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Manufacturing and Analyzing of a New Prosthetic Shank with Adapters by 3D Printer

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ABSTRACT

A lower limb amputation is most often caused by accidents or limb disease. The primary purpose of socket, shank and prosthetic foot, is to provide means to replace the skeletal function, missing structure muscles of ankle, pylon and foot. Traditional prosthetic shank is manufactured from titanium-aluminum alloy due to its light weight. In this work, the shank is designed and analysis by solid work software and then manufacturing by 3D printer to ensure good distribution of load on the walls of shank. The new shank made from different materials (ABS, PLA). During the gait cycle test by force plate, the gait cycle there are two phases, one of which is the swing phase, the second phase is the phase stance, and the reaction force of ground is generated in this phase, amount for which is at the heel, toe is 1.3 of the amputee's weight, and then design a special device to examine the life of the new shank by alternating load. After the practical and numerical analysis of the shank, it became clear that the mechanical properties of the new shank were good, according to the requirements of the properties of the prosthetic limbs.

KEYWORDS

Amputee, Shank, Solid work, Gait cycle, Fatigue Analysis.

INTRODUCTION

An amputation patient may want to be able to a different of perform of activities without the need for a variable prosthetic. Hence it is need to define pylon characteristic as used in various processes. Consequently, this work have different normal cycle of walking. In addition, the lower limb prostheses (BK) consist of four main components: prosthetic foot, pylon, socket and adapters, [1]. Shank corresponds to lower anatomical leg, and is used to connect the prosthetic foot, ankle and socket. In the shank of the skeleton, the central pylon, a narrow vertical member, is located inside the cover of foamed cosmetics. Internal structure systems allow the prosthesis to be modified and reorganized. In the shank of the exterior structure, shank strength is provided by a rigid shell of outer that is either filled with materials of lightweight or hollow.

The shank the traditional leg is made of light metal alloys to facilitate walking and reduce the effort on the amputated limb, In this work, it was focus on design of shank and it is manufacturing from polymers by 3 D printer. In this field such, there are some researcher as N. Bern, et al,1994, [2] used a pylon include sensors to measure the moments and forces during gait cycle of amputee. Ian Brown and Ross Stewart, 2001, [3] analyzed shank problems using finite element which was used to analyze crack length and growth and then constructed a model by which to calculate the life expectancy of the shank.

Glenn K. Klute et al. 2001, [4],also investigated the mechanical properties of vertical shock absorbing shanks (VSAP), which are characterized by their vertical shock absorbing ability to the standard conditions for loading to assess the effect of the VSAP on gait cycle of amputees. Coleman et al., [5], 2001, studied the effects of transtibial prosthesis pylon of flexibility on (GRF) associated with gait and stepping. Jweeg et al, [6], 2010, designed and manufactured and analyzed the new pylon made from composite materials by vacuum technique and it is tested by ground reaction force and mechanical properties. They comparing the new shank with traditional shank, then they concluded the new shank ensures that the requirements for prosthetic limbs for amputations

below the knee.

Brian J. Addison and, Daniel E. Lieberman, 2015, [7] studied effect of stiffness of footwear on the impact at heel of foot. They provided a model to estimate a tradeoff between effective mass and loading rate of impact. They conducted several tests on 19 participating in three different walking and running shoes. The results show that ;the mass of effective decrease with increasing of stiffness of footwear and which the model are often wont to conclude the effect of stiffness on danger of the injury during running and walking.

In addition, from 2011 to now, [8-32], multi researchers study different limb part with various technique and manufactured different foot and other Prosthetic parts by using various composite and polymer materials. Also, multi researchers were investigated different parameter as mechanical properties and fatigue life, in addition to, stress analysis for prosthetic parts with different methods.

The aim of the current work is to try a new shank design 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.

EXPERIMENTAL WORK

Materials

The materials of artificial shank are a very effective cornerstone for designing a new artificial shank. The important note is to choose right prosthesis and this integrate of effectively it into the testor. Thus, a understanding of comprehensive of prosthetic of materials of shank enables the manufacturer to emerge of them to achieve the optimum benefit for the amputee [6]. Polypropylene, for example, is a polymer that consists of a monomer ethylene long chain. It is good to process, low cost, has good chemical resistance and high insulation. In this work, PLA and ABS were used to manufacture the new shank with 3D printer technology.

Mechanical Properties of PLA and ABS

Strength of tensile is a range time characteristic that provides a different comparison for or classification when placed under limit of conditions of loading rates and temperature. The strength of ultimate tensile of an APL and ABS samples are typically determined in according to ASTM D638 stander type 2, [33] by testing of tensile. In this inspect, PLA and ABS samples were prepared and tested in a specific condition at a constant strain rate. From tensile test, the mechanical properties for PLA materials were greater than for ABS. Therefore, the fatigue tested for PLA only to determine the S-N curve according fatigue test specimens, [34-39].

Manufacturing of a New Shank

The pylon shape was modeled by Solid-Works software and the model was transferred to printer of 3D, then the new shank was made of PLA because it is the material that has better mechanical properties according to the results of the tensile test. Figure 1 shows the stages of making the shank.

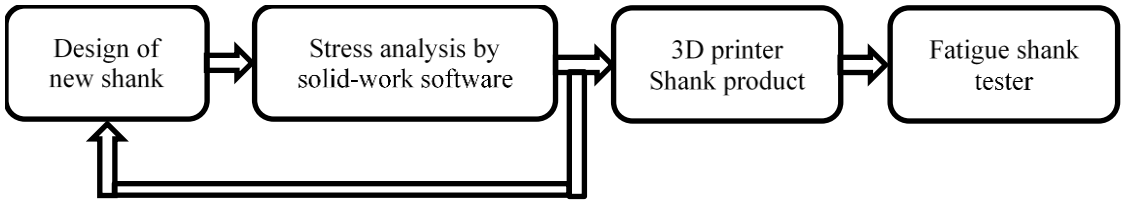

Figure 1. Manufacturing of a new shank stages.

Case Study

The kinetics data were collected via the young male subject below knee amputee, his age was about (17 years) with height (160 cm) and weight (39 Kg). The subject was wearing laminate socket with SACH foot.

Ground Reaction Force

By treadmill force plate test, the force of the foot applies on the ground is opposite and equal to the ground reaction

force (GRF). Ground reaction force is an important in step analysis because it acts as an external force on the body during movement. In the gait cycle, the highest value of the force generated is in the stance phase when the heel was strike, and then it decreases at mid stance and then rises at the toe off, so that its value was zero at the swing phase because the external forces are not affected. The moment at end of shank was generated which adds its effect due to the length of shank.

Manufacture of Life Shank Tester

A life shank tester, was designed and built shown in Figure 2, was manufactured according to ISO10328 standards, [40]. This device was manufactured to simulate a gait cycle of person's by variable load at heel strike and toe off loadings. The different components for the life shank tester at each cycle test consisted of two cylinders of pneumatic of 60 mm stroke and 40 mm bore, record the number (by counter) of completed of cycles, pair of solenoid valves, an air compressor and air filter, and indicator. All components were assembled with a regulator of pressure on the frame. The magnitude of force was according to ISO 10328 for a young patient of 39 kg generates a GRF of 480 N.

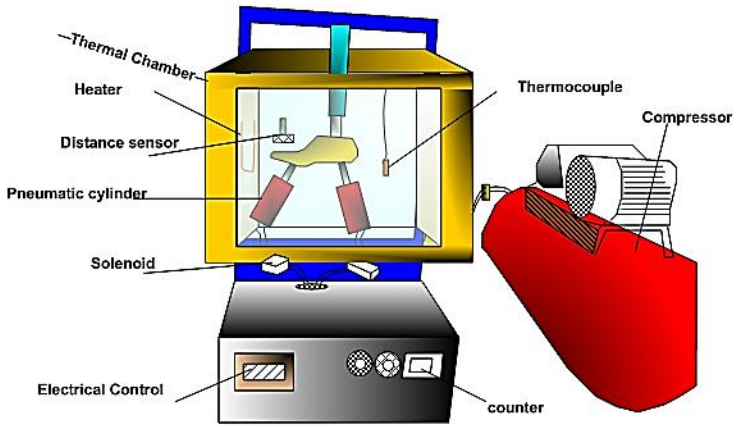

Figure 2. Drawing scheme of fatigue shank tester device.

FEM ANALYSIS OF SHANK

The numerical analysis by (FEM) was used in many fields of science and engineering widely, [41-57]. In this study, the software of solid-works was as a tool of numerical to find the Von Miss stress of the new shank proposed design. There, firstly, must select the best element type required for structure analysis, [58-69]. Then, the finite element meshing of shank, using element of a tetrahedron, was seen in Figure 3. The condition of boundary used in the solid-work software, the support was fixed at the above end of shank adapter, while the moment and load were distributed according to the GRF at toe off and heel at the appropriate differnt time. Convergence was relied upon to reduce the error and find the number of elements and nodes, or so total number of nodes of 4,166 with a number of elements was 1,713.

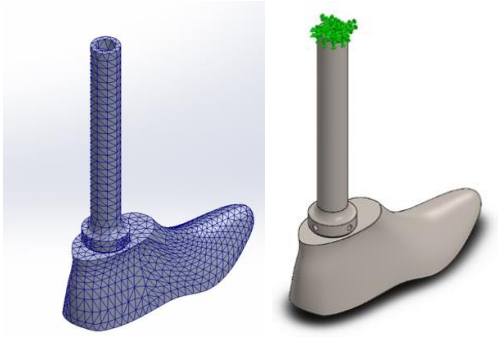

Figure 3. Mesh of shank and prosthetic foot.

RESULTS AND DISCUSSION

Results of Mechanical Properties

From tensile test properties of mechanical for ABS and PLA, Table 1. From the results of this test, it was found that: PLA material was better than ABS material, so the shank was made of PLA.

Table 1. Properties of mechanical for PLA and ABS.

Materials	E (GPa)	σ_y(MPa)	σ_{ult}(MPa)
ABS	2.9	18.9	27.4
PLA	3.7	22	31.6

Numerical Results

The numerical results as seen in Figure 4. The stress distribution at the was obtained found by using the solidwork program Workbench 15 software, as shown in Figure 4, it was found that the stress of equivalent (3.66 MPa) at toe off region in foot. The minimum equivalent stress (0.15 MPa) is found nearly from the medial and lateral sides.

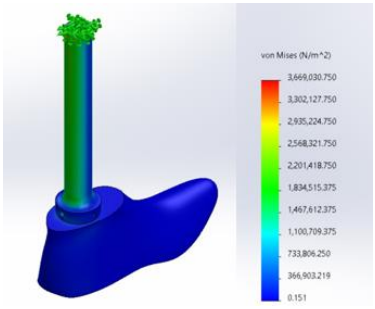

Figure 4. Stress distribution of shank and prosthetic foot.

Ground Reaction Force

The (GRF) applied under sole, because biomechanical effects on shank during gait cycle phases can be done for amputee with transtibial in right lower limb by using treadmill force plate. Walk over force plate where the force distribution is developed under sole due to patient gait cycle. The results of gait as shown in Figure 5.

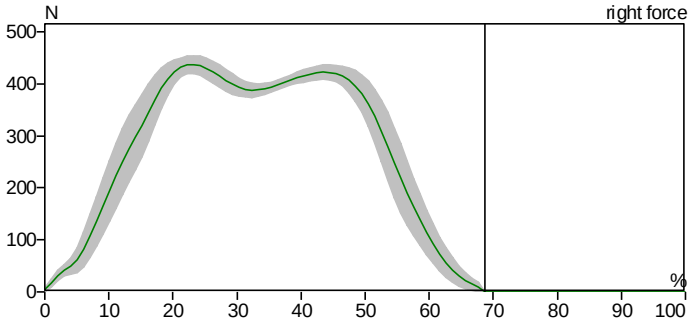

Figure 5. Ground reaction force with gait analysis.

Fatigue Shank Test Results

To determine the validity of the life of shank device compared to other devices, a non-articulated foot type SACH was used. The foot type SACH had failed at a temperature 50 ^{o}C with 1,275,341 strokes, but the shank did not fail, this indicates that the new shank was good. The shank can be replaced when replacing the failed foot, the new shank is inexpensive and easy to manufacture in addition to its light weight.

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. Using an fatigue foot – shank tester device, it was found that the SACH foot had failed before the shank, at temperatures that matched the hot climate, this indicates that the new shank was good and suitable for hot climates.

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