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# Manufacturing and mechanical behavior investigation of prosthetic below knee socket by using natural kenaf fiber

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## Abstract

This paper presented the investigation of the effect of adding natural fiber kenaf fiber on the stress and deformation in below-knee socket prosthetic structures manufactured from composite laminated materials with various reinforcement fibers. This work included theoretical, experimental and numerical study, in theoretical part the weight of the patient on the remaining limb was analyzed mathematically using Matlab 2018 a program, the result of the pressure was 165 Kpa. As for experimental part, the artificial socket was manufactured from the second proposed composite materials with kenaf, testing the ground reaction force (GRF), as the results showed that the proportion of similarity between the uninjured leg and healthy is 96%. Numerical analysis part using the finite element method was adopted to estimate the Von Mises stresses and deformation behaviors for the below-knee prosthetic structures through ANSYS 2020 R2, The simulation using the mechanical properties of the relevant composite materials taken from previous published and the pressure generated from the mathematical equations was compared with the results using the pressure readings obtained from the experimental test F-Socket readings of a similar patient condition as input to the ANSYS program. The results of the composite material using kenaf showed that the highest value of Von-Mises stress is equal to (34.14 Mpa) for the experimental F-Socket test, while the value (48.9 MPa) was obtained from theoretical part, as the stress was reduced by the lamination with kenaf in the experimental F-Socket test (43.23%) and theoretically (10%), to reduces the deformation of the material and comfort of the patient during movement. Finally, the different between the results was calculated for the theoretical and experimental F-Socket analyzes were acceptable values.

**Keywords:** Below Knee; Prosthetic Socket; Kenaf fiber; FEM; ANSYS.

## 1. Introduction

Due to the large number of injuries suffered by people in general and in Iraq in particular, in Iraq 55% of amputations are because of diseases or because of the negligence of medical care for the patient, and constitutes 36% of amputations because of accidents or attacks of terrorist bombings and 9% is because of congenital deformities from birth. Typically, 80% of the amputations are below knee (BK) lower limb amputations [1-3]. The choice of materials for prosthetic devices is one of the important factors in prosthetic limbs in terms of weight and the strength of the material has a direct effect on the level of mobility of the patient and the comfort of the socket, manufacturing low-cost, lightweight, and highdurability industrial cavities through a suitable design by selecting suitable materials with natural fiber reinforcement in which the manufacturing process is possible within the local industry [4-5].

Materials, methods of manufacturing sockets, and analysis using the finite element method have been studied by several researchers as Mustafa Tariq Ismail et.al (2013), they studied Creep-fatigue in composite materials of Socket at 60 ° C. Where the stress distribution on the socket was known. By using FEM with the help of ANSYS Workbench 12.1, found two stresses generated when walking during hot weather and changing pressures on inner surface of the socket, leading to decrease the mechanical properties over time, causing failure of the Socket material due to creep interaction and fatigue. Total deformation, fatigue age, and extreme stress and the safety factor determining [6]. Gabi Nehme et al. (2014) investigated transtibial socket design amputees where models were examined and modified using (FEM). Trial design (DOE) and the pressure distribution at the interface of the limb socket were determined. They observed changes in material properties as the shape was refined, transformed, and IGES via Solid-Works 2010 and exported to ANSYS 13. It confirmed Canfit system results with FEM and DOE analysis improving function perform prosthetic sockets [7].

Shireen Challoob et.al (2015), have explained the effect of creeping and stress relaxation in(BK) Prosthetic Socket material (Polypropylene) at (50° C), which leads to deformation of the material and sagging in the socket due to reduced mechanical properties, which makes it uncomfortable for the patient. Using the Burger model the results were analyzed and evaluated through creep test to obtain the equation of the stress relaxation (constant strain) factor, from f-socket device at mid-stance the pressure reached the peak point and determined the stress distribution on socket by using ANSYS. Their results confirmed that the materials lose their strength and hardness over time at high temperatures due to the relaxation effect, which leads to the failure of the socket [8]. Rajesh Kumar Mohanty et.al (2017), showed technological advances in the design and manufacture of prostheses in femoral amputee rehabilitation. A review of models used in and developing countries was performed with regard to design, modeling, kinetics, and finite element analysis (FEA), The displacement, strain and pressure of components under internal and external loads are calculated by displacement equation for FEM. FEA and Taguchi have been shown to be an effective method for improving the structural design of prostheses. The prosthesis design process can be facilitated [9].

And some research has been selecting natural kenaf fiber, studied the effect of adding kenaf fiber were reinforced by Thermoplastics such as Polypropylene is favored due to its following characteristics: low density, excellent processing ability, good mechanical properties, and dimensional stability [10]. as the natural fiber which show high performance compared with other natural fibers. In (2017), M.H. Nurhanisah et al. developed composite materials reinforced with kenaf fiber used for prostheses in prosthetic design as the polymer compounds combined with natural fibers reduce heat problems, discomfort, and sore skin. [11]. Muhsin J. Jweeg et al. (2017) conducted fatigue testing for samples made of natural rubber reinforced with three different black carbon particle ratios. The results showed a significant improvement in the composite material's mechanical properties, increasing the carbon particles percentage [12]. In (2018), Hawraa Ahmed Hamzah suggested using the date palm nuts powder in the lower prostheses' socket production as a reinforcing material besides lamination resin [13] A.S. Harmaen et al. (2018) produced composite materials with suitable properties by mixing kenaf core (KCF) with polypropylene(pp) by adding silica aerogel (AG). They conducted the impact tests at room temperature for several samples using an impactor machine. It was found that the addition of KCF and AG increased the tensile modulus and improved tensile strength and impact strength [14].

Muhsin J. Jweeg et.al (2019), have investigated the experimentally and numerically improving the mechanical properties of the composite materials of the socket prosthesis for below-knee (BK), the values of the maximum stress and elastic modulus of the proposed material were determined, as well as (GRF) was measured. Through the numerical part, the deformation amount (18 mm) and the dynamic stress of load as unit step were calculated using ANSYS 16.0 software and developed using the CT –Scan method and exported to ANSYS. The (DLF) that did not exceed (1.188), the composite material is much better than the traditional material (polypropylene), as well as using the CT –Scan method is very strong and much better in FEL modeling [15]. Technological advancement has led to wider range of modern orthopedic and prosthetic device. Fiber reinforced composites are most widely used for upper- and lower-limb prostheses due to their superior strength and excellent biocompatibility [16].

The main objectives of this work are improving and strengthen the prosthetic socket by using natural Kenaf Fiber for composite material with (perlon, carbon, kevler) fiber. Design and analysis the prosthetic socket to determine the subjected stresses, deformation for two group without and with kenaf . Study the patient conformability through the ground reaction forces (GRF) test.

## 2. Theoretical Investigation

### *2.1. Analytical Modelling*

An ordinary model was formed to evaluate the forces between the limb and the prosthetic socket [17-25]. To replicate the actual forces between the prostheses and the stump, a conical shape was generated due to the forcing of the socket shell. The inner bone is assumed to be a cylinder, F= Kd, and the material is assumed to be linear and isotropic. The analysis also assumes full contact between the prostheses and the stump. As shown in Figure 1, two forces affect the tissue. The first force is the perpendicular spring presupposed in the sample as the supporting force generated by compressing the soft tissue normal to the surface of residual limb. The second force is the tangential spring representing the force from the parallel shear to the interface. It has been shown that the damage of tissues relies on the resultant of shear and normal stresses $\sigma_c$. This resultant can be obtained from the equations 1 and 2, [17],

$$P = \frac{K_N}{A}\left(d_{N_o} + \frac{W\sin\theta}{(K_N\sin^2\theta + K_S\cos^2\theta)}\right) \quad (1)$$

$$\tau = \frac{K_S}{A}\left(-\frac{K_N}{K_S}d_{N_o}\tan\theta + \frac{W\cos\theta}{(K_N\sin^2\theta + K_S\cos^2\theta)}\right) \quad (2)$$

Then,

$$\sigma_c = \sqrt{p^2 + \tau^2} \quad (3)$$

Where, The average interface normal stress in (Pa): The average interface shear stress in (Pa), their values are (153244.213650 Pa) and (61297.685460Pa). When the resulting stress was taken and its value was (165.049 kPa). The MATLAB 2018a software was used to create a program using analysis model equations, the output data were implemented by using (ANSYS R2020) to analyze pressure effect on the socket and to find the shearing stress acting on the limb surface.

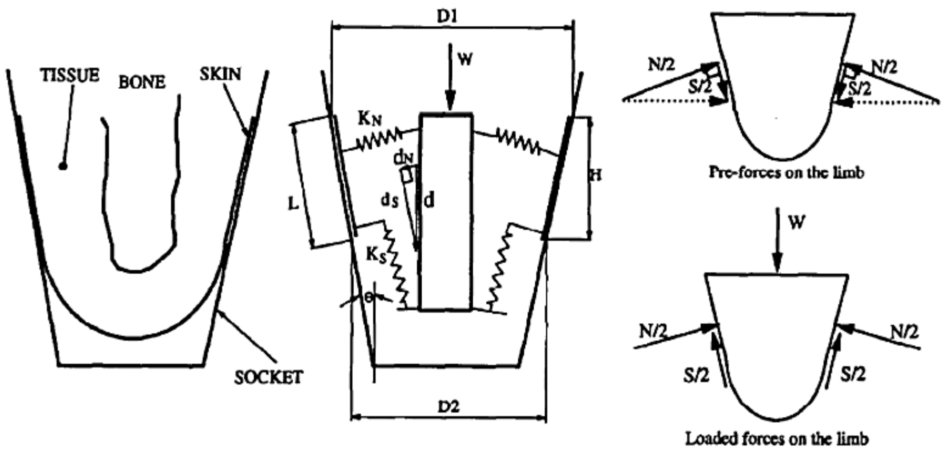


Figure 1. The simplified remaining limb model.

The analysis was conducted using some typical values for the geometric and mechanical properties associated with the limb/prosthetic socket interface: young's modulus of soft tissue E = 100 kPa, average tissue thickness t = 20 mm, coefficient of friction μ = 0.4, Poisson's ratio υ = 0.5 [26]. According to the dimensions of the patient's socket, it was taken upper diameter $D_u$ = 144.8 mm, lower diameter $D_l$ = 146.4mm, height H =30 mm, and force W= 784.8 N.

### *2.2. Numerical Analysis for BK Prosthetic Sockets*

A model was drawn by using CAD system (Solid Work2017) Program (SLDPRT) and then exported to the extension (parasolid.x-t). After that, the model imported to the ANSYS workbench (2020 R2) for its extension. Which were processed according to a default pattern in three dimensions. The dimension is same socket that was done in measurement of experimental part for a case study of lower knee amputation for a case of a 59-year-old patient in a prosthetic center with a weight of 80 kg amputation of the right limb due to diabetes, the aim of drawing models by solid work is to simulation ANSYS 2020 R2 workbench program for modeling, meshing and defining boundary condition such as applied load.

Finite element analysis is a numerical method to make an approximate solution for variables in a problem that is difficult to be solved analytically. In more solutions and application of science and engineering finite element method (FEM) is widely used. FEM is considering one of the stronger methods which used to solve the problems with nonlinear materials, [27-35]. ANSYS program has many finite element analysis capabilities, ranging from a simple, linear, static analysis to a complex, nonlinear [36-44]. The finite element method has become a powerful tool for numerical solution of a wide range of engineering problems, [45-53]. The use of ANSYS-2020R2 is approved for the construction of the finite element model [54-62]. General analysis using ANSYS features three important steps, building the geometry as a model, apply limit conditions, obtain the solution, and review results, [63-72].

The ANSYS Object Library contains over 100 different types of objects. SOLID185 is used for 3-D modeling of solid structures. It is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions, after selecting the type of element, the desired thickness could be inserted. Figure 2 shows the geometry and nodes location for this element [49]. The meshing process has been done by choosing the volume, and then the shape of element was selected as tetrahedron (Automatic meshing) as shown in Figure 3. This mesh has an element size of 0.008mm with 20097 nodes and9750 elements, which is consistent suitable mesh with converged meshes of other researchers. The model should have fixed support at the adapter (the base) of the socket and the top of socket, in addition the interface pressure between the remaining limb and the socket that obtained from the theoretical mathematical equations that are solved in Mat lab is applied to the inner surface of socket wall were do not exceed 165 kpa. And from previous studies that the pressure on the socket can be found through the f-socket test of the experimental test [73], as shows in Figure 4. The results can be considered as a theoretical pressure analysis and the resulting pressure analysis from f-socket test can be considered an experiment analysis.

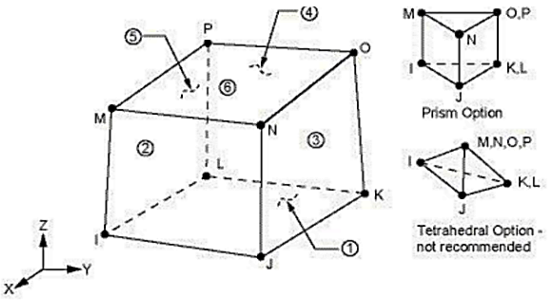


Figure 2. Solid 185, [49].

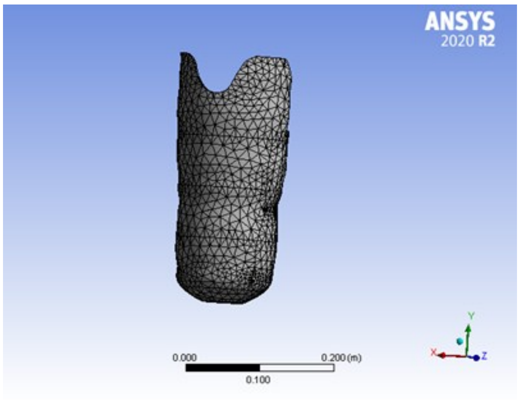
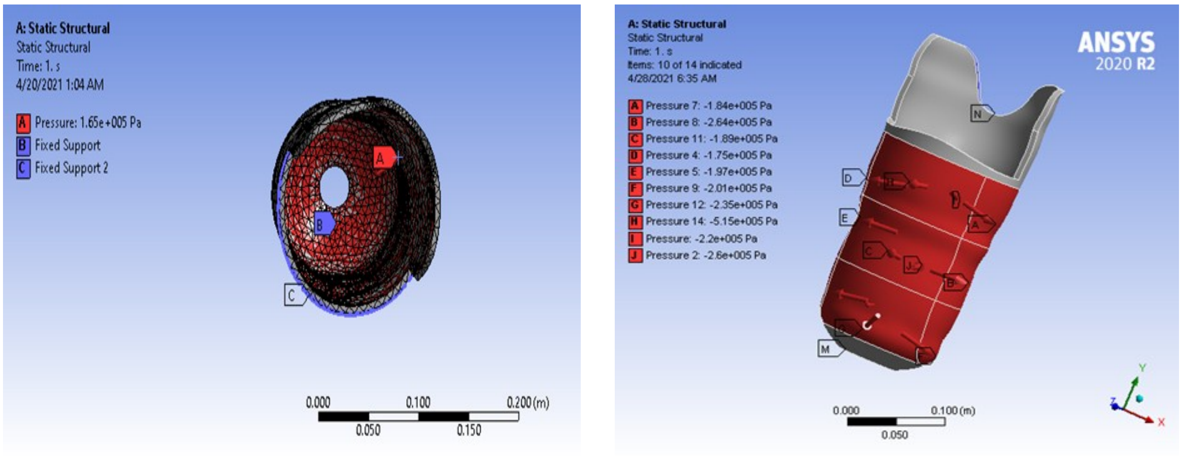


Figure 3. Mesh of the socket Model.



A: Static Structural
Static Structural
Time: 1. s
4/20/2021 1:04 AM

A Pressure: 1.65e+005 Pa
B Fixed Support
C Fixed Support 2

A: Static Structural
Static Structural
Time: 1. s
Items: 10 of 14 indicated
4/28/2021 6:35 AM

A Pressure 7: -1.84e+005 Pa
B Pressure 8: -2.64e+005 Pa
C Pressure 11: -1.89e+005 Pa
D Pressure 4: -1.75e+005 Pa
E Pressure 5: -1.97e+005 Pa
F Pressure 9: -2.01e+005 Pa
G Pressure 12: -2.35e+005 Pa
H Pressure 14: -5.15e+005 Pa
I Pressure: -2.2e+005 Pa
J Pressure 2: -2.6e+005 Pa

a. The location of pressure force on the model for the analytical part

b. The locations pressure forces on the model for the experimental part (F-Socket), [73].

Figure 4. Socket model subjected to pressure load with fixed supports.

### *2.3. Phases of Gait Cycle*

The gait cycle is defined as the period of time between two consecutive heel contacts of the same foot, there are two stages of the gait cycle, which are,

I. The Stance Phase, Approximately 62% of the walking cycle is the first contact (Heel strike) to toe off. The stance phase is divided into five sub-phases, [73].

II. The Swing Phase, This stage begins at the moment the big finger moves away from the ground and ends with touching the tip of the tip or the direct stitch of the heel. From three sub phases (initial, initial, and terminal) the swing phase is consisting, [73], as shows in Figure 5.

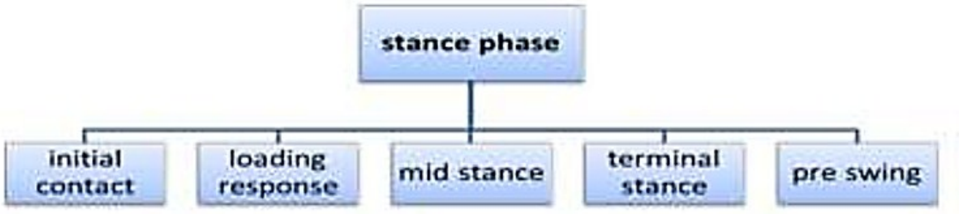


Figure 5. The Five Stages of Stance Phase, [73].

During gait and as a consequence of the force placed on the ground when the contact with the foot occurs, the ground reaction forces (GRF) is develops. The ground reaction forces are equal to the force between the foot and the ground. The ground reaction forces are directly related to the acceleration of the COM and can be described simply according to Newton's law by equation,

$$\mathrm{GRF} = \mathrm{M}\,(\mathrm{g} + \mathrm{a}) \qquad (4)$$

Where, GRF is the ground reaction force, (g) is acceleration of gravitational, (a) is the center of mass' s (COM) vertical acceleration, and (M) is the person body mass. Since (M) and (g) are constants, the changes in the magnitude of GRF depend only on the changes in the vertical acceleration, [74].

## 3. Experimental Work

### *3.1. Manufacturing of Below-Knee Prosthesis Socket*

Lamination of below knee socket were chosen the best sequence laminated with kenaf, Perlon,Carbon fiber and Kevlar with Lamination resin 80:20, Hardening powder (ottobock health care 617P37). Polyvinyalcohol PVA bag (ottobock health care 99B71). As shown in Figure 6. The equipment and tools used for the prosthetic below-knee socket lamination are: gypsum mold, vacuum system, prosthesis and orthotics workshop. Gypsum Mold Manufacturing by the following stepes,

1. Measurement for the stump as shown in Figure 7.
2. A piece of plastic was fixed between the negative mold and the patient's stump to help remove the negative mold safely and easily.
3. A negative mold from the gypsum layer (template) was fabricated for the stump.
4. After the gypsum layer (template) drying, it was cut through the plastic strip, and the negative mold was removed carefully.
5. The negative mold was filled up by the gypsum to make the positive mold.
6. Smooth the outer surface of the positive mold that. The positive mold was carved and grinded according to the measurements taken from the patient's stump.

Figure 6. Materials used.

Figure 7. Measuring the residual stamp.

Therefore, the procedures of socket manufacturing are,

1. The inner PVA bag was placed on the positive mold and closed from both sides as shown Figure 8.a. The vacuum device was working at (2 bar) at room temperature.
2. The layers of perlon and Kevlar were arranged according to the laminating lay-up group with kenaf (1Perlon+2 Carbon fiber +1Kevlar fiber+1 kenaf fiber +2 Perlon +1kenaf fiber +1 Kevlar fiber+2 Carbon fiber+ 1Perlon) layers as shown in Figure 8 (b,c,d,e and f). The outer PVA bag was placed tightly and closed from the bottom end leaving the smaller hole open to remove the air from PVA bag. The other end was left open for lamination resin supply as shown in Figure 8.g.
3. 150 mL of lamination resin 80:20 was mixed with 50 gram of hardener according to the standard ratio. Next, the produced socket is removed from the positive mold as shown in Figure 9.
4. Connected the socket with pylon and foot as shown Figure 10.

a. Laying the PVA on the soft socket

b. Laying the perlon layers

c. Fixing the adapter

d. Fixing carbon fibers

e. Fixing the Kevlar fibers

f. Fixing the kenaf

g. Pre finishing and lamination layer

h. Supplying the resin to all layers

Figure 8. Procedure of Laminating Lay-Up.

Figure 9. Socket is removed from the positive mold.

Figure 10. The socket after the completion of the manufacturing stages.

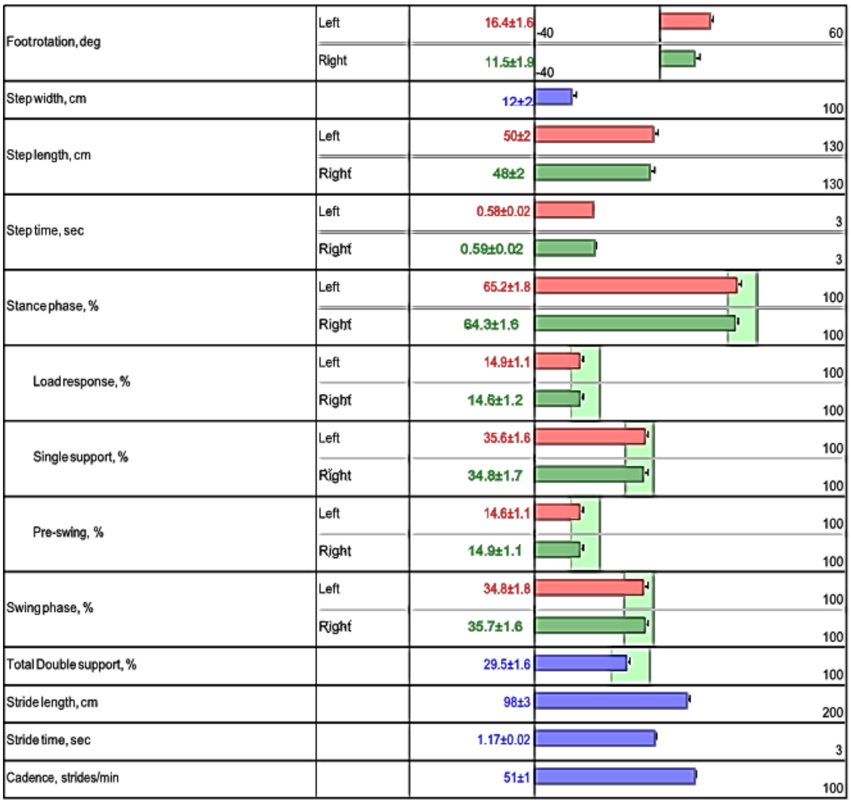
### *3.2. Biomechanical Tests*

The ground reaction force (GRF) test was conducted for the patient by using a force plate. Gait cycle analysis was done in University of Kufa/Sport Education College, on treadmill the platform (Zebris, FDM – T), In this test, the patient was asked to walk over the force plate for two minutes, [75] to assure the stability of reading, as shown in Figure 11. The results of the gait cycle test represent the parameters of the gait of two cases, amputee and normal subject are summarized in Figures 12 and 13, respectively. There different between the left (intact leg) and right leg (injured leg) of amputee subject. From comparing the results obtained for the amputee subject case study was using the socket and the normal subject case study, the difference detected as in the stance phase percent for the left leg equals to (69%) and the right (78.3%) for amputee case, while for the normal case, the differences was 65.2% and (64.3%), respectively.

Figure 11. Patient Walking on Force Plate Wearing the prosthesis.

| | | | |
|---|---|---|---|
| Footrotation, deg | Left | 15.3±2.1 | -40 60 |
| | Right | 22.0±3.2 | -40 |
| Step width, cm | | 15±2 | 100 |
| Step length, cm | Left | 29±4 | 130 |
| | Right | 30±5 | 130 |
| Step time, sec | Left | 0.70±0.07 | 3 |
| | Right | 0.65±0.06 | 3 |
| Stance phase, % | Left | 69.0±1.7 | 100 |
| | Right | 78.3±3.0 | 100 |
| Load response, % | Left | 23.7±2.3 | 100 |
| | Right | 17.8±1.7 | 100 |
| Single support, % | Left | 27.5±2.8 | 100 |
| | Right | 34.0±1.9 | 100 |
| Pre-swing, % | Left | 19.8±1.9 | 100 |
| | Right | 25.1±2.6 | 100 |
| Swing phase, % | Left | 33.0±1.7 | 100 |
| | Right | 24.8±3.0 | 100 |
| Total Double support, % | | 47.6±2.9 | 100 |
| Stride length, cm | | 53±7 | 200 |
| Stride time, sec | | 1.21±0.13 | 3 |
| Cadence, strides/min | | 40±4 | 100 |

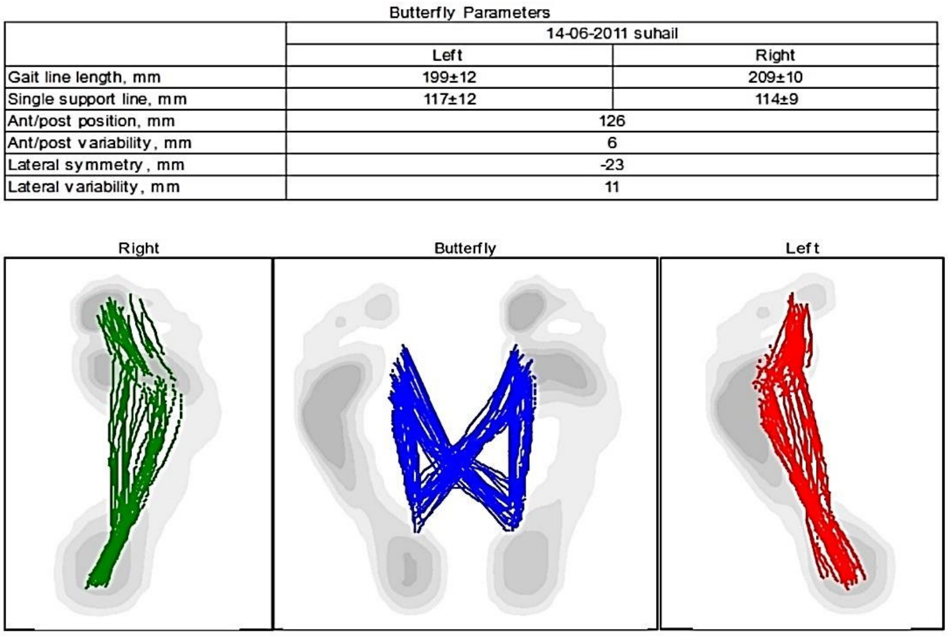
Figure 12. Parameters of the gait cycle for the amputee subject (BK) wearing the socket on his right Leg.



| | | | |
|---|---|---|---|
| Footrotation, deg | Left | 16.4±1.6 | -40 60 |
| | Right | 11.5±1.9 | -40 |
| Step width, cm | | 12±2 | 100 |
| Step length, cm | Left | 50±2 | 130 |
| | Right | 48±2 | 130 |
| Step time, sec | Left | 0.58±0.02 | 3 |
| | Right | 0.59±0.02 | 3 |
| Stance phase, % | Left | 65.2±1.8 | 100 |
| | Right | 64.3±1.6 | 100 |
| Load response, % | Left | 14.9±1.1 | 100 |
| | Right | 14.6±1.2 | 100 |
| Single support, % | Left | 35.6±1.6 | 100 |
| | Right | 34.8±1.7 | 100 |
| Pre-swing, % | Left | 14.6±1.1 | 100 |
| | Right | 14.9±1.1 | 100 |
| Swing phase, % | Left | 34.8±1.8 | 100 |
| | Right | 35.7±1.6 | 100 |
| Total Double support, % | | 29.5±1.6 | 100 |
| Stride length, cm | | 98±3 | 200 |
| Stride time, sec | | 1.17±0.02 | 3 |
| Cadence, strides/min | | 51±1 | 100 |

Figure 13. The parameters of the gait cycle for the normal subject.

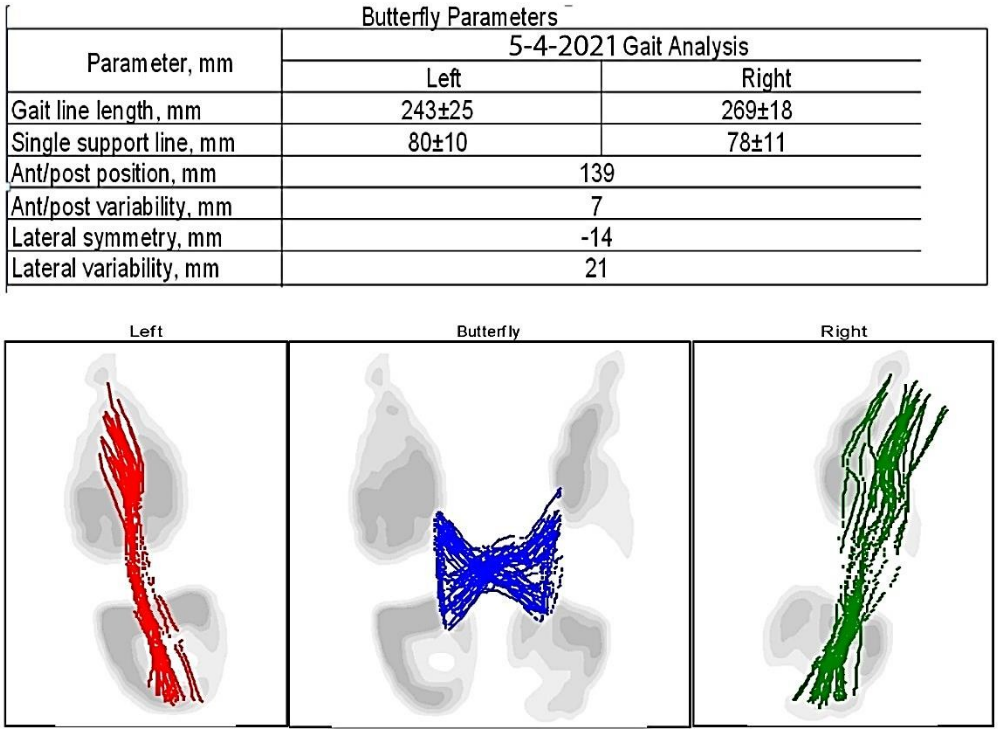
The normal subject's data were higher than the amputee subject's data for swing phase percent, about (2%) for the left leg and about (10%) for the right leg. Also, the single support percent for the amputee subject's was about (27.5%) for the left leg and about (34%) for the right leg, while for the normal subject was about (35.6%) for the left leg and about (34.8%) for the right leg, and then, the pre-swing percent was recorded with higher level than normal case, about (5.2%) for the left leg and about (10.2%) for the right leg. The total double support percent for amputee case was exceeded the normal range, about (18.1%). The result that obtained in Figures 14 and 15, have shown that the difference in gait cycle length and single support line was (10mm) and (3mm) respectively; for the normal subject. While for amputee case it was (26mm) and (2mm) respectively.



Butterfly Parameters

| | 14-06-2011 suhail | |
|---|---|---|
| | Left | Right |
| Gait line length, mm | 199±12 | 209±10 |
| Single support line, mm | 117±12 | 114±9 |
| Ant/post position, mm | 126 | |
| Ant/post variability, mm | 6 | |
| Lateral symmetry, mm | -23 | |
| Lateral variability, mm | 11 | |

Figure 14. The Butterfly parameters of the gait cycle for path of the center of pressure for normal subject.



Butterfly Parameters

| Parameter, mm | 5-4-2021 Gait Analysis | |
|---|---|---|
| | Left | Right |
| Gait line length, mm | 243±25 | 269±18 |
| Single support line, mm | 80±10 | 78±11 |
| Ant/post position, mm | 139 | |
| Ant/post variability, mm | 7 | |
| Lateral symmetry, mm | -14 | |
| Lateral variability, mm | 21 | |

Figure 15. The Butterfly parameters of the gait cycle for path of the COP for amputee subject (BK) wearing socket.

## 4. Results and Discussion

The static analysis is to investigate the stresses deformation generated by the interface pressure in the socket was in the analytical part (165 Kpa) and from the experimental test f- socket for a similar case study patient with a right leg amputation (BK) of 85 kg, [73] the result of the interface pressure in each region of leg show in Table 1. The analysis was done in the two cases for to best laminations (group G &D). The physical properties (e.g. density) and mechanical properties for two cases mentioned were estimated in the experimental part (tensile test) for previous search showed in Table 2. The analysis of Von-Mises Stresses. For the analytical and experimental parts, the lamination without kenaf prosthetic socket (group G) are (59.99 MPa) and (54.5MPa) for the lamination with kenaf prosthetic socket (group D) as shown in Figures 16 and 17 for analytical part. Figures 18 and 19 show the distribution of Von-Mises stresses in the prosthetic socket for for experimental part F-socket test, [73]. For the experimental results, Von-Mises stresses were (48.9MPa) and (34.14MPa) for lamination without and with kenaf prosthetic socket respectively. Note that a comparison in the values of the maximum stress Von-Mises with the strengthening of natural kenaf fibers has be reduced by (10%)and (43.23%) for analytical and experimental investigation. The strain values in analytical part for the lamination without kenaf and with kenaf prosthetic socket (group G& D) show in Figures 20 and 21. Figures 22 and 23, shows maximum strain in experimental part for the lamination without kenaf and with kenaf prosthetic socket (group G& D).

Table 1. Values of interface pressure, [73].

| Region | Upper Region (KPa) | Medium Region (KPa) | Lower Region (KPa) |
|---|---|---|---|
| **Anterior** | 220 | 260 | 175 |
| **Medial** | 175 | 197 | 103 |
| **Lateral** | 184 | 264 | 201 |
| **Posterior** | 515 | 189 | 235 |

Table 2. The Average Results of Mechanical properties from The Tensile Test.

| Name of lamination | Ultimate tensile stress (Mpa) | Modulus of elasticity (E)(Gpa) |
|---|---|---|
| **Group G/withot kenaf** | 134.47 | 16.78 |
| **Group D/ with kenaf** | 187.39 | 17.49 |

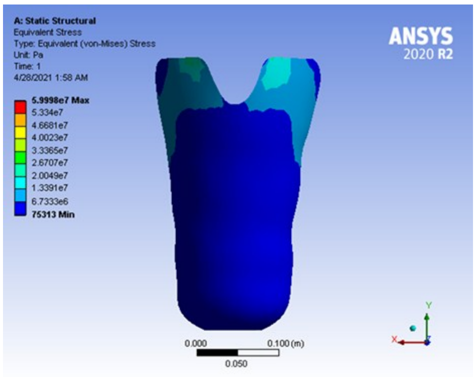


Figure 16. Von-Mises stress for analytical part for the lamination without kenaf socket (group G).

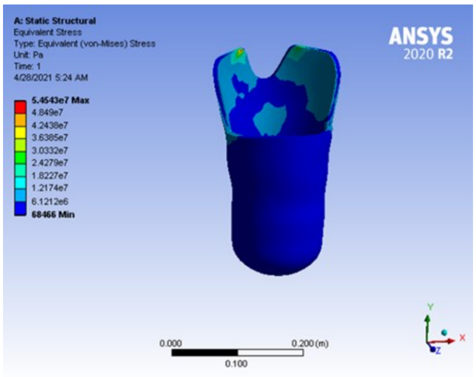


Figure 17. Von-Mises stress for analytical part for the lamination with kenaf socket (group D).

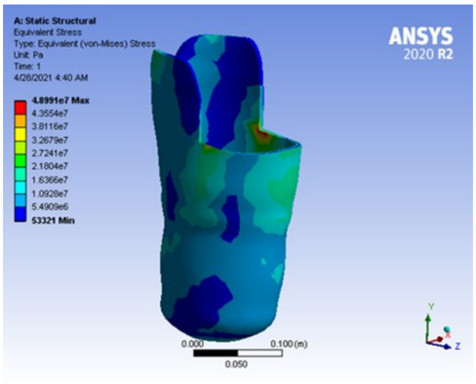


Figure 18. Von-Mises stress for experimental part for the lamination without kenaf socket (group G).

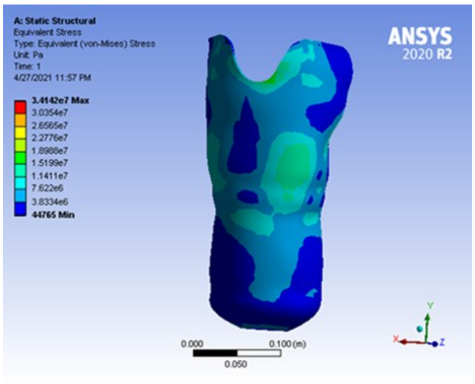


Figure 19. Von-Mises stress for experimental part for the lamination with kenaf socket (group D).

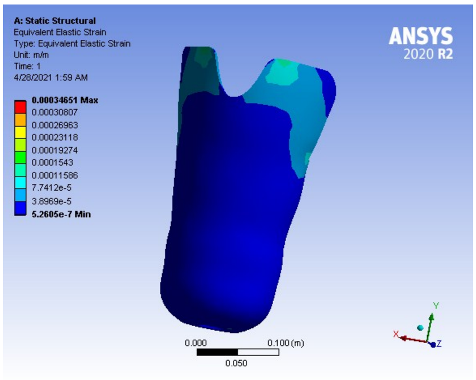


Figure 20. Maximum strain for analytical part for the lamination without kenaf socket (group G).

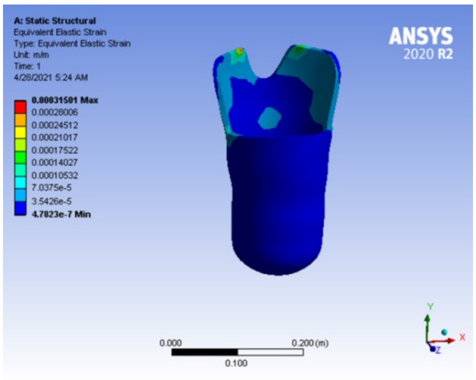


Figure 21. Maximum strain for analytical part for the lamination with kenaf socket (group D).

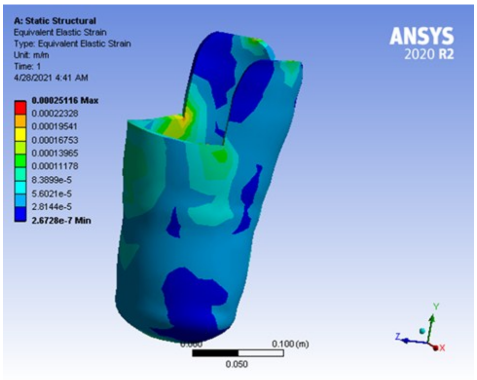


Figure 22. Maximum strain for experimental part for the lamination without kenaf socket (group G).

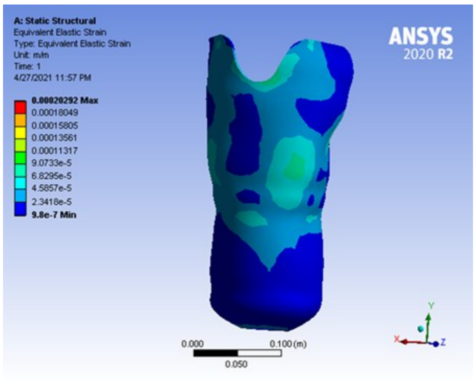
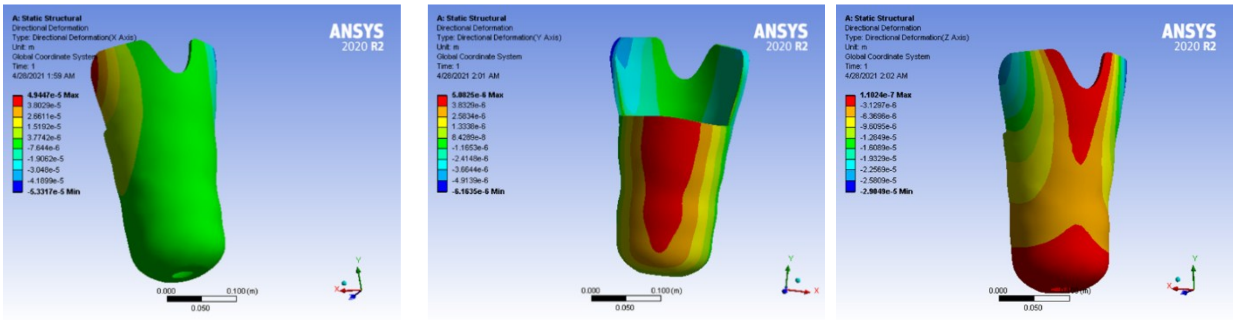


Figure 23. Maximum strain for analytical part for the lamination with kenaf socket (group D).

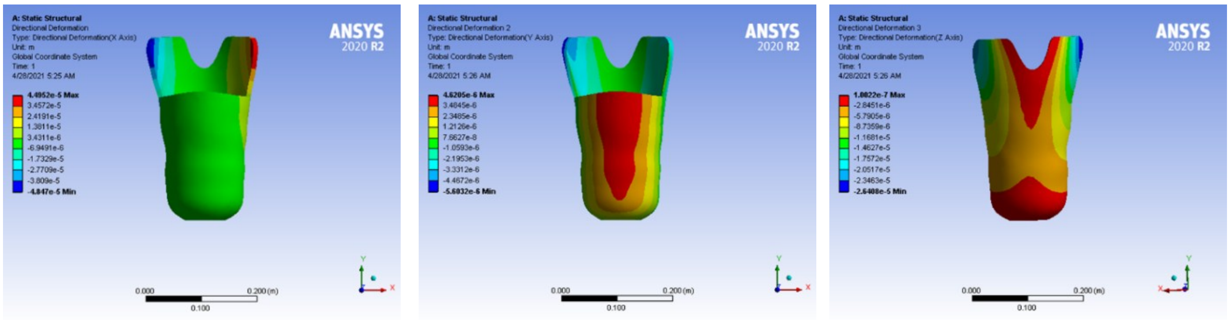
Through the results of analytical part that the highest values of strian for the lamination without kenaf prosthetic socket (group G) are (0.00034) and (0.000315) stresses for the lamination with kenaf prosthetic socket (group D), For the experimental results maximum strain were (0.00025) and (0.0002) for lamination without and with kenaf prosthetic socket respectively. Note that a comparison in the values of of the maximum strain with lamination kenaf fibers has be reduced also by (7.9%) and (25%) for analytical and experimental investigation respectively. The analytical study of deformation in (x, y, z) directions and their positions in the socket. Prosthetic socket (group G) analytical results were $4.9 \times 10^{-5}$ m, $5.08 \times 10^{-6}$ m and $1.10 \times 10^{-7}$ m as show in Figure 24.

Prosthetic, socket with kenaf (group D) for (x,y,z) directions as Figure 25 for (x,y,z) directions analytical results were $4.49 \times 10^{-5}$ m, $4.62 \times 10^{-6}$ m and $1.002 \times 10^{-7}$ m respectively. For the experimental results, Figure 26, represent the values of maximum deformation for x, y, z directional for the prosthetic socket made of composite material (group G) were $6.29 \times 10^{-5}\, m$, $9.28 \times 10^{-6}\, m$ and $9.36 \times 10^{-5}$, respectively. Figure 27, represent the values of maximum deformation for x, y, z directions for prosthetic socket made of composite material (group D) were, $1.27 \times 10^{-5}\, m$, $1.49 \times 10^{-6}\, m$ and $2.60 \times 10^{-6}\, m$ respectively. X-direction, while the lowest values takes place in (y) and (z) directions with kenaf prosthetic socket (group D).



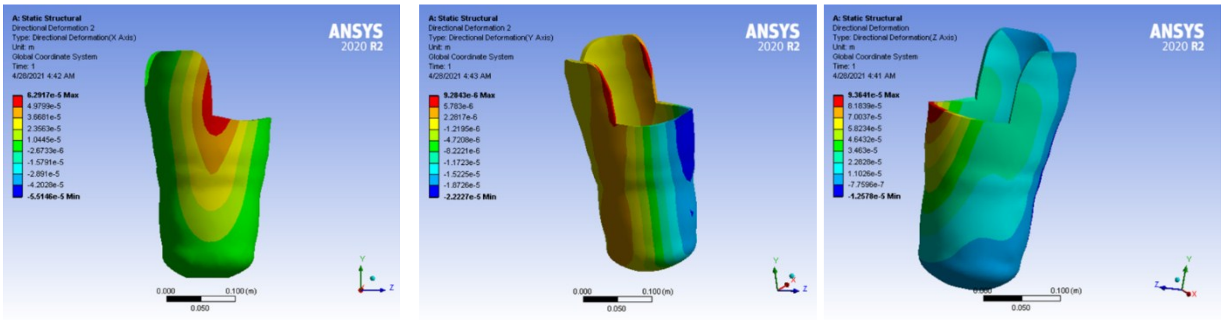
a. x-direction b. y-direction c. z-direction

Figure 24. Deformation for the lamination without kenaf socket (group G) for the analytical part.



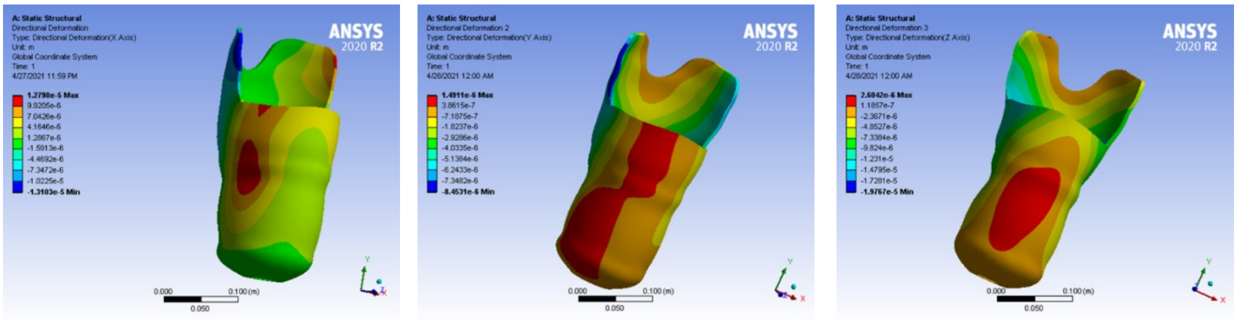
a. x-direction b. y-direction c. z-direction

Figure 25. Deformation for the lamination with kenaf socket (group D) for the analytical part.



a. x-direction b. y-direction c. z-direction

Figure 26. Deformation for the lamination without kenaf socket (group G) for the experimental part



a. x-direction b. y-direction c. z-direction

Figure 27. Deformation for the lamination with kenaf socket (group D) for the experimental part

From the previous results, it can be noticed that deformations are at their minimum values for the lamination with kenaf prosthetic socket (group D) design in both studies, experimental and analytical. That can be justified by the fact that the lamination with kenaf has good mechanical properties when compared with the available material, and all figures showed the posterior zone has maximum deformation because the maximum value of pressure in posterior zone. Then can summary the results above in Table 3. Conclude that when a certain pressure is applied to the socket, this pressure leads to the formation of stress. When calculating this stress in a uniform distributing pressure method [13, 15], the results will be higher than the calculated stress by the F-socket method. This means that the socket needs to be designed with higher materials or measurements, and therefore the design will be at high safety factor, but the design will lead to an increase in cost due to the increase in the safety factor.

Therefore, the method of a uniform pressure distribution can be adopted to find the stress, as it forces the designer to design the socket with specifications that bear a higher stress than the real stress that is formed on the socket and calculated by the F-socket. The correct method is the f socket method [73-74], but the theoretical method can be used because its results give results for higher stress, meaning higher safety. The reason for conducting the theoretical analysis by the method of uniform pressure and the experimental f-socket method is to clarify the possibility of adopting the theoretical method of analysis in the event that unable to done a test f-socket method for the analysis of pressure. The difference between the values of resulting from the analysis of the socket with uniform pressure distribution was calculated from the mathematical equations in the analytical part 165Kpa, ie the theoretical, and the resulting from the pressure applied from the f- socket experimental part (which should be more accurate) [73]. Table 4 show the difference between the values is acceptable.

Table 3. The summary of results of Figures 16 to 27.

| **Type Analyses** | **Analytical Results** | **Experimental Results** | **Group Name** |
|---|---|---|---|
| Von-Mises Stresses | 59.99 MPa | 48.9 MPa | (group G) |
| Equivalent Elastic Stain | 0.00034 | 0.00025 | |
| Maximum deformation for x, y, z directions | $4.9 \times 10^{-5}\ m$, x direction<br>$5.08 \times 10^{-6}\ m$, y direction<br>$1.10 \times 10^{-7}\ m$, z direction | $6.29 \times 10^{-5}\ m$, x direction<br>$9.28 \times 10^{-6}\ m$, y direction<br>$9.36 \times 10^{-5}\ m$, z direction | |
| Von-Mises Stresses | 54.5 MPa | 34.14 MPa | (group D) |
| Equivalent Elastic Stain | 0.000315 | 0.0002 | |
| Maximum deformation for x, y, z directions | $4.49 \times 10^{-5}\ m$, x direction<br>$4.62 \times 10^{-6}\ m$, y direction<br>$1.0 \times 10^{-7}\ m$, z direction | $1.27 \times 10^{-5}\ m$, x direction<br>$1.49 \times 10^{-6}\ m$, y direction<br>$2.6 \times 10^{-6}\ m$, z direction | |

Table 4. The difference between the analytical and the experimental results.

| **Type Analyses** | **Different** | **Group Name** |
|---|---|---|
| Von-Mises Stresses | 11.09 Mpa | (groupG) without kenaf |
| Equivalent Elastic Stain | 0.00009 | |
| Von-Mises Stresses | 20.36 Mpa | (groupD) with kenaf |
| Equivalent Elastic Stain | 0.000115 | |

## 5. Conclusions

From the experimental and theoretical work can be listing the following conclusion, as,

1. The best lamination (group D) with kenaf show a decreases in equivalent stress (Von- Mises) and strain by (10%) and (7.9%) for analytical investigation. And (43.23%) and (25%) respectively for experimental investigation.
2. For the analytical investigation the highest value of deformation exits in the (x), while the lowest values takes place in (z) directions and(y) direction for the lamination without kenaf prosthetic socket (group G) and with kenaf prosthetic socket (group D).while for the experimental investigation, the highest value of deformation exits in the (z)and(x), while the lowest values takes place in (y) direction for the lamination without kenaf prosthetic socket (group G), and the highest value of deformation exits in the

(x) direction, while the lowest values takes place in (y)and(z) directions with kenaf prosthetic socket (group D).

3. The theoretical method can be adopted to analyze the socket, but the design will lead to an increase in cost due to the increase in the safety factor.

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