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Manufacturing of A New Prosthetic Shank from Porous Functionally Graded Materials and Measuring of Properties it

Zainab H. Zaier[1*] Kadhim K. Resan[1]

[1] Dept. of Material Engineering, College of Engineering, Mustansiriyah-University, Baghdad-Iraq

Abstract

Amputations of the lower limbs are becoming more common as a result of vascular injuries or to remove the lower limb below the knee when it has been seriously injured. It must also be rehabilitated in order to regain strength and mobility in the safest manner feasible. The primary purpose of a socket, shank, and prosthetic foot is to allow someone who has had a limb amputated to do functional tasks, particularly ambulation (walking) that would otherwise be impossible. Prosthetic limbs are made of a variety of metals, aluminum, titanium, steel, and others. They are a common metals used for medical and engineering applications it has good strength to weight ratio, excellent corrosion resistance, and it is lightweight.

In this work, the shank was designed and analyzed in the Solid Work program and manufactured by a 3D printer. Two types of materials are used to construct the shanks (PLA, ABS). Then it was design a special device to examine the life of the new shank by alternating load. The mechanical characteristics of the new shank were good, corresponding to the specifications of the qualities of prosthetic limbs, after the practical and numerical examination of the shank.

Keywords: Amputee, Shank, Solid work, FGM , 3D printer, life Shank device

Introduction

A prosthesis is a device that allows someone who has had a limb amputated to perform functional functions, such as ambulation (walking). Lower limb prostheses are devices that attempt to replicate the function or appearance of a lost lower limb to the greatest extent possible. A prosthetic foot, pylon, adaptor, and below knee prosthetic socket are the four fundamental categories of lower limb below knee amputees [1]. The socket is connected to the ankle-foot assembly by the pylon and adapters. These pylons are intended to reduce fatigue and promote comfort by attenuating the shock loads generated when walking [2]. The shape of the shank, its weight, and the methods of interfacing are just a few of the important factors that influence the design of these components. The traditional leg's shank is built of light metal alloys to make walking easier and lessen the strain on the amputated limb. In this work, it was focus on the design of a shank, which was manufactured from polymers with function graded materials using a 3D printer. The previews studies indicate that the weight of prosthesis an important role based on where it is located with according to the components of the limb . Weight light is allow for more of the segments used in the improvement of the prosthesis to be added without having to change functional of desired properties [3]. In this field such , there are some researcher as **M Hillery, 2000** [4] Their studies were to design a dynamic elastic response of transtibial prosthesis which the power absorption and generation properties of an intact foot and shank segments could simulate .

K. L. COLEMAN, et al,2001 [5] They compared between a pylon made of aluminum and another made of nylon, and the results were that the nylon pylon was more comfortable and flexible and would enable people to walk faster.

Nathanial Grunbeck, et al, 2020 [6] designed of a low cost , easily manufacturing prosthesis and that has the ability to simulate of the gait cycle of a amputee , from ABS material, as it has high strength and good resistance of variation of temperature so it can be used in extreme climates in different countries.

Fariborz Tavangarian, et al, 2019 [7] studied of pylon of lower limb prosthetic was manufactured by additive fabricating technique. ABS materials was used as the filament materials of pylons for 3D printing. The 3D printed specimens have good compression requirements. This results is confirm that additive fabricating can be used to easily and efficiently create shanks and without using conventional methods.

Ameer A. Kadhim et al (2021) [8] design the shank with a 3D printer. As well as to study the effect of the new shank on the analysis of the patient's gait, and then to find out how much the new shank can withstand the repeated loads by knowing its mechanical properties.

The aim of the current work is to try a new shank design and manufacturing with a the porous functionally graduated in different dimensions by 3D printer. As well as to study the effect of the new shank on the analysis of the patient's gait, and then to find out how much the new shank can withstand the repeated loads by knowing its mechanical properties.

Also, the foot structure was investigation by different researchers to improvement the fatigue and mechanical properties for materials used to manufactured the foot, [9-12], therefore, many researchers used different reinforcement fiber to increase the strength and fatigue strength for foot, [13-16].

Experimental Work

Materials

The shank in this study , was made of two type of materials that must be high strength and light. In this work, PLA and ABS were used to manufacture the new shank by 3D printer technology. Also , and the porous functionally graduated materials method was used, to ensure a light weight and better distribution of the load, [18-20] .

Mechanical properties of PLA and ABS

- **Tensile test:** The mechanical properties of the materials are tested by tensile testing. The strength of tensile of an APL and ABS samples are typically determined in according to ASTM D638 [21]. PLA and ABS samples were tested and prepared in a controlled condition at a constant strain rate. The mechanical properties for PLA materials was greater than for ABS.
- **Hardness test :**Shore D Durometer is used to investigate hardness of specimens according to ASTM D2240 [22]. Type D is used to test hard rubbers and plastics.

Manufacturing of a new shank

Pylon shape was designed by SolidWorks software in the form of porous functionally graduated materials as shown in figure (1) There are three different spherical pore diameters from the shank center to its surface : 5 mm, 4 mm and 3 mm respectively , and the distance between them is 1.5 mm . These spherical pores were distributed in a radial manner in two models: the first with an angle of 45 and another model with an angle of 60. From the results of the analysis in the ANSYS program, it was found that the model whose radial angle was 45^{o} did not fail, nor did the model whose distribution angle was 60^{o}, but the number of spherical pores in the first model was larger and therefore its weight is less, so it was chosen, and then manufactured by the 3D printer .

The new shanks are made of PLA because it is the material with better mechanical properties than ABS according to tensile test results. Figure (2) shows the steps for manufacturing the shank.

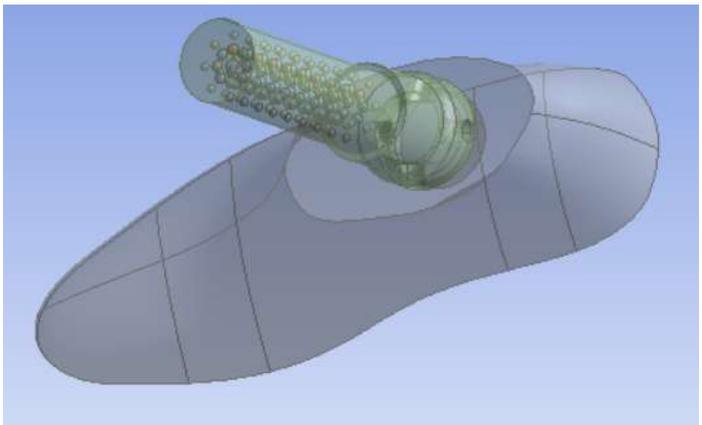


Figure (1) design of the porous functionally graduated materials shank .

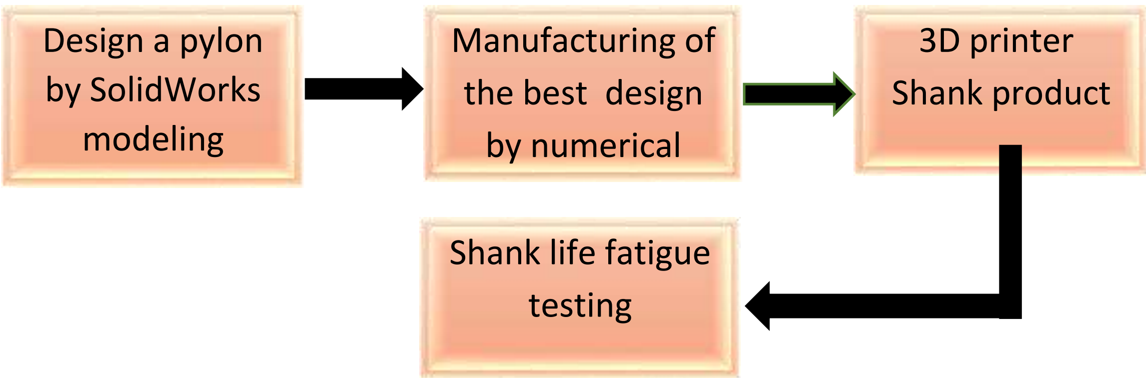


Figure (2) Manufacturing of a new shank steps

Case Study

The ground reaction curve starts low and then rises after the heel strike for a period of about 1.25 weight of person then the reaction value decreases at mid stance to reach a value of about 0.8 of the original body weight and then rises again to reach about 1.25 at toe off , until it drops just before the toe as shown in Figure3 . In this study, the weight of the amputee was 60 kg, and thus the highest reaction force was 735 Newton.

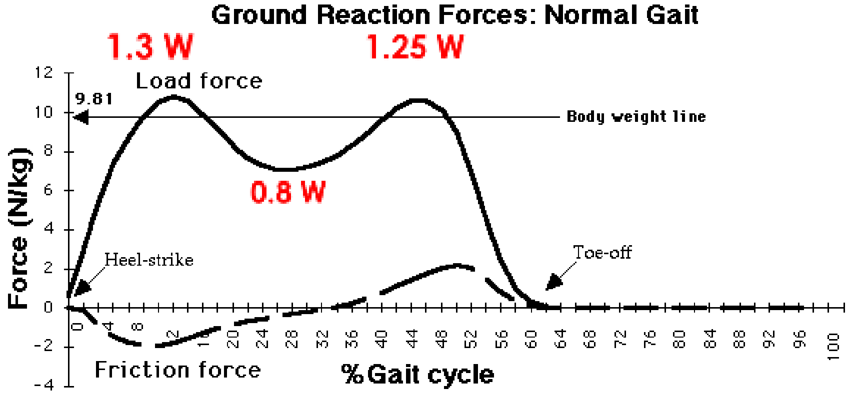


Figure (3) Ground reaction force curve

Design and Manufacturing of life shank tester

A life shank tester, was designed and built as shown in figure 4, was designed and built according to ISO10328 standards [23]. This device was manufactured to simulate a gait cycle of person's by variable load at heel strike and toe off loadings. At each cycle test, the electrical and mechanical components for the life shank tester included a two cylinders of pneumatic with a 60 mm stroke and 40 mm bore, as well as a record by counter to the number of cycles completed, a control system, two valves of solenoid, an air compressor, and an air filter, and electrical circuit control . All components were assembled with a regulator of pressure on the structural frame .

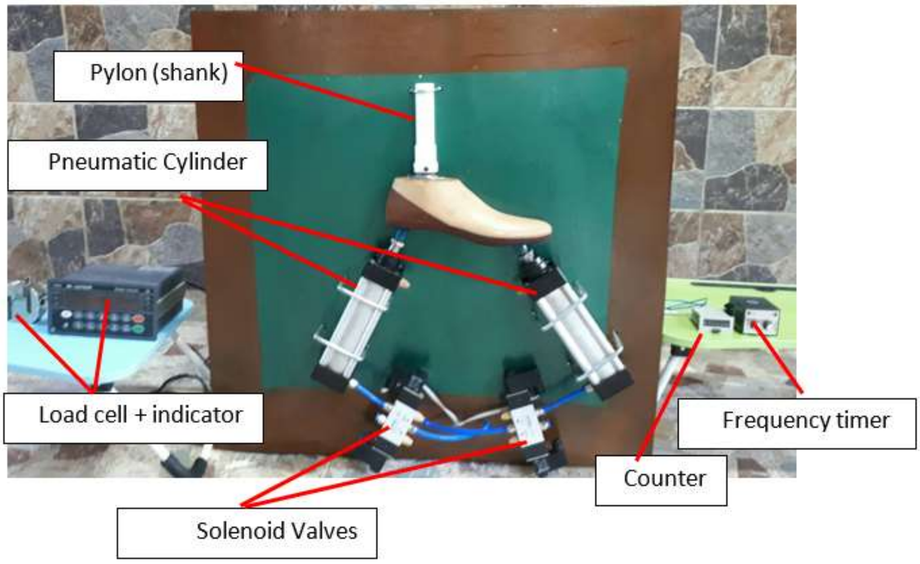


Figure (4) fatigue shank tester device

Numerical Analysis:

The numerical analysis was done by the ANSYS Workbench 20 program, after the two models (45° and 60°) were drawn and designed with the solid work program, and then the top of the shank area was fixed and a load was applied to the foot that simulates the simulating of ground reaction force, according to case study (735 N) in the case of the heel strike and then an area at the toes off . Firstly required selected the best element types can be used, [24-29], and then calculated the best element and node number must be used in the numerical technique by using mesh generation technique, [29-32]. The total number of nodes is 73453, type of element is Tetrahedral elements, shown in figure (5). After this, modeling the structure and applied the boundary condition for structure, and finally applied the load on the stricture was investigation, and finally solving the structure accordant to modeling selected, [32- 45].

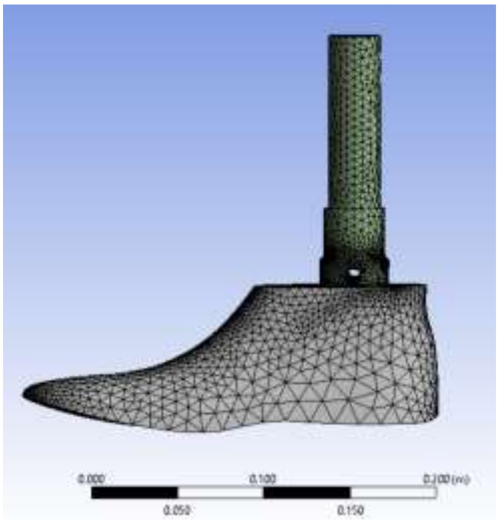


Figure (5) mesh of prosthetic foot and shank

Results and Discussion

- Tensile test results : from table (1) the ultimate stress , yield stress and modulus of elasticity of PLA is more than of ABS .

Table (1) properties of mechanical for PLA and ABS .

Materials	E (GPa)	σ_y(MPa)	σ_{ult}(MPa)
ABS	2.87	19.3	26.3
PLA	3.7	23.6	32.7

- Hardness (Shore D):

From table (2) the hardness type shore D for PLA materials is more then of ABS .

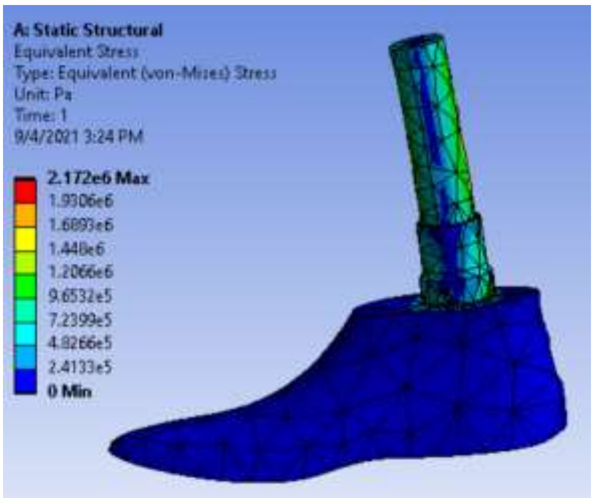
Table (2) Hardness value of PLA and ABS.

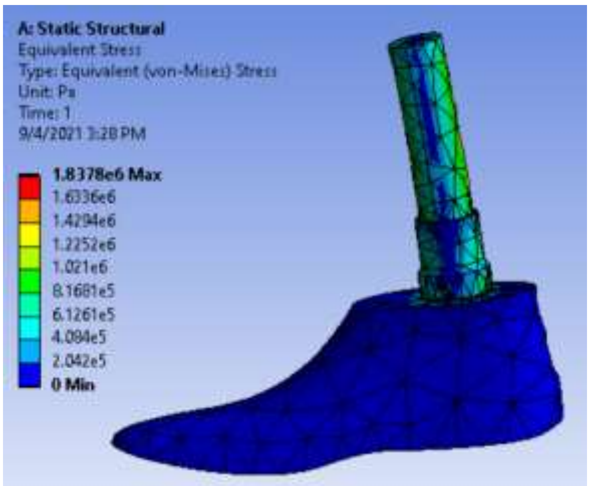
Materials	Value
ABS	34
PLA	46

From tensile test and hardness the mechanical properties for PLA materials was greater than ABS, therefore we used the PLA materials to manufacture of pylon.

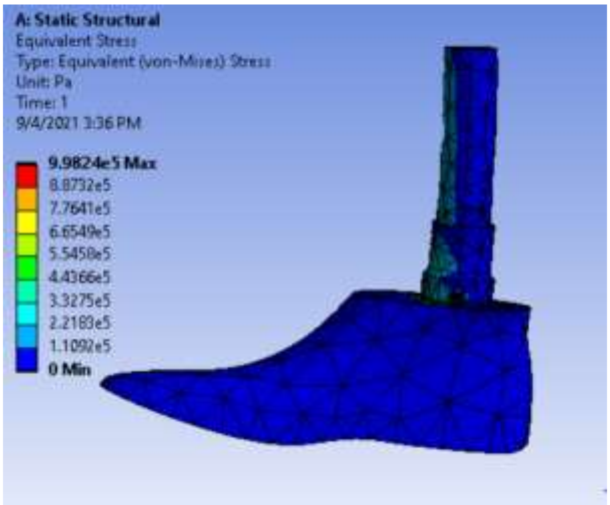
Numerical Results:

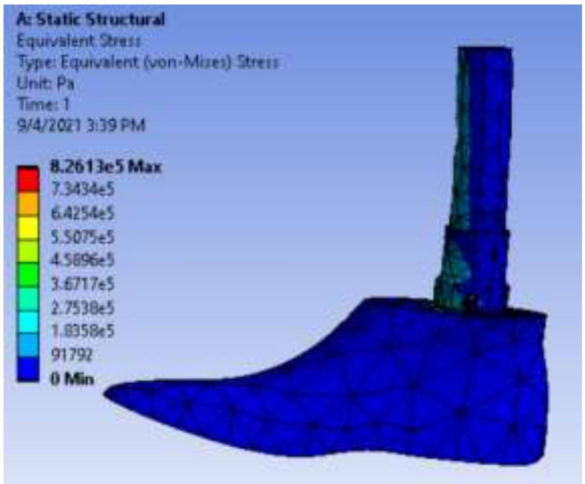
By numerical analysis of the first model and the second model, it was found that the difference of the highest equivalent stress was not large between them, as shown figure (5) and that also , the safety factor was large in all cases (at the heel strike and at the front of the foot).





(A) (B)





(C) (D)

Figure (6) Von Misses stress of A) model 45° at toe off , B) model 60° at toe off , C)) model 45° at heel strike , and D) model 60° at heel strike .

Fatigue Shank Test Results

The life expectancy of the shank (model 45°) was tested by the shank life test device and it was found that the SACH prosthetic foot had failed with a number of 473,241 steps, before the shank failed, therefore the shank is considered good (un-failed) and its resistance to repeated load that simulates the human walking movement (gait cycle) and the ground reaction force during normal walking.

Conclusion

1. The new shank is easy to manufacture and inexpensive in addition to its light weight.
2. The 3D printer technique can be used to produce important and precise prosthetic parts such as the shank with adapters.
3. The new shank has good life comparing with the SACH foot .

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