Analysis and manufacturing of above knee prosthesis socket by using revo fit solution

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Analysis and manufacturing of above knee prosthesis socket by using revo fit solution

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Abstract . The large numbers of terrorist attacks and wars in Iraq led to increase the numbers of amputees. However, typically a large number of the amputations are trans-femoral or above knee (AK). In this work, manufacturing a socket by using new method (REVO FIT SOLUTION) for manufacturing trans-femoral prosthetic socket by two molding. The main objectives of this work is to design and manufacturing of above knee prosthetic socket by revo fit solution method to increase suspension, decrease weight of socket and easier to doffing and donning especially for the elderly. The experimental work included subjecting the socket materials to tensile and fatigue testing. The results show that the mechanical properties for (4 layers of carbon fiber) are σ_{ult} =213MPa , σ_y =135MPa and E=3.5GPa. The Fatigue life equation for carbon fiber are $\sigma=739.6\ (N_f)^{-0.13}$ and The fatigue limit are 90 MPa The data of gait cycle (force plate) and Interface pressure between the socket and the residual limb was calculated using F-Socket device, the pressure in anterior region equal to (222Kpa)between the socket and the residual limb for patient(male) suffering from above knee right leg amputation and age(42)year. The finite element technique (ANSYS) is used to analyze the model of prosthetic socket and calculate the safety factor, equivalent (Von Mises) stress, and total deformation. The obtained results from ANSYS gave the profile of safety factor of fatigue, for AK with carbon fiber is (1.26).

Keywords: Above knee socket, tensile, fatigue, Laminated composites resin, safety factor.

1. Introduction

Trans femoral amputations, also called above-knee-amputations or (AK), this amputation has three levels; long AK, mid AK and short AK. Above knee represents amputation about 26% of the total lower limb amputations, 55% of them are due to diseases or without medical care from the patient, 36% of amputations are due to accidents or attacks and 9% are congenital deformities [1]. In this type of human being , the patient loses two joints of the body; knee and ankle. The knee joint is important in human gait cycle because it works as a link between thigh socket and pipe. The main types of knee joint locks and unlocks ,one is through the strike of heel and the other is during the toe off [2]. Above knee prostheses are designed for patients who suffer from leg trans femoral amputation . The prosthetic leg consists of a socket knee joint, pylon, ankle joint and a prosthetic foot[3]. Muhsin J. Jweeg et al [4] initiated a database for the properties of materials used in manufacturing sockets of prosthetic limbs as lamination materials .They put them in 14 groups of various systems of stacking materials. These layers are made by using perlon, fiber glass and acrylic resin. The effect of increasing and decreasing the fiber glass layers and the perlon on the physical and mechanical properties of sockets was investigated .They subjected the 82 manufactured samples of the different 14 groups of laminations to tensile and flexural tests. Muhsin J. Jweeg, et.al, [5]. used (perlon 6, 9 and 12 layers). Muhsin J. Jweeg and Jana S. Jaffar[6]. worked on composite material of carbon fiber with perlon (4-24) and perlon only. S.S.Hasan, et.al, [7]. used different composite material for laminations .Muhsin J.Jweeg. et.al, [8]. Worked on different layers of compsite material laminations.

In this work, tensile and fatigue tests were implemented to different samples of laminations of (4 layers of carbon fiber) with matrix of lamination c-orthocryl resin. The results of these tests were used in manufacturing (AK) socket to achieve the better material socket for acceptable mechanical properties. Finally the fatigue safety factor was calculated numerically using ANSYS work bench.

2. Experimental procedure

2.1Materials

The materials of socket were chosen and manufactured by vacuum pressure technique for this study.

1. Carbon fiber.
2. C- orthocryl lamination resin for use with carbon fiber.
3. Hardening powder.
4. Polyvinyalcohol PVA.
5. Materials for Jepson.

2.2 Specimens Preparing For Mechanical Properties

2.2.1 Mounting the positive mold (Jepson manufactured with size 10*15*25 cm^3) at the laminating stand and completing the connection with the vacuum forming system through the pressure tubes and pulling the inner (PVA) bag on the Jepson mold as opening the pressure valves with the value of (20) KPa.

2.2.2 Putting the carbon fiber(4carbon fiber)layers and pulling the outer (PVA) keeping the smaller end positioned over the value area using cotton string to tie off the (PVA) bag.

2.2.3 Mixing the C-orthocryl lamination resin for using with carbon fiber with the hardener about(500-600)ml of resin mixed with(1-2) part of hardener and then putting the mixture inside the outer (PVA)bag and distributing the matrix homogeneously over all area of lamination .

2.2.4 Maintaining constant vacuum until the carbon fiber materials becomes cold and then lifting the resulting lamination as shown in figure 1.

Figure 1. Carbon fiber block

2.2.5 Cutting the carbon fiber materials after cold by special tool (vibrational cutter) to manufacturing samples for tensile and fatigue testing.

2.3 The Tensile tests

All specimens were tested by using the testing instrument (testometric). The composite material specimens were cut according to the standard ASTM D638 [9]. The crosshead speed for tensile test of composite material specimens was 5mm/min. Figure 2 shows the tensile specimen’s of carbon fiber.

Figure 2. The general shape of tensile specimens.

2.4 The fatigue test

A high cycle fatigue test was performed with alternating bending stress. The samples deflection was perpendicular to the axis of the specimens. Specimens are 100mm length and 10mm wide according to the fatigue testing device with variable thickness due to lay up. Figure 3 shows the Specimens fatigue test.

Figure 3. The general shape of fatigue specimens

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2.5 Manufacturing Procedure of above knee prosthetics with revo fit.

The manufacturing process for AK will be explained in the following steps:

2.5.1 Mounting the positive mold at the laminating stand according to the dimensions of the patients suffering from above knee amputation and completing the connection with the vacuum forming system through the pressure tubes, pulling the inner (PVA)bag in the positive mold, and opening the pressure valves to value.

2.5.2 Putting the 2 layers of carbon fiber and pulling the outer (PVA) keeping the smaller end positioned over the value area by using cotton string to tie off the (PVA) bag .

2.5.3 Mixing the C-orthocryl lamination resin with hardener and then putting the mixture inside the outer (PVA)bag and distributing the matrix homogeneously over all area of lamination figure 4 shown lamination used for manufacturing above knee prosthesis(AK).

Figure 4. Lamination used for manufacturing (AK).

2.5.4 Maintaining constant vacuum until the carbon fiber material becomes cold and then left the resulting lamination and cutting the increase that will not required and will the wedge smooth as shown in figure 5.

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Figure 5. Cutting and smoothing for manufacturing (AK).

2.5.5 Drawing the place of revo fit solution, fixing this device and draw the place of cutting in several part of the socket
2.5.6 Fixing the socket adapter and close the cavity of the socket adapter and fix with carbon straps as shown in figure 6.

Figure 6. Fixing socket adapter.

2.5.7 Putting the 2 layers of carbon fiber on first mold also putting the outer PVA to keeping lamination resin and operating the vacuum to pulling any air, bubbles to get good socket and smooth as shown in figure 7.

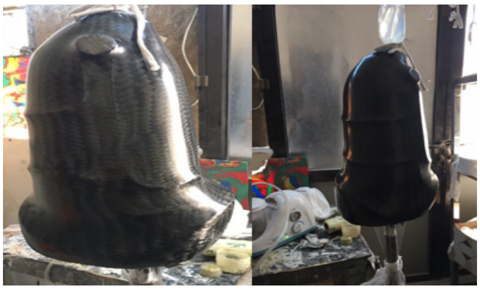

Figure 7. Secondary operation molding.

2.5.8 After secondary molding socket drawing the cutting region and drilling a circle hole to putting the valve device to outflow the air that between stump and socket as shown in figure 8.

Figure 8. Putting the valve.

2.5.9 Finally Assembly of AK Prosthesis after smoothing the socket.

2.6 The F -Socket Test

Interface pressure test for patient wearing a prosthetic type AK (age (42years) , height (185 cm) and weight (95 kg)) suffered from right leg above knee amputation due to explosion was performed in the laboratories of the P&O department of Al-Nahrain University using sensor type (Mat Scan) which is acceptable for this type of dynamic load, as shown in figure 9.

Figure 9. Patients with F-socket sensor.

2.7 Gait Cycle Testing

The Walkway system provides static and dynamic gait data and barefoot pressure and force measurements for patient as shown in figure 10.

Figure 10. The patient with AK on gait cycle table.

3 Finite element method (FEM)

The FEM was consulted to measure the fatigue life, the factor of safety and the total deformation for prosthetic socket. The model of prosthetic socket was designed using SOLIDWORKS software and the final geometry model was exported to ANSYS-14.5 workbench. In this work numerical Analysis using ANSYS Workbench 14.5 software was made to calculate the effect of fatigue on socket structure and to determine the equivalent stress, total deformation and fatigue safety factor.

4 Results and discussion

4.1 Tensile properties results

The results of the mechanical properties (tensile test) of the socket materials are shown in table 1 The specimens for carbon fiber were tested to get stress-strain curve. figure 11show the stress-strain curve for a sample of the carbon fiber.

Table 1. Mechanical properties of socket materials

Material of socket	Thickness(mm)	σ_y (MPa)	σult (MPa)	E (GPa)
Carbon fiber(4-layer)	3.6	135	213	3.5

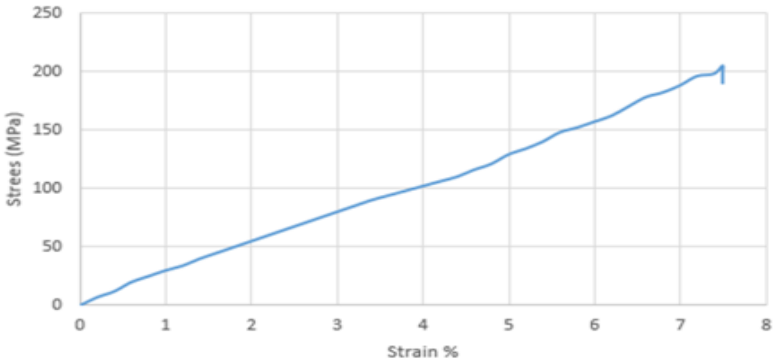

Figure 11. Stress-strain curve for carbon fiber.

4.2 Fatigue properties results

Fatigue failure of flat specimen occurred when the specimen fracture appear under alternating bending stress with high cycle fatigue. The tests results were recorded by the fatigue tester machine which gave the number of cycles when the specimens fractured. The S - N curves for each specimens of all laminations are shown in figure 12.

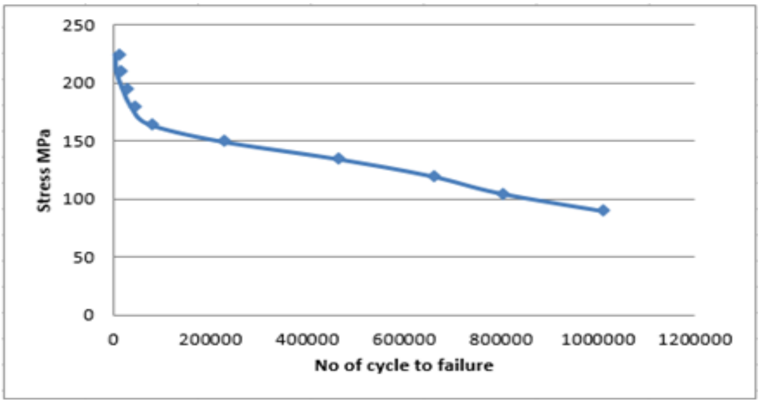

Figure 12. SN-Curve for (4 layers of carbon fiber)

4.3 The F-Socket results.

The pressures are only considered over the gait cycle by contact method between the stump and socket. The data are normalized to 100 percent of gait cycle. The pressure for subjects are different at weight acceptance from one patient to another. The experimental part of case study with trans femral amputee wearing AK prosthetic. The results show that the maximum value of interface pressure between the stump and socket at the anterior reign , The figure 13 show the pressure distribution on the socket as a relation between force and time ,table 2 show the magnitude of pressure about socket region.

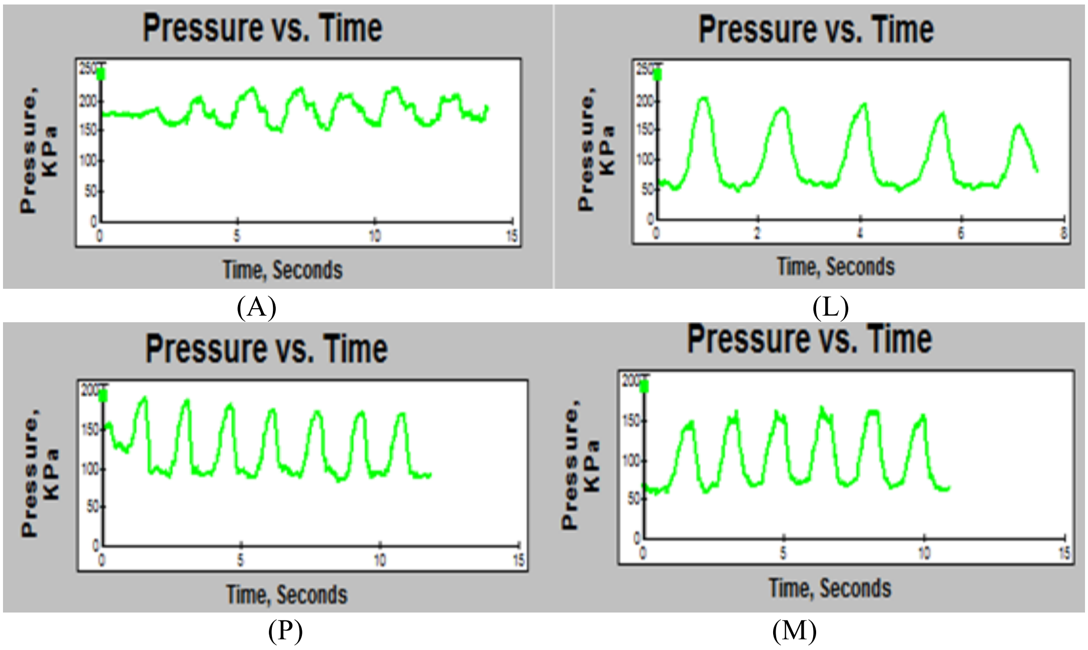

Figure 13. the pressure vs. time.

Table 2. the magnitude of pressure about socket region.

Socket Regions	Anterior	Lateral	Posterior	Medial
IP(Kpa)	222	204	193	170

4.4 The Gait Cycle Parameters Results

The obtained data from the gait cycle test recognize the major differences for the parameters of the right and the left leg. The main parameters which are shown in tables 3& 4 describe the behavior of the gait cycle for patient wearing AK socket data for one complete gait cycle from heel to heel strike.

Table 3. Gait Cycle Table (sec).

Gait Cycle Table (sec)	Patient1		
	Left	**Right**	**Difference**
Gait Cycle Time	1.23	1.19	-0.04
Stance Time	0.79	0.74	-0.08
Swing Time	0.44	0.48	0.04
Single Support Time	0.46	0.45	-0.01
Initial Double Support Time	0.17	0.18	0.01
Terminal Double Support Time	0.18	0.17	-0.01
Total Double Support Time	0.34	0.34	0.00
Heel Contact Time	0.64	0.45	-0.19
Foot Flat Time	0.58	0.17	-0.41
Mid stance Time	0.45	0.27	-0.18

Active Propulsion Time	0.03	0.06	0.03

Table 4. Step-Stride Table.

Step-Stride Table	**Patient 1**		
	Left	**Right**	**Difference**
Step Time (sec)	0.57	0.62	0.05
Step Length (m)	0.373	0.383	0.01
Step Velocity (m/sec)	0.657	0.620	-0.037
Step Width (m)	0.117	0.103	-0.014
Stride Time (sec)	1.23	1.19	-0.04
Stride Length (m)	0.740	0.805	0.065
Stride Velocity (m/sec)	0.600	0.676	0.076
Impulse (N*sec)	334.55	195.82	-139.27
RMS Pressure (KPa)	214	350	136
Foot Angle (degree)	4	1	-3

4.5 Numerical results

The analysis of above knee socket model for patient was made by ANSYS Workbench 14.5 to determine the equivalent (Von-Mises) stress and fatigue safety factor. According to Von-Mises theory the yield stress criteria are; ($\sigma e<\sigma y$, safe), ($\sigma e = \sigma y$, critical) and ($\sigma e>\sigma y$, failed). Where, (σe) is the equivalent stress, and (σy) is the yield stress. It can be seen that the safety factor of fatigue within limit according to design applications which assumes that the safety factor should be about or more than (1.25) [10].

The results of Von-Mises stress for above knee socket model were presented in figure 14. Figure 15 show the total deformation for lamination composites. The average safety factors for composite material specimens having the layup (4carbon fiber) is about (1.26) which is considered safe and acceptable within design applications figure 16, shows the safety factor for (4carbon fiber) of composite material.

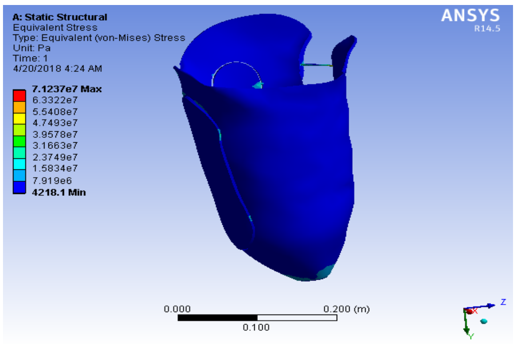

Figure 14. Equivalent stress (Von-Mises).

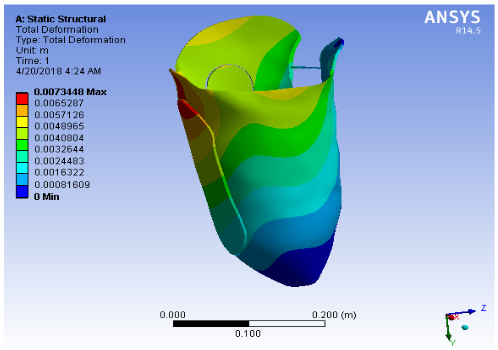

Figure 15. total deformation.

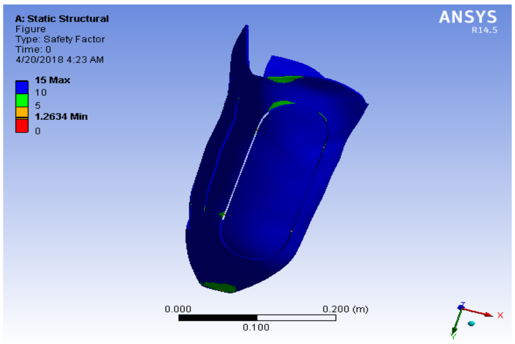

Figure 16. The safety factor for fatigue.

5. Conclusions

1. The lamination above knee prosthesis gave good results in equivalent Von-Mises stress and the safety factor for fatigue, and this led to the longer life design.
2. Higher in friction between above knee socket and stump by rovo fit solution and prevent dislocation of stump by increasing suspension.
3. Provide comfortable for patient of easier doffing and donning of adjustable socket especially elderly.
4. The matscan sensor, which is used to measure the interface pressure, was suitable for the alternating load between the socket and the stump. The interface pressure between patients and AK follows a wave pattern and reaches its maximum value at the anterior and lateral (222 and 204) respectively.
5. The above knee composite material socket model showed that the fatigue safety factor for (4layers of carbon fiber – C-orthocryl lamination resin) was (1.26) which considered as safe in design.

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