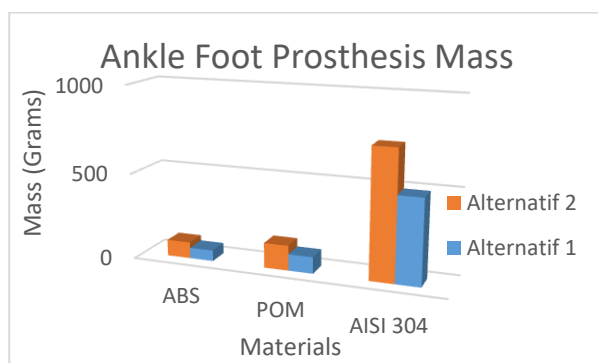


Fig. 3. Ankle foot Prosthesis Mass

Table 1. Ankle Foot Prosthesis Mass

Ankle Foot Prosthesis Design	Mass (gram)		
	ABS	POM	AISI 304
Alternatif 1	62.69	95.88	491.69
Alternatif 2	94.65	144.77	742.39

The results of mass measurements from two alternative ankle foot designs with several types of materials are shown in Fig. 3. Based on the results of mass measurements, the design that has the lowest mass is the alternative design 1 with this type of material is ABS of 62.69 grams. If seen on the graph,

the mass value in alternative 1 ankle foot design in each material is smaller than alternative design 2. This happens because in alternative 1 ankle foot design there is a reduction in material in the middle of the design. The mass measurement values for each design and material are shown in Table 1. Based on mass measurements, all alternative ankle foot designs meet the predetermined criteria, which is less than 2.3883 kg. However, these designs still require loading simulations to determine the strength of the design and the selected material.

4 Conclusion

This study makes an alternative ankle foot design by developing the geometry and materials used. The design is made to meet one of the specified criteria, which is light but able to support a body weight of 100 kg. There are two alternative designs that were produced by experimenting with three materials, namely ABS, POM, and AISI 304. Based on the design results, the lightest design was produced by an alternative design 1 with ABS material which was 62.69 grams. This design then needs to be simulated for the strength of the material to see if this design is able to meet the predetermined safety factor, so that it is strong when used, but has a light mass.

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