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EFFECT OF THE GAIT SPEED ON A NEW PROSTHETIC SHANK BELOW KNEE

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Abstract: One of the most important problems that the components of the prosthetic limbs suffer from; the increase in walking speed leads to an increase in the ground reaction force. In this research, a new shank was design and manufactured using the porous functionally graded materials by a 3D printer of PLA material, and to ensure the success of this shank, several tests were conducted on it, including to know the mechanical properties, as well as the life test by a special device that was manufactured. A test was conducted to know the life of the shank when normal walking (about 1.35 m/sec) and running (about 6 m / sec) , and it was found that this shank that was successful and did not fail in that test, the prosthetic foot (type SACH) failed before it at normal speed and high speed.

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

1. 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. Light weight is allowing 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

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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 an 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 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. In the gait cycle, the increase in walking speed increases the force of the ground reaction to about three times that of normal walking, which makes it difficult to choose the components of the prosthetic limbs, as young people are more active and perform various activities, including running or pushing carts and others. [9], therefore, many researchers used different reinforcement fiber to increase the strength and fatigue strength for foot, [10-12]. The aim of this research, study of effect of the gait speed on a new prosthetic shank below knee.

2. Experimental Work

2.1. Materials

The shank in this study, was made of two type of materials that must be high strength and light. In this work, PLA was 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.

2.2. Mechanical Properties of PLA

Tensile test: The mechanical properties of the materials are tested by tensile testing. The strength of tensile of an PLA sample are typically determined in according to ASTM D638 [13]. PLA samples were tested and prepared in a controlled condition at a constant strain rate.

2.3. Manufacturing of a New Shank

Pylon shape was designed by SolidWorks software in the form of porous functionally graduated materials as shown in Fig. 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 with an angle of 45 ^{o}. Fig. 2 shows the steps for manufacturing the shank.

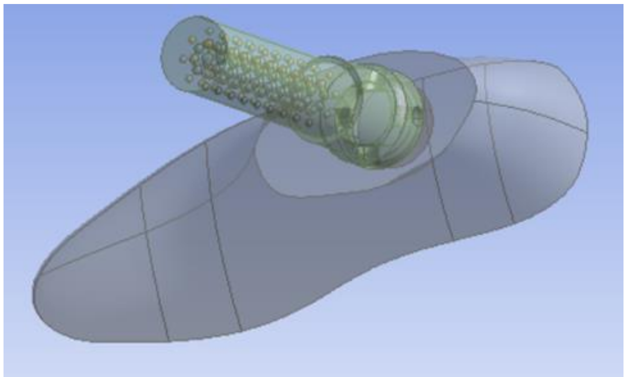


Figure 1. design of the porous functionally graduated materials shank.

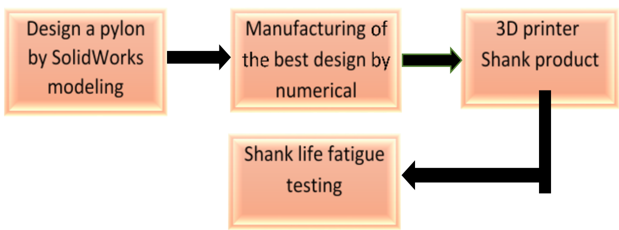


Figure 2. Manufacturing of a new shank steps.

2.4. Case Study

The ground reaction curve (normal walking) 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 Figure 3. In this study, the weight of the amputee was 60 kg, thus, the highest reaction force when walking was normal, which amounted to 735 Newton's, while when running, the maximum reaction force was 1618 Newton's [14].

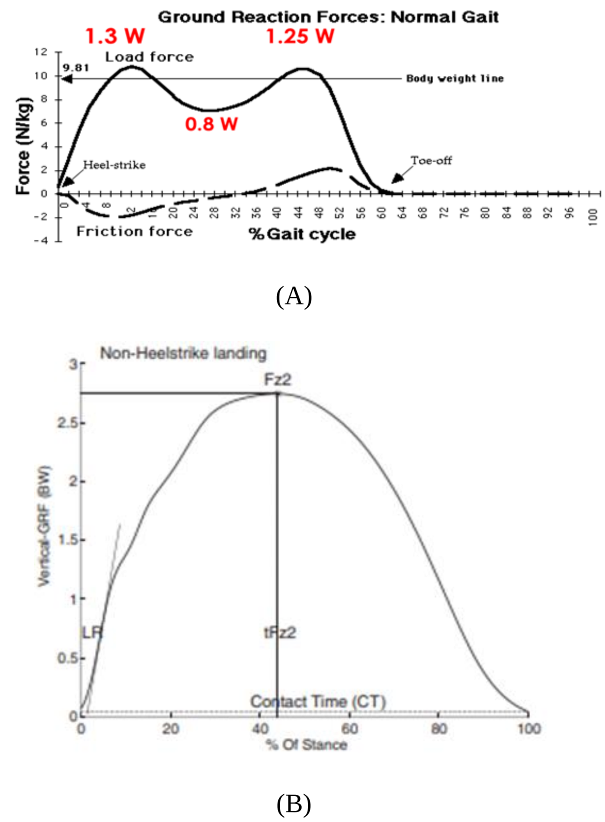


Figure 3. Ground reaction force curve at: A) normal gait, B) running.

2.5. Design and Manufacturing of Life Shank Tester

A life shank tester, was designed and built as shown in Fig. 4, was designed and built according to ISO10328 standards [15]. This device was manufactured to simulate a gait cycle of persons 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.

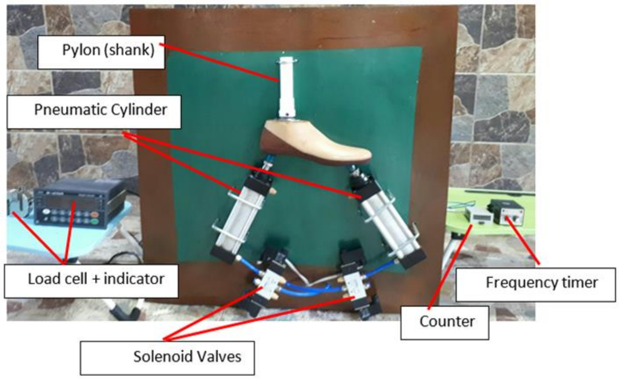


Figure 4. fatigue shank tester device

2.6. Numerical Analysis

The numerical analysis was done by the ANSYS Workbench 20 program, after the o model was 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 at normal walking (735 N) and at running (1618 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, and then calculated the best element and node number must be used in the numerical technique by using mesh generation technique. The total number of nodes is 73453, type of element is tetrahedral elements, SOLID186, shown in Fig.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, [16- 18].

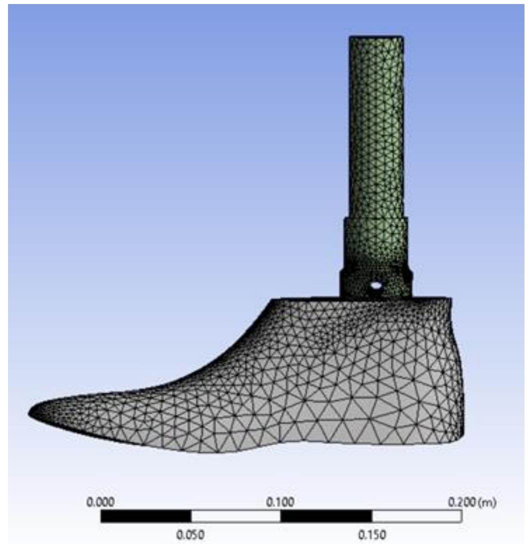


Figure 5. mesh of prosthetic foot and shank.

3. Results and Discussion

3.1. Tensile test results:

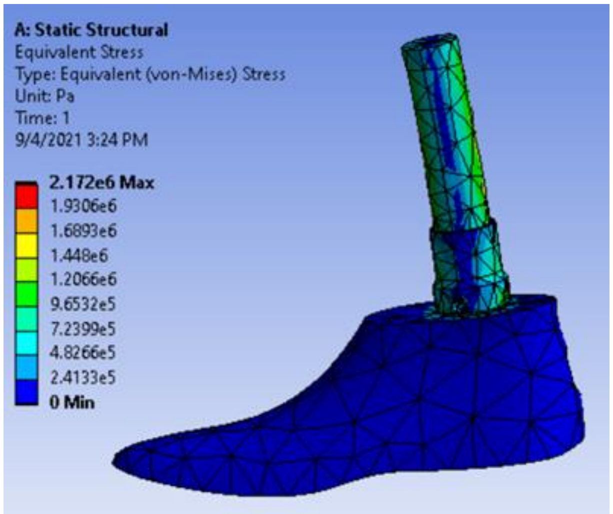
From table (1) the ultimate stress, yield stress and modulus of elasticity of PLA is more than of ABS.

Table 1. Properties of mechanical for PLA and ABS.

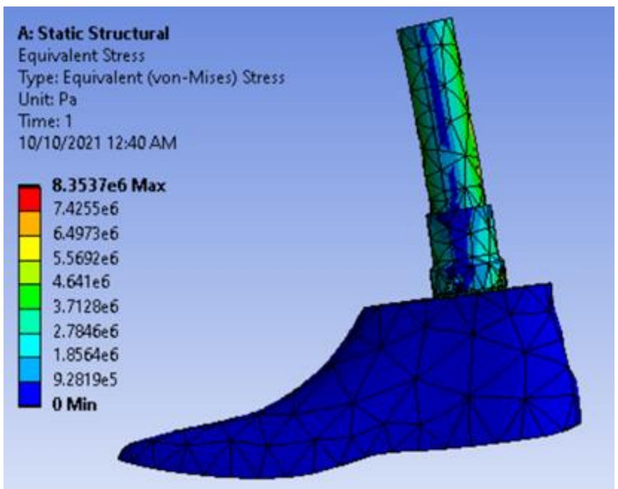
Materials	E (GPa)	σ_y(MPa)	σ_{ult}(MPa)
PLA	3.7	23.6	32.7

3.2. Numerical Results:

From the Fig. 6 it is clear that the stress at the toe off is higher than at the heel strike for model, because the torque in the toe off phase is greater than at the phase of the heel strike as shown in Fig. 7, which results in a high bending stress.



(A)



(B)

Figure 6. Von Misses stress of A) normal walking at toe off, B) running.

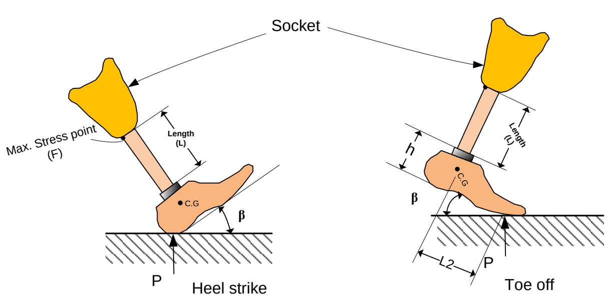


Figure 7. heel strike and toe off forces distribution.

Moment at point F

At heel strike

$$M = Psin\beta_1 \cdot (L + h) \quad (1)$$

At toe off

$$M = P(\cos\beta_2 . L_1 - sin\beta_2 \cdot (L + h)) \quad (2)$$

$$\beta_1 < \beta_2 \quad (3)$$

And β_2 is small

$$sin\beta_1 < \sin\beta_2 < \cos\beta_2 \quad (4)$$

Therefore moment at heel strike < moment at toe off

And the value of maximum stress at heel strike < maximum stress at toe off

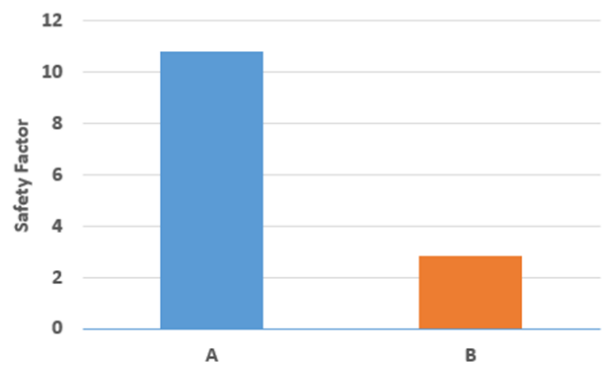


Figure 8. Safety factor A) normal walking B) running.

3.3. Fatigue Shank Test Results

The life expectancy of the shank (at normal walking) 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.

When running, the foot also failed with a number of 126,379 steps, because the ground reaction force was increased about three times as a result of the difference in acceleration of center of body and strength of the shock, and the phases did not appear clear. The cost reduction ratio between the new shank and the cost of the traditional titanium shank was about 92%. The weight reduction ratio between the new shank and the weight of the conventional titanium shank was about 37 %.

4. Conclusion

1- When the speed is increased, and with the increase in the reaction force of the ground, the new prosthetic leg did not fail.
2- The new shank design is characterized by low weight and good strength.
3- There is no heel strike phase when running fast, so the shape of the ground reaction force is in the form of a mountain with one peak.
4- The safety factor decreases by 72 % when running compared to normal walking

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Conflict of interest

The author confirms there are no conflicts of interest.

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