Manufacturing, modeling and analysis of ankle disarticulation prosthetic for transmalleolar amputation

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Abstract. Three groups of composite material layers are used in this work to measure the mechanical properties of ankle disarticulation prosthetic socket. The polymer matrix acrylic (Lamination 80:20) and reinforced with different materials, the first type is (4Perlon) layers, second type ( 2 Perlon and 4 Glass fiber and 2 Perlon) layers and third type is including (2 Perlon, 4 Carbon fiber and 2 Perlon) layers used in this study. Tests Results showed that the mechanical properties of all groups, ultimate strength, yield stress and Young modulus for the first group; were 10.12MPa, 38.8MPa and 1.16GPa respectively , for second group were 73.8MPa, 146MPa  and 1.45GPa respectively  and for the third group were 106.6MPa, 209.4MPa and 1.9GPa respectively . The results of the bacteria test growth show inability of bacteria (Staphylococcus aureus) to analyze of the surfaces of materials available and suggested for feeding it therefore bacteria can grow on them. By using (F-socket) the pressure between stump and socket measured and the values are (236kPa) and (275kPa) for the lateral and posterior reign. From fatigue test for all groups and ANSYS 14.5 software , the safety factors for composite material (2Perlon ,4carbon fiber,2perlon) layers is about (1.57) which are safe and acceptable in design applications.

Keywords: ankle disarticulation amputation, composite material, fatigue properties and F-socket

1-Introduction

The ankle disarticulation amputation is cutting through the malleoli and the weight bearing on the end of residual limb. The fat pad takes load directly and transfers this directly to the distal tibia [1]. With the use of dynamic feet at this level of amputation which decreased energy expenditure with ambulation as compared with higher and midfoot amputation [2–5]. This amputation preserves function of the knee with a long stump of tibiaand allowing patients expend less energy when walking. The original technique included disarticulation of the foot at the ankle joint with resection of the malleolar projections [6]. Saif M. Abbas, [7] worked on different material such as carbon fiber and perlon. Ayad M. Takhakh [8] used carbon fiber material for KAFO. S. M. Abbas [9] studied the effects of layers on the prosthetic socket material for partial foot amputation. Saif M. Abbas, [10] studied the mechanical and fatigue behaviours of prosthetic for partial foot amputation. Ayad M. Takhakh [11] worked on different range of layers of composite material laminations for prosthetic...
applications. Saif M. Abbas [12] used four layers of carbon fiber composite material to make a socket for above knee amputation. Anwar Luay Kahleel, Ghanim Sh. Sadiq [13] used to design a custom foot orthosis (CFO) and manufacturing from composite lamination (3nylglass 2carbon fiber 3nylglass). In this paper, manufacturing of ankle disarticulation (AD) prosthetic symes type made of composite material is presented. Many types of reinforcement were used to determine the best one using mechanical tests and gait analysis.

2-Experimental procedures
According to ASTM D638 type I [14] three samples for each groups were prepared for tensile test with dimensions shown in figure 1.

![Figure 1. Tensile test specimen.](image1)

In fatigue test ten samples used for each lamination. The length of samples are 100 mm and width 10 mm according to the fatigue device test and the thickness is varies for each type of groups as shown in figure 2.

![Figure 2. Fatigue test specimen.](image2)

F- Socket test used to measure the interface pressure of patient wearing ankle disarticulation prosthetic (age (62 years) and weight (105 kg)) with left leg amputation due to accidents as shown in figure 3.
Figure 3. Patient with MatScan sensor

Medical examination that are directly in contact with human skin, you must examine the portability of materials to assist bacterial growth on them, so that there will not be the complications to the user of that material. In this work (residual limb with socket) there is a chance for the growth of bacteria in the residual limb due to the presence of moisture as a result of sweating and warmth because of body heat. Bacterial infection is serious complication with prosthesis. The specimen is isolated from patient suffering from leg amputation. The isolated were identified depending on clinical criteria by the medical staff.

2.1 Steps of the test:
1. Prepare the media (nutrient Agar) as shown in figure (4-a) and sterilization by (auto cluve)as shown in figure (4-b)is a device used for evacuation all bacteria at temperature 121°c and pressure 104 KPa for 20 minutes.
2. The media prepare was put in plastic petridishes under ultra clean environment.
3. Take the swab from stump of patient and cultringin media (petridishes).
4. These dishes were put in an incubator at temperature of 37°C for 24 hour as shown in figure (4-c)and read the result.

(a) nutrient Agar  
(b) auto cluve  
(c) incubator

Figure 4. Devices used in growth in bacteria test.

3-Results and Discussions
The measured properties from tensile test of all groups explained in Table (1). Figure (5) show the stress-strain curve for each lamination. The results explain that the properties of (Group B) when increasing four layers of glass fiber with constant Perlon, are increasing yield strength ($\sigma_y$)86 %, ultimate tensile strength ($\sigma_{ult}$) about 73% and (E) 20% as compared with (Group A). For (Group C) the results explain when increasing four layers of carbon fiber with constant Perlon, lead to increase yield strength $\sigma_y$ 91% , ultimate tensile strength $\sigma_{ult}$ about 82% and E 39% ) as compared with (Group A). The increase in those mechanical properties is attributed to the inclusion of the samples and the mechanical properties for Glass fibers and carbon fibers higher as much as Perlon.

| No. of Lamination | Total No of layers | Thickness (mm) | $\sigma_y$ MPa | $\sigma_{ult}$ MPa | E GPa |
|-------------------|--------------------|----------------|---------------|------------------|------|
| Group A           | (4perlon)          | 4              | 1.9           | 10.12            | 38.8 | 1.16 |
| Group B           | (2perlon – 4 glass fiber- 2perlon) | 8              | 3.8           | 73.8             | 146  | 1.45 |
The fatigue failure of specimen can occur when the specimen begin to fractures under alternative applied loading. The readings were recorded by the fatigue tester machine give the number of cycles when the specimens were fractured. The S - N curves for each sample of all laminations as shown in Figure 6.

The interface pressure between the patient and prosthetic socket can be measure by using the F-Socket sensor. The sensor was put on four regions of the stump(Anterior, Lateral, Posterior, and Medial) as shown in Figures from 7 to 10. The positions and values of the pressure on socket are as detailed in Table 2. Higher pressure emerging at the posterior region is 275KPa and the lateral region is 236KPa. The reason is that the lateral and posterior muscles are more active at the movement of the patient which avoids the pressure at the tibia (anterior and medial) regions.
Table 2. Interface pressure for prosthetic socket.

| Socket Direction | Anterior | Lateral | Posterior | Medial |
|------------------|----------|---------|-----------|--------|
| Interface Pressure kPa | 144      | 236     | 275       | 174    |

Figure 7. Interface Pressure at Anterior Socket Region

Figure 8. Interface Pressure at Lateral Socket Region
After putting a swab on dish which contained the middle nutrient (solid nutrient agar) and all these dishes was placed in bacterial incubator for 24 hours at a temperature 37˚. Then take dishes of nutrient agars to calculate the number of colonies and isolated the species of bacteria. After calculating it was found that the number colonies of bacteria on the solid nutrient agar was $2 \times 10^5$ colony forming units per milliliter (CFU/ml), as shown in figure (11) and most bacterial isolated is *Staphylococcus aureus* is diagnosis by biochemical test.
Figure 11. Colonies of bacteria on the solid nutrient agar

4- Numerical results
Analysis of ankle disarticulation prosthetic model for patient was set up by FEM software to compute the equivalent stress, total deformation and Safety Factor of fatigue.

The results show the Safety Factor for all groups of ankle disarticulation socket model in figures 12, 13 and 14 respectively, the different properties of materials which effect on the results of Von-Mises stress. The Von-Mises stresses for the each type of all groups are shown in figures 15, 16 and 17, figures 18, 19 and 20 shows the total deformation for the each type of lamination composites. The S.F for (2Perlon +4carbon fiber+2perlon) layers is about (1.57) which are safe and acceptable in design applications.

Figure 12. The Safety Factor for fatigue Group A.
Figure 13. The Safety Factor for fatigue Group B.

Figure 14. The Safety Factor for fatigue Group C.
Figure 15. Von-Mises stress for Group A

Figure 16. Von-Mises stress for Group B.

Figure 17. Von-Mises stress for Group C.

Figure 18. Total deformation Group A.
5-Conclusions
There are a large difference in the mechanical properties ($\sigma_y$, $\sigma_{ult}$ and $E$) of (Group C) when increasing of carbon fiber four layers with constant Perlon, are increasing yield strength $\sigma_y$, 91% , ultimate tensile strength $\sigma_{ult}$ about 82% and $E$ 39% ) as compared with (Group A). For group (B) the results explain when increasing four layers of glass fiber with constant Perlon, lead to increase yield strength $\sigma_y$, 86% , ultimate tensile strength $\sigma_{ult}$ about 73% and $E$ 20% ) as compared with (Group A). The lifetime for prosthesis depends on the applied stress and the composite material type. The lamination which consists of (2P4C2P) layers has Endurance limit stresses ($\sigma_e$) as much as longer than the other laminations. This increase in lifetime for the patient wearing partial foot prosthetic.

Higher interface pressure at the posterior region is 275 KPa and the lateral region is 236 KPa of the socket because of that the lateral and posterior muscles are more active at the movement of the patient which avoid the pressure at the tibia (anterior and medial) regions.

The ankle disarticulation material showed that the fatigue Safety Factor for (2Perlon +4carbon fiber +2perlon) was (1.57) which safe in design.

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