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MECHANICAL AND FATIGUE BEHAVIORS OF PROSTHETIC FOR PARTIAL FOOT AMPUTATION WITH VARIOUS COMPOSITE MATERIALS TYPES EFFECT

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ABSTRACT

The mechanical behaviors as safety factor, Von-Mises stress and total deformation for prosthetic for chopart amputation, in addition to, the fatigue behaviors are investigation with various composite laminate materials effect. Thus, in this research, there are three types of composite materials are used for to analysis of the fatigue and tensile properties of partial foot prosthetic partial foot which laminated using vacuum system. The composite material matrix of composite material was Lamination 80:20 then used three types of composites as reinforced; the first type is including (8 perlon), second type is including (4Perlon, 2carbon fiber and 4perlon)and third type is including (4Perlon, 2N-glass, 4perlon). The tests results of all groups properties: ultimate strength, yield stress and elasticity modulus for the first group; were 36 MPa, 39 MPa and 1.08GPa respectively, for second group were 77.3MPa, 97.5MPa, and 1.4GPa respectively and for the third group, were 43 MPa, 43.7 MPa and 1.16 GPa, respectively and. The pressure inside the stump of patient and the socket was measured by Matrix scan F-sensor and the maximum value of pressure is (161 kPa) and (138 kPa) were showed for the posterior and lateral sections respectively. From fatigue test for all groups and ANSYS 14.5 software, the safety factors for composite material (4Perlon, 2carbon fiber, 4perlon) laminated is (2.43) which are acceptable and safe in applications of design.

Keywords: Chopart Amputation, Fatigue, F-Socket, Prosthetic, F.E.M, ANSYS.

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1. INTRODUCTION

Prosthetic is the substitutes devices of missing parts of body for the amputee due to accidents or disease. The missing part can be replaced by socket, shank and foot to meet as same of lower limbs of human, [1]. The amputation of partial foot is begin from the joint of ankle to of lower limb distal. Also, the amputation of partial foot Prostheses is different in functional and design. A prosthesis partial foot that is extremity of protects from impact at strike of heel and toe off, is acceptable cosmetically with normal gait simulation is a near perfect but in a hard solution, [2]. Partial foot and foot amputations are often referred to by different names, such as trans metatarsal, Chopart, Lisfranc, Syme's, and ankle disarticulation. These names refer to where the actual amputation occurs on the foot with some named for the surgeons who first performed them (Chopart, Lisfranc and Syme's). Foot partially amputees indicate to the miss of part of either the foot, [3-8]. However anomalies of congenital and frostbite of trauma as example of the amputations causes, [9]. F. Chopart investigated level amputation through the joint, [10], as shown in Fig. 1. The amputation was thought to limited operation due to the partial foot of residual was susceptible to deformity of progressive equinovarus. the amputation of Chopart is getting favor because the limb length was the potential complications of the stages are successfully addressed and retained. Combining fusion of ankle and amputation of foot hind apropulsive ambulation is allowed and a shoe topped modified, [11–16].

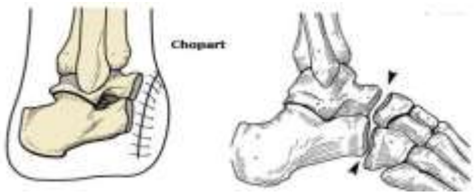


Figure 1 The Chopart Amputation [10].

In this work, tensile and fatigue tests were implemented to different samples of laminations of (4perlon - 2carbon fiber- 4perlon), (4perlon -2N-glass -4perlon) and (8perlon) with matrix of lamination (80:20) resin. The results of these tests were used in manufacturing partial foot amputation (PFA) socket to achieve the better material socket for acceptable mechanical properties. Finally the fatigue safety factor was calculated using ANSYS work bench.

2. EXPERIMENTAL PROCEDURES

At experimental techniques, first selected the materials used to manufacture the partial foot Prosthetic. Then, the materials are used to manufacture the partial foot socket materials used in lamination for this study, carbon fiber, perlon fiber nyle glass, acrylic resin 80:20, and PVA. Therefore, after selected the materials, must be test it materials to given the agreement for its materials to use for manufacturing the partial foot Prosthetic. Where, the preparing of samples for tensile and fatigue test, as,

1. Set the rectangular mold at the stand of vacuum pressure system.

2. Use the Perlon stockinet, Perlon and carbon fiber stockinet Perlon and N- glass stockinet as indicated by the overlaying lay-up.
3. Blend the overlay resin 80:20 polyurethane with the hardener.
4. Maintain constant vacuum with pressure approximately (30-60 KPa) at room temperature. until the laminations become cold and cut according to the dimension of samples.

For tensile test three samples, [17-20], were prepared for each lamination according to ASTM D638 type I, [21-27]. Fig. 2. shows the dimensions of tensile sample. Also, To evaluating the fatigue characterizations for materials by fatigue test required to testing multi fatigue sample for each group of material, [28-31]. Then, the fatigue, Eight specimens for each group used for test of fatigue. The dimensions of samples are length 100 mm and width 10 mm according to the fatigue device test while thickness various with the kinds of laminate. Fig. 3. shows the shape of fatigue samples. Therefore, after manufacture of tensile and fatigue samples, then testing its samples to evaluating the mechanical and fatigue properties for materials used. Thus, the fatigue equipment used in this respect are as follows,

1. Jepson rectangular mold that manufactured with dimensions (10*15*25 cm3).
2. Vacuum pressure system including pump and tube.
3. Universal instrument machine test (testometric) for tensile.
4. Material fatigue test for flat specimen as shown in Fig. 4.

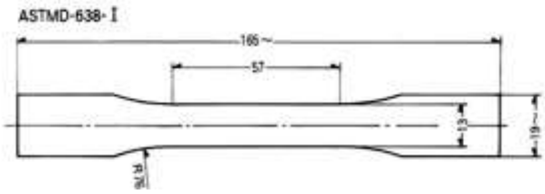
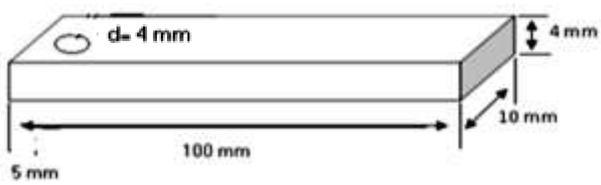


Figure 2 The Dimensions of Tensile Specimen.



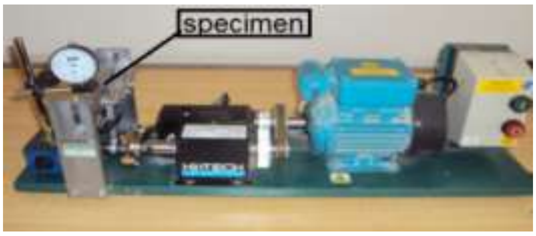


Figure 3 The Shape of Fatigue Specimen **Figure 4** Fatigue Test Device.

Finally, manufacturing of partial foot Prosthetic, where, the Measurement, manufacturing, and alignment of partial foot prosthesis for patient amputated through the foot. The manufacturing procedure is summarized as follows,

1. Taking Measurement, included, stump circumferences, medio-lateral diameter at Calcaneous and Malleolus, length of amputee, length of normal foot, and heel height of patient shoe
2. Handing Casting
3. Preparing for Rectification and Cast Rectification
4. Fabrication of the Soft socket
5. Lamination of Socket, and, Trimming and Finishing.

Then, testing partial foot Prosthetic by using the F-socket. Where, the Interface pressure test for patient wearing a prosthetic type AK (age (51 years), height (187 cm) and weight (85 kg)) suffered from left foot amputation (chopart amputation) due to explosion using sensor type (Mat Scan) which is acceptable for this type of dynamic load, as shown in Fig. 5.

Figure 5 Patient with Mat Scan Sensor.

3. NUMERICAL INVESTIGATION

The numerical technique included using finite element method to evaluating the fatigue characterizations of materials were used to manufacturing the prosthetic part. Then, the numerical results were evaluated are comparison with experimental fatigue results obtained to presenting the agreement of experimental fatigue test used, [32-41]. Thus, the numerical technique, finite element method by using ANSYS program, was required first mesh the model sampled for composite materials, and then evaluating the fatigue properties for material by input the mechanical properties for composite materials, it's evaluated by experimental technique, [42-45]. Therefore, the number of element required is selected by stability of output results for ANSYS program, [46-52], there, the Fig. 6. is shows the fatigue results, for different sample, were evaluated by using ANSYS program with various element number. Then, the best number of element could be used are about (400000) elements. Then, the numerical technique also using to analysis various behaviors for atrial foot socket model. Therefore, the safety factor for fatigue, Von-Mises stress and total deformation, for partial foot socket, are evaluated for various group materials used.

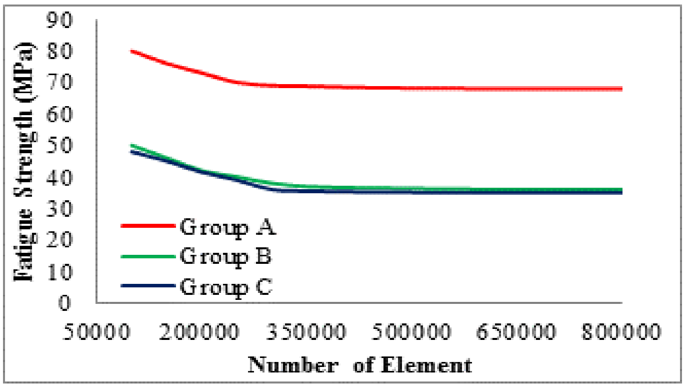


Figure 6 Fatigue Results with Various Number of Element.

4. RESULTS AND DISCUSSION

4.1. Tensile Properties Results

The properties for laminations can be obtained as shown in Table 1. The mechanical properties of samples can be determined from these curves and recorded in Table 1. The results explain that the properties of group (B) when increasing two layers of n-glass with constant Perlon, are increasing strength of yield σy16%, ultimate stress σult about 11% with E 7%) as compared with (Group C). For group (A) the results explain when increasing two layers of carbon fiber with constant Perlon, lead to increase strength of yield σy 53%, ultimate stress σult about 60% with E 22%) as compared with (Group C). The properties is increased that's because to the inclusion of the specimens and the mechanical properties for glass fibers and carbon fibers higher as much as perlon.

Table 1 Mechanical Properties Evaluated from Stress-Strain Curves.

No. of Lam.	No of Layers	Thickness (mm)	σy (MPa)	σult (MPa)	E (GPa)
Group A 4perlon-2carbon fiber-4perlon	10	4	77.3	97.5	1.4
Group B 4perlon–2N glass-4perlon	10	3.7	43	43.7	1.16
Group C 8Perlon layers	8	2.9	36	39	1.08

4.2. Fatigue Properties Results

The failure of fatigue of flat specimen can occur when the specimen fractures under alternative loading. The readings were recorded by the fatigue tester machine give the number of cycles when the specimens were fractured. The comparison between experimental and numerical fatigue results are given in Figs. 7 to 9 for various groups (A, B and C), respectively. Therefore, from the Figs. 7 to 9. shown that a good agreement for results evaluating, with maximum error about (8.39%). Then, the S-N curves for each sample of all laminations as shown in Fig. 10. The failure stresses are decreasing and the number of cycles to reach to the failure is increasing at constant temperature. There, from Fig. 10. shown that the fatigue strength and number and cycle, for group A, are greater than the fatigue characterizations for other group.

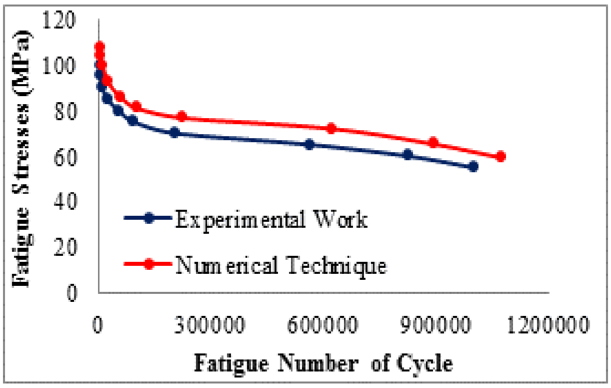


Figure 7 Numerical and Experimental of Fatigue Behavior Results for Group A Materials

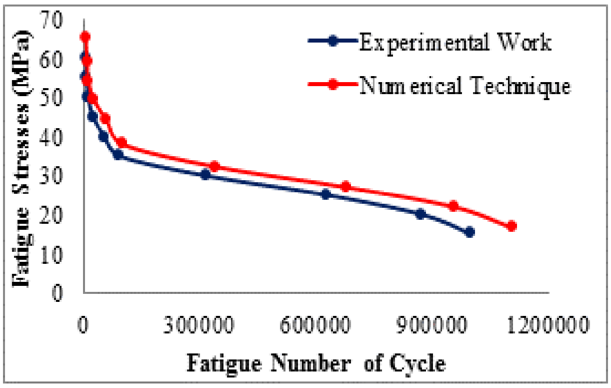


Figure 8 Numerical and Experimental of Fatigue Behavior Results for Group B Materials

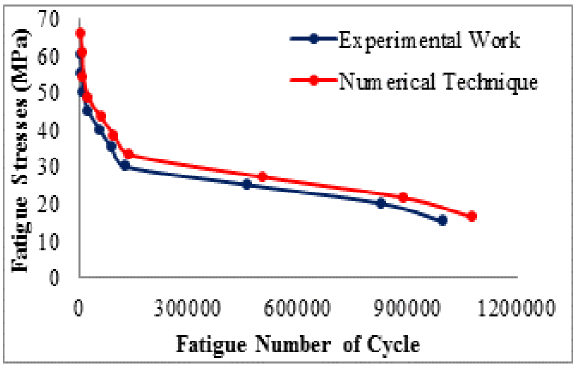


Figure 9 Numerical and Experimental of Fatigue Behavior Results for Group C Materials

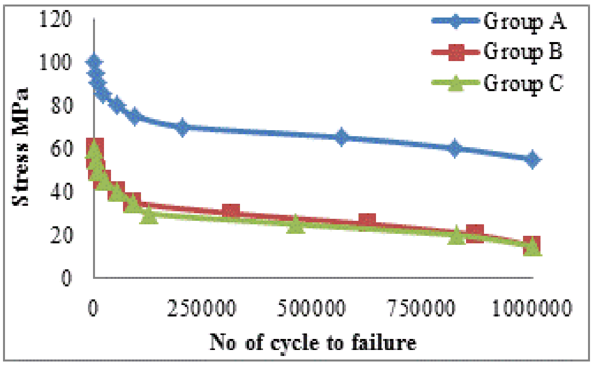


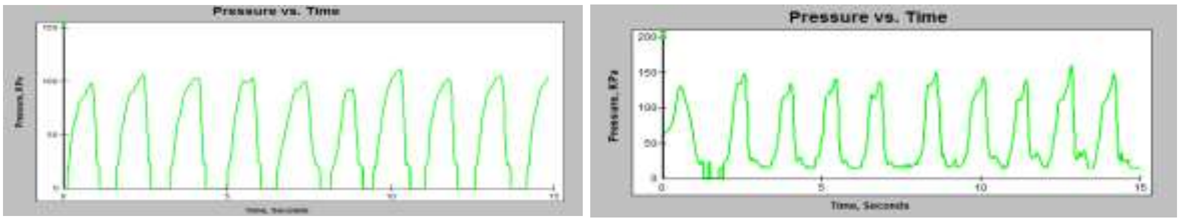
Figure 10 S-N Curves for Each Laminations.

4.3. Pressure of interface Result

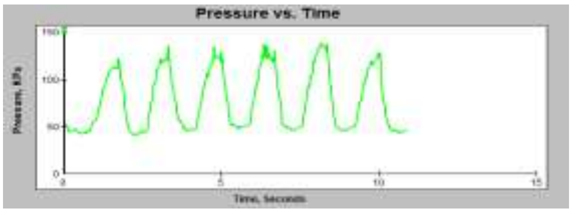
The pressure of interface between the stump of patient and socket can be measured by the F-Socket sensor. The sensor was connected with software (F-Socket) to found the pressure curve applied to the sensor. The sensor was put on different regions of the stump(Anterior, Lateral, Posterior, and Medial) as shown in Fig. 11. The values of the socket pressure and positions are as detailed in Table 2. Higher pressure emerging at the lateral region is 161 kPa and the posterior region is138 KPa. The reason is 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).

Table 2 Values of Interface Pressure for Prosthetic Socket.

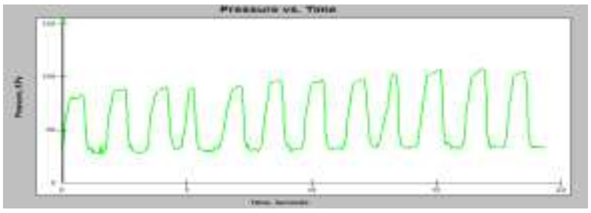
Socket Regions	**Anterior**	**Lateral**	**Posterior**	**Medial**
Interface Pressure (kPa)	112	161	138	108



a. Time at Anterior Socket Region b. Time at Lateral Socket Region



c. Time at Posterior Socket Region.



d. Time at Medial Socket Region

Figure 11 Interface Pressure vs.

4.4. Von-Mises Stresses and Safety Factor Results

The analysis atrial foot socket model for patient was set up by FEM software to compute the equivalent (Von-Mises) stress and safety factor of fatigue. It is seen that the fatigue safety factor is safe in design applications if the safety factor is more than (1.25), [53]. The results show the safety factors for three types of partial foot socket model are presented in Figs. 12-15, the changes of the properties of materials are affecting on the results of Von-Mises stress. The Von-Mises stress for the each type of lamination composites are shown in Figs. 16-19. Figs. 20-23 shows the total deformation for the each type of lamination composites. The safety factors for composite material (4Perlon+2carbon fiber+4perlon) layers are about (2.429) which are safe and acceptable in design.

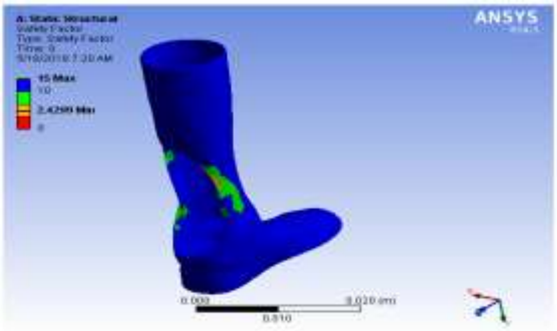


Figure 12 The Safety Factor for Fatigue Group A.

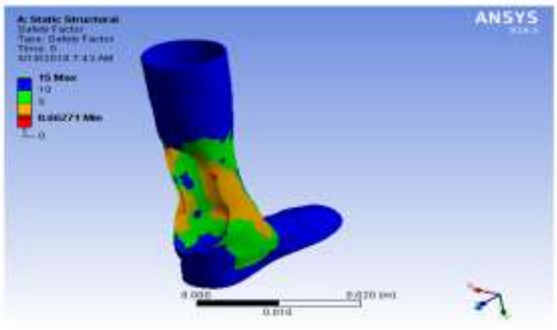


Figure 13 The safety factor for fatigue Group B.

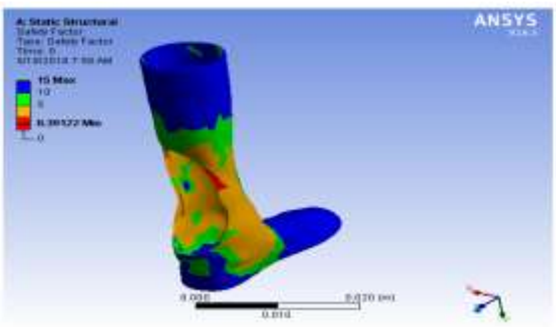


Figure 14 The safety factor for fatigue Group C.

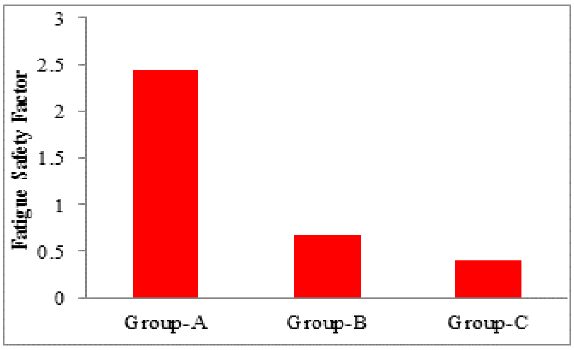


Figure 15 Fatigue Safety Factor for Various Group.

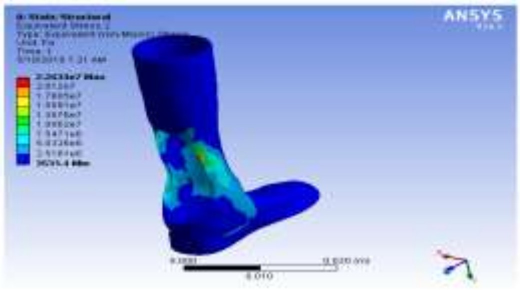


Figure 16 Von-Mises stress for Group A

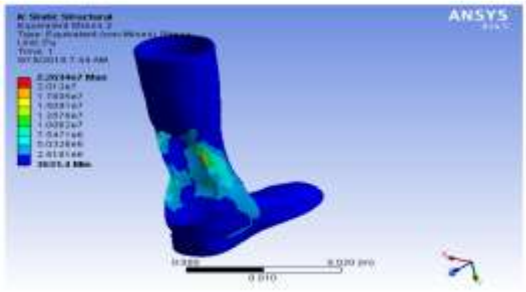


Figure 17 Von-Mises stress for Group B.

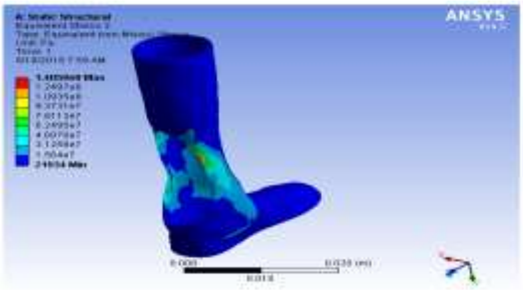


Figure 18 Von-Mises stress for Group C.

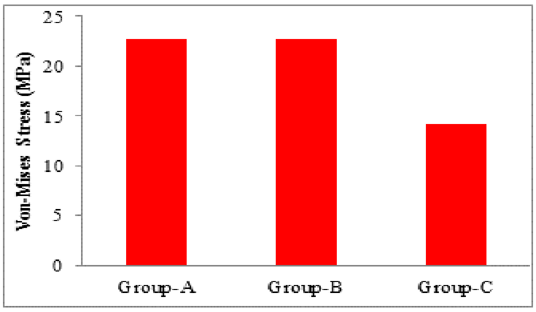


Figure 19 Von-Mises for Various Group.

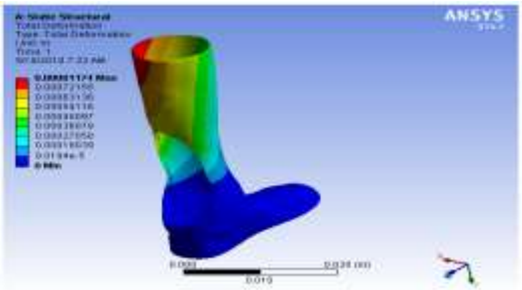


Figure 20 Total deformation Group A

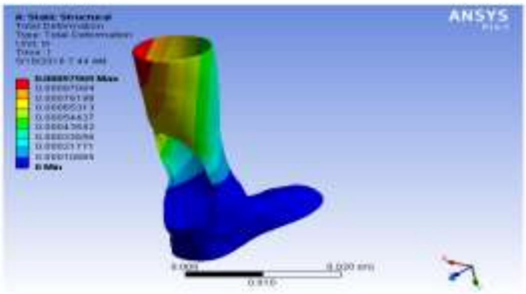


Figure 21 total deformation Group B.

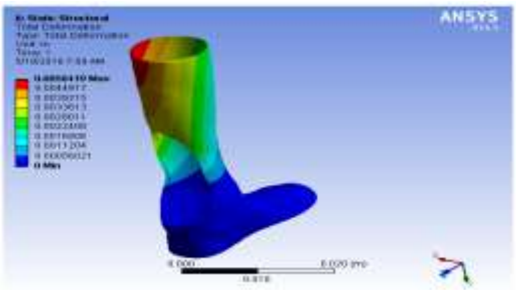


Figure 22 total deformation Group C.

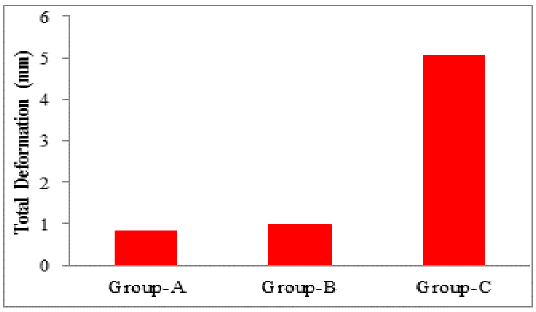


Figure 23 Total Deformation for Various Group

5. CONCLUSIONS

1. The experimental technique used to evaluating the fatigue characterizations for laminated materials, groups A to C, was a good tool can be used by comparison with numerical fatigue results. Where the maximum error for the results evaluated by two techniques about (8.93%).

2. The numerical technique used, by using ANSYS program, was a good techniques can be used to evaluating a various behaviors, fatigue safety factor; Von-Mises and total deformation, for laminated materials used.
3. There are a high value in the characteristics (σy, σult with E) when used carbon fibers in samples and lead to increase about (yield strength Ϭy 53%, ultimate tensile strength Ϭult 60% and modulus of elasticity E 22%) for group (A) as compared with group (C) and increasing about (strength of yield σy 16%, ultimate stress σult 11% with E 7%) for group (B) as compared group (C).
4. The lifetime for partial foot are depend on value of the applied stress with type of the materials composite l. The lamination which consists of (4P2C4P) layers has Endurance limit stresses (σe) as much as longer than the other laminations. This increase in lifetime for the patient wearing partial foot prosthetic.
5. Higher interface pressure at the lateral region is 161 KPa and the posterior region is138 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.
6. The partial foot composite material socket model showed that the fatigue safety factor for (4Perlon +2carbon fiber +4perlon) was (2.43) which considered as safe in design.

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