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Cite as: AIP Conference Proceedings **2114**, 050017 (2019); https://doi.org/10.1063/1.5112461
Published Online: 26 June 2019

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Numerical Analysis of Stress and Displacement on The Index Finger of The Prosthetic Hand Due to Hook Position

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Abstract. Upper limb disabilities become a serious concern in Indonesia. There are many prosthetic hand products from other countries, yet they rarely fit to Indonesian citizen, neither for the price nor the size. Due to this reason, Diponegoro University developed a prosthetic hand to solve the problem currently faced by the Indonesian citizen. It is expected that the produced prosthetic hand will be useful and suitable for Indonesian people, in terms of price and size. The design safety becomes the main concern in the development of prosthetic hand, and this paper investigated the reliability of the index finger of the prosthetic hand under the hook load. The results found out that the upper part experienced maximum stress at the value 17.993 MPa while the lower part experienced maximum stress at the value 29.472 MPa. The maximum stress that occurs on the index finger of the prosthetic hand is still under the yield stress of material. With the safety factor about 3.9 and 2.37 for upper part and lower part, respectively, it can be declared that the developed prosthetic hand is safe to perform hook position.

INTRODUCTION

According to the data of the National Socio-Economic Survey in Indonesia, in 2012, there are 2.45% of people with disabilities from an estimated 244,919,000 from Indonesian population [1]. Meanwhile, according to the statistics data from the data and information center of the Ministry of Social Affairs of Indonesia, there are approximately 119,529 persons with disabilities in arms and fingers. Of course, this number cannot be categorized as a small number. In the Law of the Republic of Indonesia No. 4 of 1997 concerning Disabled People, it is written that in the implementation of national development aimed at creating a just and prosperous society based on Pancasila as the ideology of the nation, people with disabilities are part of Indonesian society who also have the same position, rights, obligations and roles. Nevertheless, there is a problem related to the existence of supporting tools to overcome their limitations, especially for people with hand disabilities [2]. The majority of people with hand disabilities still use passive artificial hands so that they cannot perform most of functions in daily activities. Several commercial prosthetic hands are already available, including the Michelangelo, Bebionic, iLimb, and Vincent hands.

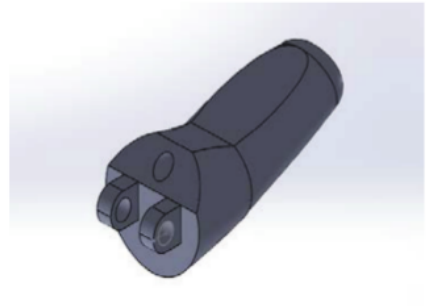
Exploring Resources, Process and Design for Sustainable Urban Development
AIP Conf. Proc. 2114, 050017-1–050017-6; https://doi.org/10.1063/1.5112461
Published by AIP Publishing. 978-0-7354-1850-9/$30.00

These hands have been designed with great performance for carrying out the daily activities, but the problem is the price is still relatively unaffordable for the majority of Indonesian people. Ariyanto et al. [3], in 2016, investigated about the low cost of anthropomorphic prosthetic hand. The target is to create a prosthetic hand that is affordable to Indonesian people. This research becomes one of the research initiated the development of prosthetic hand in Diponegoro University. As one of the prosthetic products that have been developed in Diponegoro University, this developed prosthetic hand was expected to be product that can solve the current problem. Having a cheaper price and size that is affordable and suitable for the majority of Indonesian people, the produced hand is potential as an alternative for disabled person. The present study is intended to investigate the reliability of the prosthetic hand currently developed in Diponegoro University, especially on the index finger in order to ensure it design safety.

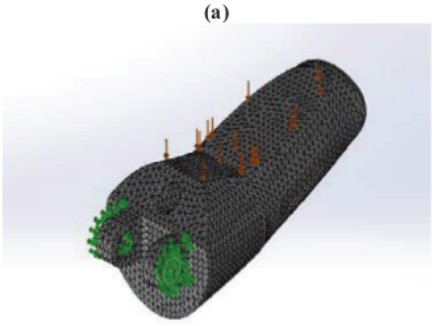
MATERIAL AND METHOD

Geometry Model

The geometry used in the present study was the index finger of the prosthetic hand that had been developed by Diponegoro University. The index finger was selected because the index finger always takes part in every movement as listed by the Southampton Hand Assessment Procedure (SHAP) [4]. The assembly of index finger consisted of two parts, namely the lower part of proximal phalanx and the upper part of middle phalanx and the distal phalanx. The mesh type selected for this study was the tetrahedral type. The selection of tetrahedral mesh was based on its capacity to model very complex geometry [5]. The detail of the total elements and nodes of each component can be seen on Table 1. Figure 1(a) shows the geometry model of the upper part while Fig. 1(b) shows the model of the upper part that has been meshed. Fig. 2(a) shows the geometry model of the lower part, and Fig. 2(b) shows the model of lower part that has been meshed.



(a)

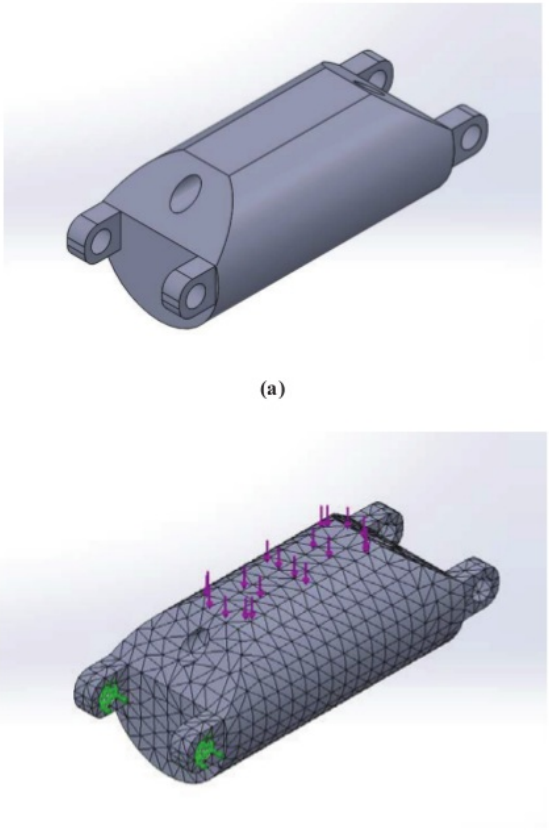


(b)

FIGURE 1. The geometry of the upper part of index finger of Asto hand V2: **(a).** The upper part geometry, **(b).** The upper part that has been meshed and the boundary condition position has been defined

TABLE 1. The total element and nodes of each models

Model	Elements	Nodes
Upper Part	19108	28762
Lower Part	13998	21234



(a)

(b)

FIGURE 2. The geometry of the lower part of index finger of Asto hand V2: **(a).** The lower part geometry, **(b).** The lower part that has been meshed and the boundary condition position that has been defined

Material

The material used in this research was Polylactic Acid (PLA). It is the material commonly used in the prototyping process of the prosthetic hand, which is created using the FDM 3D printing technology. The detail of mechanical properties of PLA has been clarified by Torres et al. [6]. Table 2 shows the mechanical properties of the Polylactic acid.

TABLE 2. The material properties of Polylactic Acid (PLA)

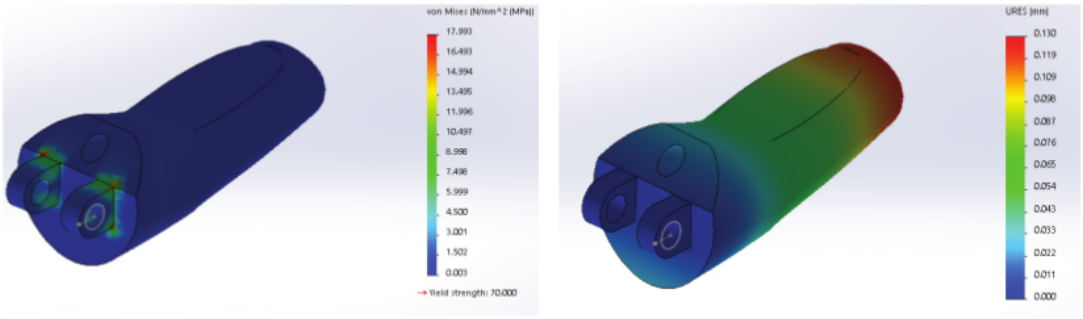
Material	Modulus Elasticity (GPa)	Poisson's Ratio
Density	g/cm^3	1.24
Elastic modulus	MPa	3500
Shear modulus	MPa	1287
Poisson's	-	0.36
Yield strength	MPa	70
Ultimate tensile strength	MPa	73
Elongation	%	~7

Boundary Condition

In order to determine the stress of each component of the prosthetic hand, the static simulation was conducted. In the present study, the static simulation was done based on Jones et al. [7]. The total load due to hook, W_h, is 112.8 N. Figure 2(a) shows the boundary condition of the upper part of the prosthetic hand. The upper part does not experience any direct load, in which based on Jones et al. [7], the upper hand applied by a load of 49 N distributes the load along the surface of the fingers. The joint of the upper part is also fixed and does not allow any movement in any direction. The red arrow shows the surface which the load is applied, and the green arrow shows the fixed support of the model. Figure 2(b) shows the boundary condition of the lower part. The lower part is applied with the load equal to $W_h/4$. The joint of the lower part is also fixed so it cannot be moved to any direction. Similar to the upper part, the red arrow shows the surface which the load is applied and the green arrow shows the fixed support.

RESULTS AND DISCUSSION

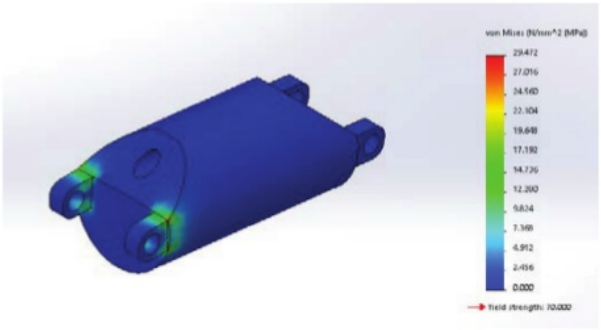
The result of the simulation is presented as the von Mises stress and displacement. Figure 2(a) shows the stress distribution that occurs due to the load that is applied on the upper part of the prosthetic hand. Figure 2(a) demonstrates that the maximum stress value occurs at the edge of the joint with the value of 17.993 MPa. This maximum stress occurs due to the sharp edge on the joint. This sharp edge creates a concentrated stress on the upper part. Despite of the stress that occurs on the upper part, this part still can be classified as a safe component with safety factor value of 3.9. It is because the maximum stress that occurs does not pass the yield stress of the material. Furthermore, Fig. 2(b) shows the displacement of the upper part. In Fig. 2(b) shows that the highest value of displacement occurs at the tip of the upper part with a value about 0.13 mm. The displacement on the tip occurs due to the distance from the fixed support that has been placed on the joint.



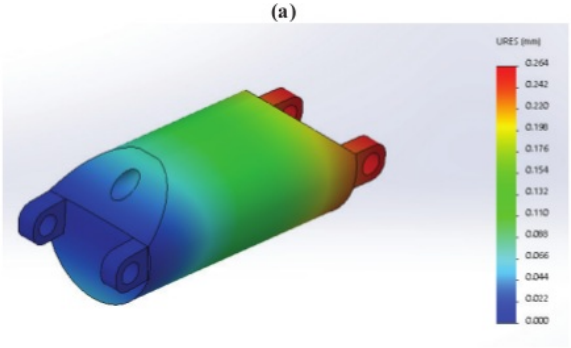
(a) **(b)**

FIGURE 3. The result of the simulation on the upper part: **(a).** Stress distribution that occurs on the upper part , **(b).** The distribution of displacement that occurs on the upper part

In Fig. 4(a) shows the distribution of stress that occurs on the lower part of the prosthetic hand. It can be seen that the maximum stress value occurs on the lower part, which is 29.472 MPa. From Fig. 4(a), it also can be seen than the maximum stress occurs on the edge of joint, similar to the condition of the upper part, in which this phenomenon is also caused by the sharp edge on the joint. However, the stress that occurs does not pass the yield stress of the material. With the safety factor of 2.37, the lower part can be classified as a safe part. In Fig. 4(b) shows the distribution of the displacement on the lower part. It can be seen that the highest displacement value of 0.264 mm occurs on the tip of the lower part. Similar to the upper part, the highest displacement value occurs due to the distance between the tip of the lower part and the fixed support.



(a)



(b)

FIGURE 4. The result of the simulation on the lower part: **(a).** Stress distribution that occurs on the lower part , **(b).** The distribution of displacement that occurs on the lower part

CONCLUSION

In the present study, the stress and displacement that occur due to the hook activity on the index finger of the prosthetic hand developed by Diponegoro University have been investigated. The index finger of the developed prosthetic hand becomes the focus of the study consisting of 2 (two) parts, namely the upper part and the lower part. The material used in the study was Polylactic acid (PLA). Based on the result, the upper part and lower part experience a maximum stress with value of 17.993 MPa and 29.472 MPa, respectively. The maximum stress of both parts occurs in the same place, the sharp edge of the joint. This sharp edge creates a concentration stress, and although the stress is still under the yield stress value, it still cannot be ignored. It is highly recommended that in the future design, the sharp edge can be fillet so that there is no sharp edge anymore. The fillet will help the geometry to sustain high stress.

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