EFFECT OF COMPOSITE MATERIALS LAMINATIONS ARRANGEMENT ON THE PROSTHETIC BELOW KNEE SOCKET LIFE AND PROPERTIES

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Abstract

This paper studies the effect of changing layers arrangement of composite materials (four samples consisting of 8 layers with a change in the arrangement of layers and composite materials were used glass fibers, carbon fibers and perlon with lamina matrix) on the mechanical properties (yield stress, ultimate stress, Young's modulus, and Poisson's ratio) of the prosthetic below knee socket (BK) by using tensile test device. Also, calculate the (S-N) curves for these samples by using bending fatigue test device to calculate the fatigue life.

The pressure distribution between the (BK)socket and the residual lower limb using pressure sensor and the information on gait cycle was by using force plate on the case study patient with (BK) amputation.

The solid work program to drawn the socket and ANSYS workbench 14.5 was used to analyze and evaluate the fatigue characteristic by observing the maximum stress, total deformation and safety factor.

The results show that the yield stress in the samples 2, 3 and 4 is increased about 18 %, 95%, and 91% respectively more than the standard sample1. While the ultimate stress in the samples 2, 3 and 4 is increased 32%, 89%, and 68% respectively more than the standard sample1, the Young's modulus in the samples 2, 3 and 4 is increased about 5%, 18%, and 12% respectively more than the standard sample1, the Poisson's ratio is increased about 3%, 6%, and 7% respectively more than the standard sample1, and the fatigue life is increased about 23%, 73% and 29% in the samples 2, 3 and 4 respectively more than the standard sample 1.

Keywords : Composite materials, mechanical properties, fatigue life ,below knee socket.

I.   Introduction

Prosthesis is a device that replaces a missing body part cutting by injury or from birth or accident. [III] The socket is the link between the patient's body and the artificial end. show in Figure.(1), main purpose of studying the prosthetic it have stability and yet comfortable [XI] . (BK) prosthetic consist four main components :socket ,the gate , the artificial foot and couplings as shown in Figure.(2). Studied the design of socket, leather and wooden sockets used to be very popular, but they need great skill and a long working time. This socket was made by sculpting a piece of wood and was attached using traditional methods with the pylon, the leather /metal limb is also manufacturing from metal bars, a thick piece of leather, and a pylon made from wood. M .J. Jweeg et al 2009 [XIII] , study effect change the layers of perlon and fiber glass layers on mechanical and physical properties. Results show that the lamination (3perlon +2fiberglass +3perlon) appear the best mechanical properties and it is decrease cost of socket lamination to acceptable cost value. found that increasing the fiber glass layers from (zero to two) layers when the perlon layers was fixing leads to increase in mechanical properties and the group of sandwich lay up when perlon distributed equally on each side improving mechanical properties. A.P. Irawan et al 2012 [I] , manufacturing the composite socket by used epoxy with reinforced fiber (bamboo) at thickness 0.3 ± 0.05 mm and width 3 ± 0.5 mm with volume fraction (10%, 20%, 30%, 40%, and 50%). The results led to the epoxy with reinforced fiber bamboo composite at (40%) volume fraction gives results better than composite at (10%, 20%, 40%, and 50%) (tensile strength is 78.09 ± 1.97 MPa, modulus of elasticity is 8.96 ± 0.33 GPa, impact strength is 1.3 kJ/m2, and compressive strength is 87.1 ± 4.3 kN). Muhammed A. M. in 2016 [XIV] , study the mechanical properties for hybrid composite materials, that made from fiberglass, carbon fiber, perlon, and epoxy resin. Result show that, the increased numbers of perlon layers to 11 stratums and 44% improved in Young's modules (E) but 22% decreased tensile strength.
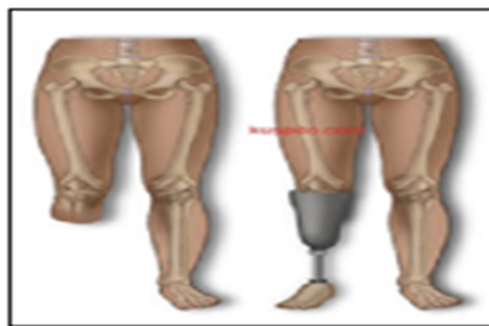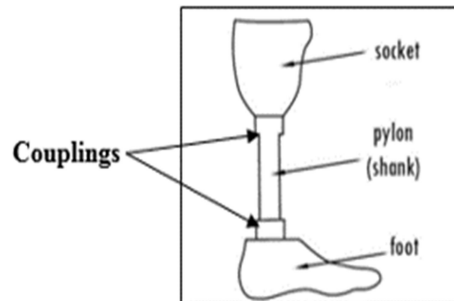

Fig. 1: Below-knee amputation [III]

Fig. 2: The prosthesis component. [XI]

II.   Analysis Gait Cycle

To understand the behavior of lower limb important to know the walking process because it series of repeated process, patient's while stand on one leg the second leg will moves forward . This repeated process called the gait cycle [XVI] . Analysis the gait cycle provide useful date to performance a patient's ability to walking and it descried to:

A. Stance Phase: defined by initial heel strike contact to toe-off. Stance phase accounts for equal to 60% of the walking cycle and is divided in to five sub-phase (first contact, loading response, mid stance, terminal stance and pre swing) [XII] .

B. Swing Phase: start from toe-off to touching the tip of the tip or the direct stitch of the heel contact. Swing phase approximately 40% .The swing phase is consisting from three sub phases (initial, initial, and terminal) [XII] .

III.   Numerical Analysis

The analysis of socket models used in this work by the software ANSYS (14.5) workbench as numerical solution to found the equivalent (Von-Mises) stress ,total deformation and the safety factors .The process was done firstly choose the socket that be drawn by solid work program (2013) and inter the material properties for all lamination and then the mesh process has been done (generally mesh) see in Figure.(3). The fixed support has choose in the ANSYS in the bottomarea at the adapter of socket and the pressure was distribution according to particular position the total number of element was (22163) with total number node (6671).
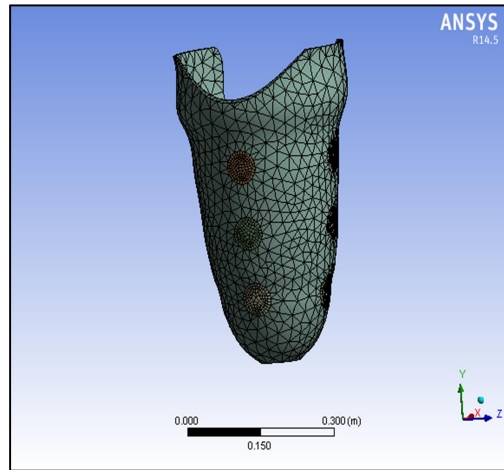
Fig. 3: The mold with mesh

IV.   Experimental Works

The steps of this work can be summarized as:

1. Described the process of socket manufacturing made of perlon / fiberglass/ fiber carbon / perlon with polyester.

2. Make special model to have a lot of different samples of composite materials standard of flat specimens for tensile and fatigue tests made from four types of laminations to calculate a mechanical properties of these material specimens.

IV.i.   Materials are Used

The materials used in this work, for manufacturing lamination of the BK prosthetic socket, are :

1. Perlon stockinet.

2. Woven fiber glass.

3. Woven carbon fiber.

4. Lamination resin 80:20 with hardening powder.

5. Polyvinyl alcohol PVA bag.

6. Materials for gypsum mold, see Figure .(4).

Fig. 4: Materials for BK socket.

IV.ii. Prosthetic Socket Manufacturing by Vacuum Technique

The large numbers manufacturing methods have to become accessible to patients who wanted the best mechanical properties .The vacuum technique is one of the most tradition and widely available socket manufacturing methods, see Figure.(5).

1.   Putting the mold socket in the vacuum device, see Figure.(5a).

2.   Addressing the inner bag (PVA) into the mold and open the pressure valve , see Figure.(5b).

3.   The perlon, fiber carbon, fiberglass and perlon are putting then the outer bag is PVC bag and adding the mixing (resin 80-20 polyurethane with the hardener and colors) according to the stander ratio for each 100 part of acrylic resin mixed with (2-3) part of hardener, see Figure.(5c) [X] .

4.   The mixture is moved to ensure the homogeneous distribution of the mixture inside the area.

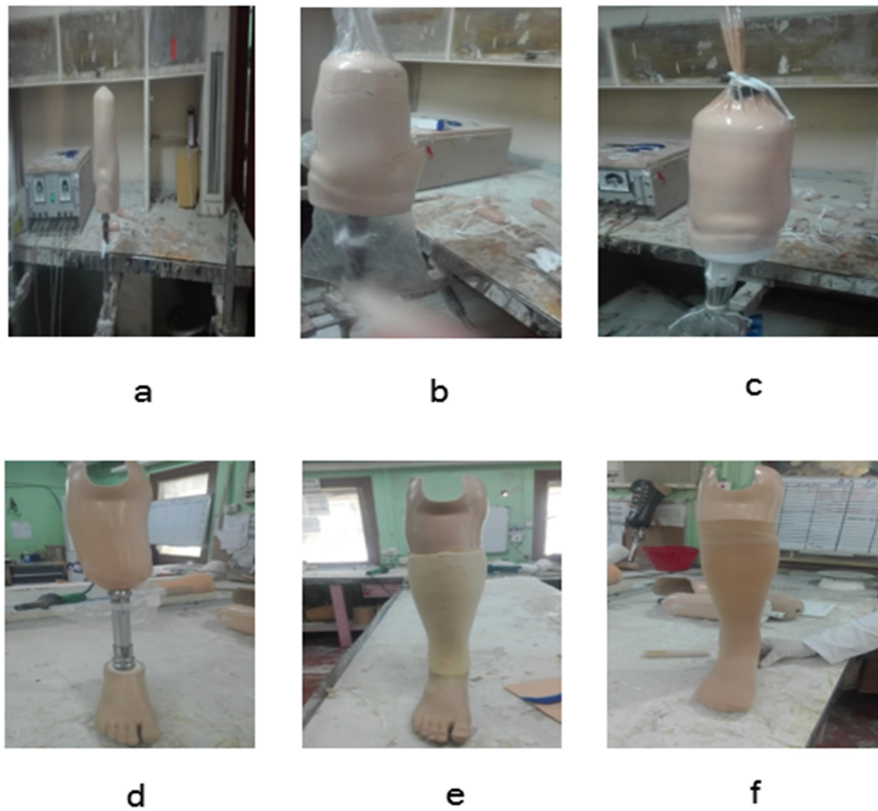5.   The final shape of socket, see Figure (5d,5e, and 5f).

Fig. 5: Manufacturing steps of socket

IV.iii.Experimental Procedure of Lamination

Manufacturing specimen using a process similar to the manufacturing of prosthetic socket to found the mechanical properties of socket :

1. Gypsum block mold made from wood for flat specimens with dimension (20*10*10)cm3, see Figure.(6a)

2. Covering the block by of perlon before PVA to protect PVA from rupture then adding the PVA (polyvinyl alcohol) to the positive mold and open the vacuum, see Figures.(6b, and 6c)

3. Addressing the perlon, fiber glass , fiber carbon and perlon, see in Table(1) and Figure.(6d)

4. Covering the mold with outer PVA bag open from tip to add mixing (lamination resin and hardener), see Figure.(6e).After the cubic composite cold then cutting this material in to required dimensions, see Figure (6f)
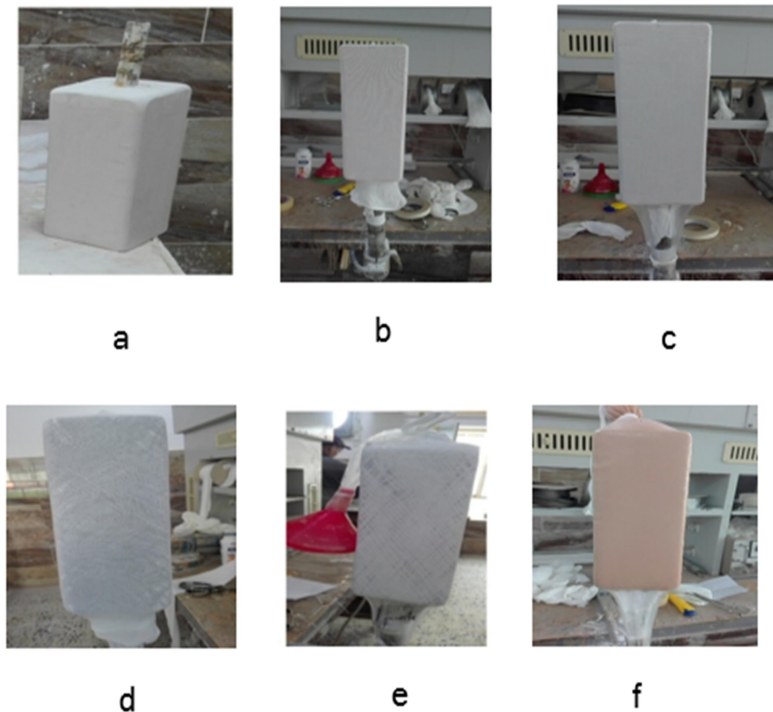
Fig. 6: Process of sample fabrication.

Table 1: Laminations arrangement

Sample	Reinforcement	Method
1	2perlon+1fiberglass+2perlon+1fiberglass+2perlon	Vacuum technique
2	2perlon+1fibercarbon+2perlon+1fibercarbon+2perlon	Vacuum technique
3	2perlon+1fiberglass+2fibercarbon+1fiberglass+2perlon	Vacuum technique
4	2perlon+1fibercarbon+2fiberglass+1fibercarbon+2perlon	Vacuum technique

IV.iv.   The Tensile Test

To calculate the mechanical properties for all lamination, flat specimens were test in the Department of Mechanics of Al-Nahrain University .Three specimens for each lamination were machined according to ASTM D638 type 1 [XV] . Figure (7) described the dimension of specimen when thickness change according to lay-up these specimens see Figure.(8). All the specimens were tested at room temperature (25o C) to find the mechanical properties of different composite lamination. Figure.(9) shown specimen under tensile test.
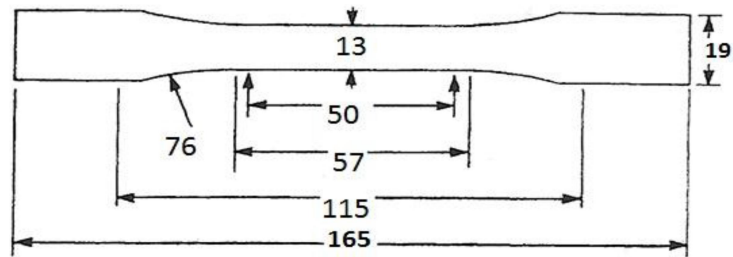
Fig. 7: Standard dimensions in (mm) of tensile test specimen

Fig. 8: Tensile test specimens

Fig. 9: Tensile test device

IV.v.   The Fatigue Test

 Eight specimens for each lamination layers of composite material according to(HSM20 Alternating bending fatigue machine) as shown in Figure.(10) , the dimension for the sample (100mm)length and (10mm) width and the thickness depends on type of composite material as shown in Figure(11). The specimen in the

device one side is free and the other is fixed and effect the deflection perpendicular to their axes at one side .This process done by using alternating bending fatigue with constant amplitude, see Figure.(12).
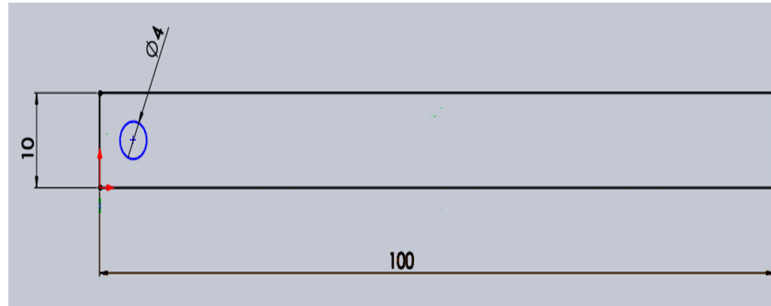

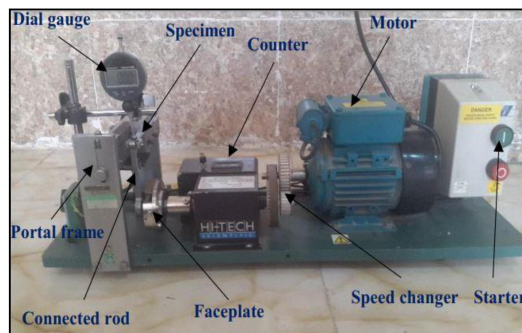**Fig. 10:** Standard dimensions in (mm) of fatigue test specimen

Fig. 11: Fatigue test specimens

Fig. 12: Fatigue test device

IV.vi.   Interface Pressure Test

F-Socket sensor was used to measure the pressure between the stump and the socket . The pressure measured during the stance phase by connecting the sensor and measuring its response. Four position in leg regions was divided longitudinal for three parts. Butting the F-Socket sensor in all region to calculate pressures. Table (2) show the case study data of this work.

Table 2: Case study data of this work.

Gender	Age (years)	Weight (kg)	Length (cm)	Type of amputation	Side amputation	The length of amputation
male	50	70	160	BK	Right	26

V.   The Result and Discussion

V.i. The Tensile test results

The mechanical properties as shown in the Table 3. For each lamination type take three specimens for testing and show a stress-strain curve. Figure.(13) shown sample for each lamination.

Table 3: Mechanical properties for all laminationsamples

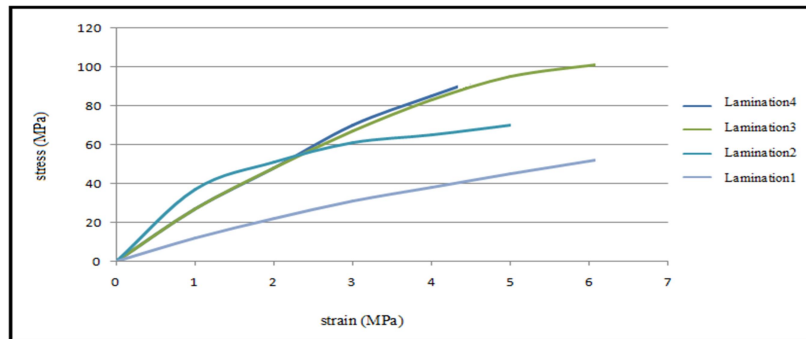| Sample	Yield Stress (MPa)	Ultimate Tensile Strength (MPa)	Young's Modulus (E) (GPa)	Poisson's Ratio (v)
1	29.195	53.474	2.1307	0.330
2	34.641	70.536	2.142	0.339
3	57.171	101.114	2.518	0.349
4	55.95	90.089	2.387	0.353

Fig. 13: Stress –strain curve for all lamination

V.ii.   Fatigue Test Results

The S-N curve is used to define the fatigue failures of composite material . The S-N curve results as shown in Figure. (14). S-N curve for all lamination samples type : when stress failure rates for the sample less and the number of cycles increase until reach failure point.
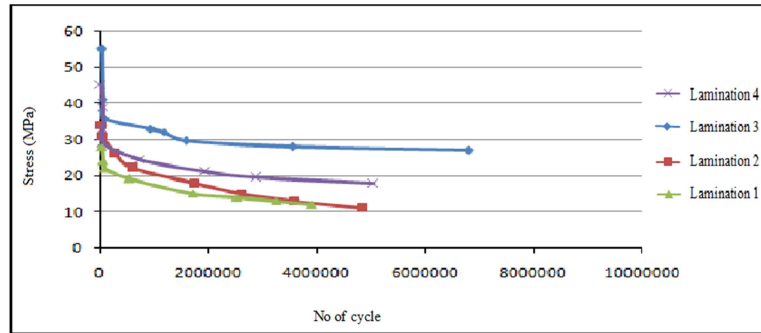
Fig. 14: S-N curves for all samples

V.iii.   Pressure Distribution Results

The socket interface designs can divided to four basic region (posterior, anterior, medial and lateral). For calculate the motion system of patient, interface pressure between the patients stump and prosthetic was calculate using F-socket sensor were recorded as each participant walked at a self-selected, as shown in Figures. from 15 to 19.
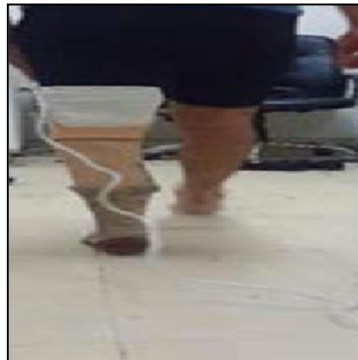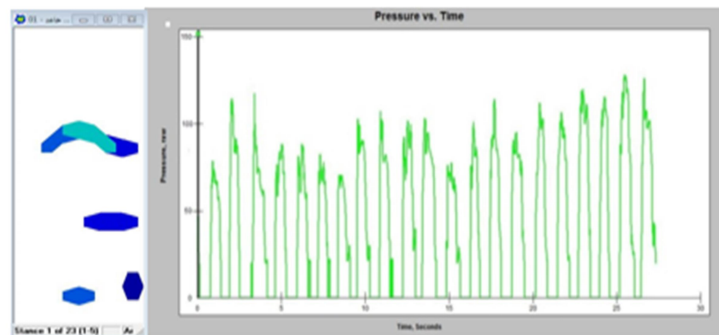

Fig. 15: Case study

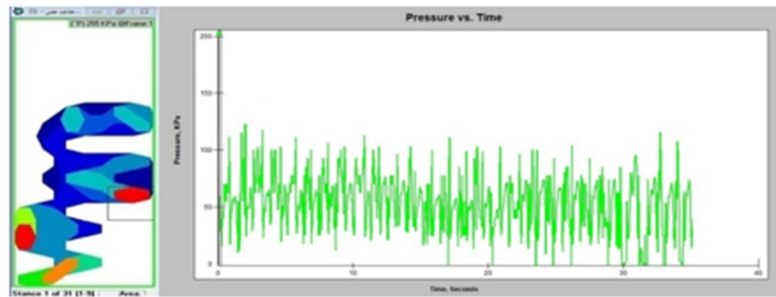**Fig. 16:** Pressure result at anteriorpart

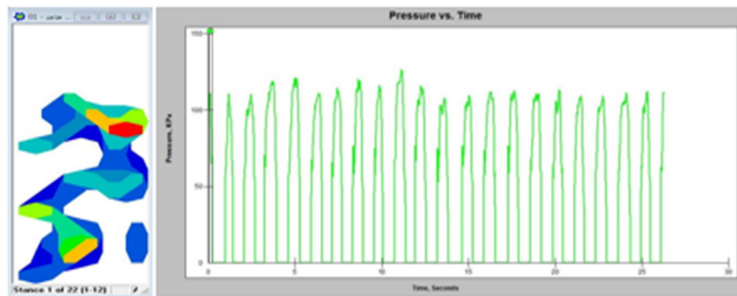**Fig. 17:** Pressure result at posterior part

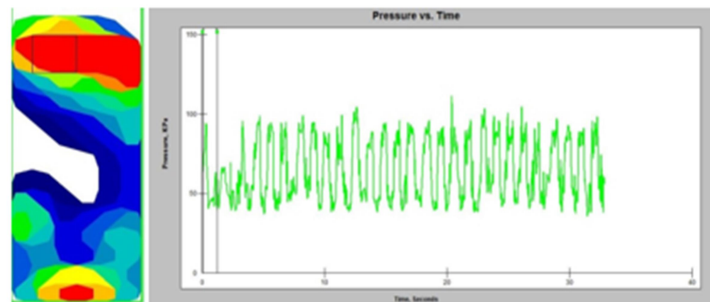**Fig. 18:** Pressure result at medial part

Fig. 19: Pressure result at lateral part

VI.   Numerical Ansys Results

Results show that the maximum equivalent Von Mises stress equal to (1.4609e7 Pa) while the minimum is(38552 Pa) shown in Figure.(20) .The safety factor depended on type the composite material inter in sample manufacturing as shown in Figures. from 21 to 24.
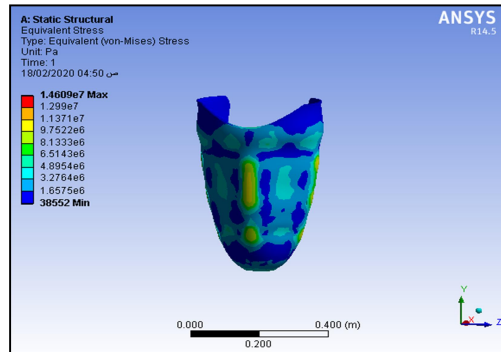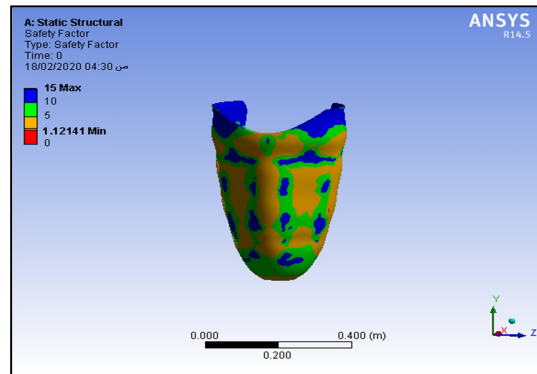
Fig. 20: Equivalent stress on socket
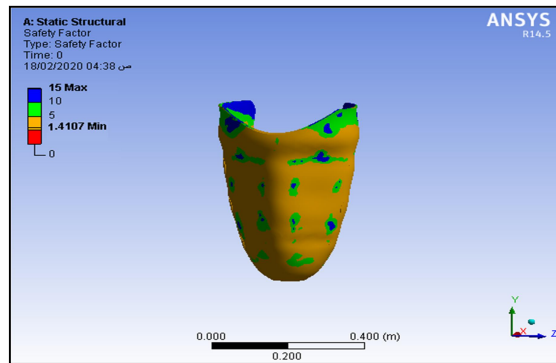

Fig. 21: safety factor for sample1

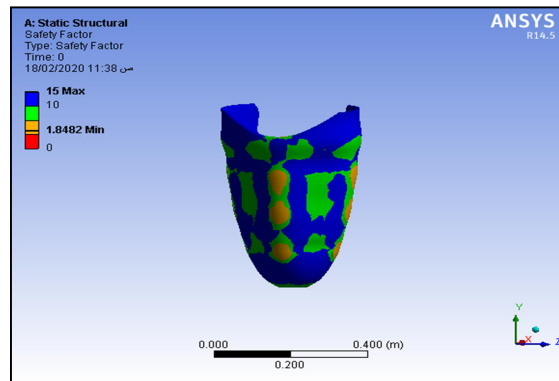**Fig. 22:** safety factor for sample2
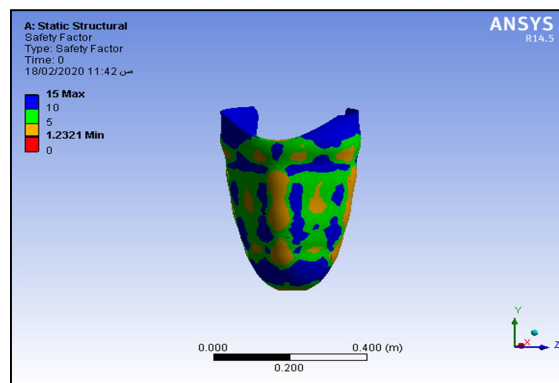
Fig. 23: safety factor for sample3

Fig. 24: safety factor for sample4

VII.   Conclusions

The suggestion materials have been successful in mechanical test. The improvement of the mechanical properties was based on changing the types of composite materials without change the number of layers in order not to increase the weight of the socket and effect on the patient's. The following conclusion remarks may be drawn:

1.   The yield stress results of samples 2, 3 and 4 is increased about 18 %, 95%, and 91% respectively more than the standard sample 1.

2.   The ultimate stress of samples 2, 3 and 4 is increased about 32%, 89%, and 68% respectively more than the standard sample 1.

3.   The Young's modulus results of samples 2, 3 and 4 is increased about 5%, 18%, and 12% respectively more than the standard sample 1.

4.   The Poisson's ratio results of samples 2, 3 and 4 is increased about 3%, 6%, and 7% respectively more than the standard sample 1.

5.	The fatigue life results is increased about 23%, 75% and 29% in the samples 2, 3 and 4 respectively more than the standard sample 1.

6.	The deformation values for the socket are acceptable when using of the three composite materials due to it is necessary to deform the socket when applied the interface pressure to provide comfort to the skin of the patient.

7.	The difference results between the maximum stress 14.609MPa generated in the socket and the yield stresses are 29.195 MPa for sample (1), 34.64MPa for the sample (2), 57.171MPa for the sample (3) and 55.95MPa for sample (4) confirms the success of the suggestion materials to bear the weight of the patient.

8.	The best suggested material to be selected is from the third suggested sample (2 perlon, 1fiber glass, 2 fiber carbon, 1fiber glass, 2 perlon with lamina) due to its high mechanical properties and its high strength with ability to bear high weights for patients without failure.

9.	The maximum error's percentage between numerical and experimental fatigue life results are (23%,24%,22% and 20%) in the samples (1,2,3 and 4) respectively.

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