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Fatigue Characterizations Modifying for Below Knee Prosthesis Composite Materials by using Natural Knitted Kenaf Reinforcement Fibers

Sumeia A. Mechi, Muhannad Al-Waily

Department of Mechanical Engineering, Faculty of Engineering, University of Kufa, Iraq.

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Abstract
This research approach of several composite materials with 12 layers were suggested from perlon, kevlar and woven carbon fibers, and natural knitted kenaf, the purpose findings mechanical, physical properties and fatigue life that help to use the socket with good design at longest period. There are two best types of composite materials are used for to analysis of the fatigue and tensile properties of prosthetic socket below knee which laminated by using vacuum system. The pressure inside the stump of patient and the socket was 165 kpa. Originality of using natural kenaf fibers led to the improvement of the maximum tensile strength 39.35% and safety factor of 2.52, with research limitations at the lowest costs and longest period of time. So, the experimental and numerical techniques were used to calculate the fatigue characterizations for effect of kenaf reinforcement fiber of composite materials used. Therefore, the experimental work included manufacturing for composite samples with different lamination layers and various layer number of kenaf fiber, in addition to, calculated the mechanical properties and fatigue life of its samples. The experimental results of fatigue have a good agreement with those obtained using the Finite Element approach. It was found that sample with kenaf has a maximum number of cycles up to failure =18.35 × 105 cycle at stress ratio (R= -1). The analytical part, using ANSYS2020 R2 to model (BK) from suggested materials with and without kenaf for the patient suffering from lower knee amputation for diabetes. Practical implications of experimental and numerical methodology showed that kenaf fibers have achieved the requirements of safety.
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Keywords: Below Knee; Prosthetic Socket; fatigue test; Natural Fibers; FEM.

1. Introduction
Below -knee amputations or "BK" amputations, known as transtibial amputations, represent the largest percentage of lower limb amputations [1]. Components of a prosthetic limb are, socket, pylon, ankle, and foot as shown in Figure 1, [2]. The problem of stress and deformities of the socket (amputation below the knee BK), such as sagging and socket fracture caused resulting patient's weight during movement and walking, which causes discomfort to the patient and instability of his movement [3-5]. This will cause a fatigue in the socket due to the induced tension and compression stresses developed during the gait cycle. Therefore, many researchers presenting study for fatigue characterization of composite materials used to manufactured the socket structure as,

Kahtan Al-Khazraji et.al (2012), studied the tensile and fatigue properties of lower prostheses sockets (BK) made of composite materials. They used epoxy with woven fibers (carbon, glass, perlon), with micro and nano silica particles using vacuum technology. Evaluation of fatigue characteristics using (ANSYS-11) program [6]. Saif M. Abbas et.al (2018), examined mechanical properties as a safety factor, fatigue behavior, Von Mises stress in the amputation prosthesis. Using ANSYS 14.5, the safety factor was (2.43) for best group and considered safe and acceptable in designs [7].

Ahmed. K. Abdulameer et.al (2018), investigated theoretically and numerically the fatigue strength of the Syme's prosthetic socket. Suggested materials to find the resistance material to repeated loads during the walking cycle. The model is made of a 6-layer Perlon fiber, 4-layer carbon woven and acrylic resin, allowed safety factor (4.637) [8]. Ehab N. Abbas et.al (2020), studied the fatigue characterization to prostheses materials to maintain the dynamic load that the patient is exposed to during the gait cycle. Sequence was chosen (perlon, glass, carbon, Kevlar). They performed a fatigue test for constant and variable amplitude Low-High and High-Low fatigue test to obtain the correct age for consideration, Finite element technique was used to calculate the fatigue behavior of composite materials [9]. Where the papers submitted showed that the use of reinforced fibers in the manufacture of prostheses are necessary to modify the characteristics of the manufactured socket. Fatigue and fracture are one of the main sources of failure sockets that result in unreliable wear and cause socket failure plus the cost of replacing the prosthesis [10, 11]. The composite material used in socket manufacturing was developed by adding natural fibers such as cotton, flax, kenaf and sisal in order to improve the properties of the composite material and obtain the best properties of the fatigue at the lowest weight and cost.

A.P. Irawan et.al (2011), presented a study on the development of (BK) socket manufacturing by using natural fibers. They chose natural ramie fiber reinforced with epoxy composite (RE) instead of glass fiber (FGP) reinforced with polyester composite [12]. Agustinus P. Irawan et.al (2015), proposed to develop the production of the (BK)Socket prosthesis by adding natural fibers Rattan fiber as reinforcing material with epoxy (RFREC) have good strength and light weight. The socket product an alternative that can be used more comfortably and safely, add to advantages of using natural fibers that can be recycled as environmentally friendly [13]. Bushra.H. Musa (2016) ,presented on improving the mechanical properties of the composite material of socket reinforced with natural Kenaf fibers [14]. J.K. Odusote et.al (2016), investigated the mechanical properties of pineapple leaf fiber reinforced thermoset composites as possible alternatives to the glass fiber reinforced (AK) prosthetic socket [15]. Jumaa S. Chiad et.al (2017), suggested using of monofilament lamination, perlon fibers and cotton in the manufacture of prosthetic socket (AK). The socket was simulated by using ANSYS.The results show an increase in Young's modulus and a decrease in tensile, yield stress, deformation and increase the stress endurance and the safety factor of 0.323 to 1.05 of the suggested material [16].

The research aims to find composite materials consisting of several layers with natural fibers (kenaf) that are used in the manufacture the below knee (BK) socket with good fatigue life and low cost and high efficiency for the comfort of the patient. So, the experimental and numerical techniques used to calculate the fatigue characterization for materials.

Figure 1. Components of a prosthetic limb [2].

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2. Fatigue Methodologies

Fatigue is an important phenomenon to be taken into the behavior of mechanical components subjected to constant and variable amplitude loading. Fatigue is the process of a cumulative damage in a benign environment that is caused by repeated cyclic loads. Generally, there are three main techniques used in fatigue analysis which are: stress life, strain life and fracture mechanics. In this work, the stress life approach had been considered to predict the cyclic life of specimens used for the alternating bending machine, [17-20].

2.1 Constant-amplitude loading

Constant-amplitude load histories can be represented by a constant load (stress) range, ($\Delta\sigma$); a mean stress σ_m ; an alternating stress or stress amplitude, σ_a and a stress ratio R,
Constant stress range,

$$\Delta\sigma = \sigma_{max} - \sigma_{min} \tag{1}$$

Mean stress,

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} \tag{2}$$

Stress amplitude,

$$\sigma_a = \frac{\Delta\sigma}{2} = \frac{\sigma_{max} - \sigma_{min}}{2} \tag{3}$$

Stress ratio,

$$R = \frac{\sigma_{max}}{\sigma_{min}} \tag{4}$$

R= -1 and R= 0 are two common reference test conditions used for obtaining fatigue data. In this work, the type of loading conditions was fully reversed bending loading (R= -1) due to availability of fatigue testing machine and at the same time for certain application different R ratios have been employed by using finite element analysis.

2.2 Basquin's model

The stress-life curve is a graphical representation of fatigue data. It represents the relationship between fatigue life, in cycles, and the applied stress amplitude. Basquin's relation the most commonly used model and provides an analytical expression of the S-N curve, for finite life (low or high cycle fatigue). By using this technique an estimation of life prediction, with little information on the material can be obtained. The simple Basquin's curve is,

$$\sigma_a = a.N_f^{\,b} \qquad \text{Basquin Equation} \tag{5}$$

Where σ_a is stress amplitude (MPa) andN_f is the number of cycles to failure; the parameters a, b are both constant, depending on the material and on the geometry, respectively . The value of fatigue limit is not clearly obvious on the S-N curve; therefore, the fatigue limit can be calculated by using the fatigue life estimation equation at 106 cycles [21]. Fatigue ratio has calculated theoretically according to the equations [22],

$$\text{Fatigue ratio}(R_r) = \frac{\text{Endurance Limit}(\sigma_e)}{\text{ultimat tensile strength}(\sigma_{ts})} \tag{6}$$

2.3 Modeling of Prosthetic Socket Using ANSYS

The finite element method (FEM) is now widely used in a variety of fields in engineering and science, [23-34]. In this work, ANSYS-2020R2 software was used. The meshing process has been done by choosing

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the volume, and then the shape of element was selected as tetrahedron (Automatic meshing) as shown in Figure 2, [35-50]. This mesh has 20097 nodes and 9750 elements, as shown in Figure (3).

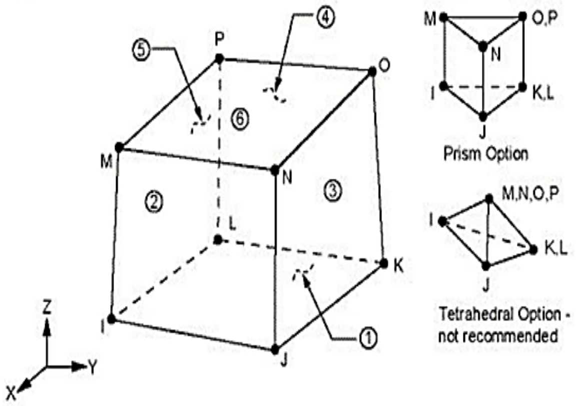

Figure 2. Solid 185 element, [51].

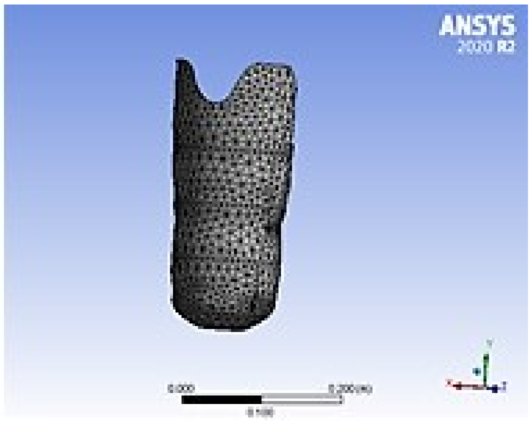

Figure 3. Mesh of the socket Model.

The aim of this analysis is to investigate the stresses and safety factor of socket at maximum pressure the interface pressures between socket and stump was (165 Kpa) for patient 80 kg by applying uniformly distributed on the inner surface of the socket, and from the experimental test f- socket for asimilar case study patient with a right leg amputation (BK) of 85 kg. The analysis was done in the two cases for to best laminations (group G &D_f). The physical properties (e.g. density) and mechanical properties e.g. ultimate stress ($\boldsymbol{\sigma_{ult}}$), Modulus of elasticity (E) and fatigue life for two cases mentioned above were estimated in the experimental part (tensile test) of this work.

3. Experimental Procedures

3.1 Materials used in below knee socket lamination

Materials needed in the lamination of the below knee socket for this study are: Natural knitted kenaf, Carbon fiber, Kevlar Fibers, Perlon stockinet and Lamination 617H19 resin. Hardening powder, Polyvinyl alcohol PVA bag and Materials for Japson mold is used with vacuum system to prepare the test samples according the Table 1.

Table 1. The selected lamination of composite materials for prostheses.

Group name	Lamination Lay–up Procedures	Thickness (mm)
Group G/withot kenaf	(1)perlon+(2)carbon fiber+(1) Kevlar fiber+(4)perlon + (1) Kevlar fiber +(2)carbon fiber +(1)perlon	3.8
Group D/ with kenaf	(1)Perlon+(2) Carbon fiber +(1) Kevlar fiber+(1) kenaf fiber +(2) Perlon +(1) kenaf fiber +(1) Kevlar fiber+(2) Carbon fiber+ (1)Perlon	4

3.2 Tensile Test

Three specimens of two samples were prepared using a CNC machine based on the recommendation of ASTM D638 [52] as Figure 4, the test was carried out at the speed of 5 mm/sec and at room temperature.

3.3 Fatigue Test

The alternating bending fatigue machine used in this test with speed of motor 1440 rpm, Voltage 230 V, Frequency 20Hz, Power 400W. Ten specimens were prepared for without and with kenaf according to the machine's manual test, where, ten samples required test for each fatigue test samples, [53-60]. Figure 5.a shows the dimensions of specimen and Figure 5.b shows fatigue machine. The specimen was subjected to a perpendicular deflection according to its axis at one side of the specimen and a stress ratio of R= - 1 (tension– compression), while the other side was fixed. The deflection depends on composite material and subjected to a lower speed compared with the metal. A nomogram is used to determine the cantilever length of the specimen and the required deflection to apply the desired stress. A dial gage is used to select the

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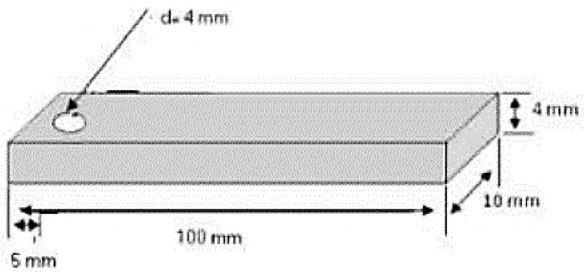
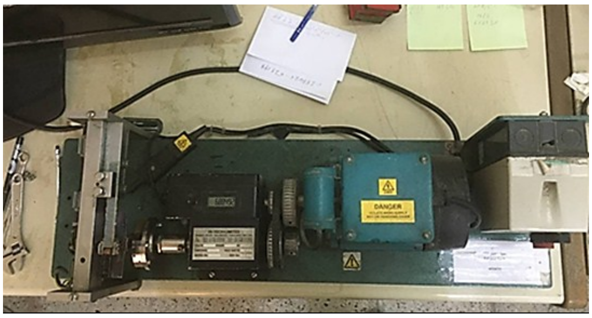
deflection. The stress was applied to the specimen until a crack appeared. The specimens before and after test are shown in Figure 5.c and d. This test denotes the stress- the number of cycle diagram (S-N) which gives the failure behavior of material stress, to create a curve alternating stress (σ_a) values are determined form, [61],

$$\sigma_a = \frac{1.5\ E_b\ *t_a*\delta}{l^2} \tag{7}$$

Figure 4. Tensile samples before and after test respectively.



(a) tander dimensions of fatigue specimens



(b) Alternating-bending fatigue testing machine

(c) Fatigue sample before test

(d) Fatigue sample after test

Figure 5. Fatigue specimens and machine.

4. Results and Discussion

After the tensile test was done, the average value for three specimens were calculated. The ultimate stress (σ_{ult}) for Group G/without kenaf (134.47Mpa) and the modulus of elasticity (16.78Gpa). The ultimate stress (σ_{ult}) for Group D/with kenaf (187.39Mpa) and the modulus of elasticity (17.49Gpa). These properties were used later to conduct the fatigue test and to be imported to ANSYS 2020 software to simulate the prosthetic socket.

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4.1 Fatigue Test Results

The results of fatigue test for best laminations (group G &D_f) according to maximum ultimate stress. The fatigue S-N curve was drawn by plotting a curve which reflecting the experimental data of fatigue tests by using a power formula of least squares regression [62-68], as shown in Figure (6) which shows stress to number of cycles (S-N) curves for two composite materials. While Table 2 explains the equation of fatigue life for each lamination materials gives the fitting equation of stress and a correlation coefficient (R2) where it is considered important parameter to know how strong the relationship between stress and number of cycles for the proposed laminations where the closer is R2 to 1, the stronger is the relationship between σ and N.

The figure and the table explain that the fatigue life was highly increased in the lamination of kenaf. Compared with other lamination without kenaf. This means that the suggested material has high fatigue properties and a long time without need to replacing or maintenance. The presence reinforcement with kenaf fibers anticipated strong high tensile properties suggest that would be orientated with their longitudinal axis perpendicular to the crack wave, effective in bridging the initial crack and preventing crack propagation, further enhancing the mechanical integrity of the composite material [69-72]. This enhancement has advantages for kenaf lamination materials in manufacturing prostheses can be shown that the modifying for fatigue behavior for composite materials reinforcement with kenaf, and that because of decrease in the rate of crack. Also, the endurance stress of the best lamination with kenaf was increased (38.97%) percentage compared with group G lamination without kenaf and without increasing the weight for composite materials. Hence the fatigue strength of materials is a function of its stiffness. In other words, materials with higher modulus of elasticity and higher maximum tensile strengths possess higher fatigue strength [61]. It is noted that this type of composite material has a high S-N curve because carbon fibers, Kevlar and kenaf are described by high fatigue properties. So, by using this type of material in the manufacturing of socket, the socket could remain for longer time without fracture as compared to polypropylene material.

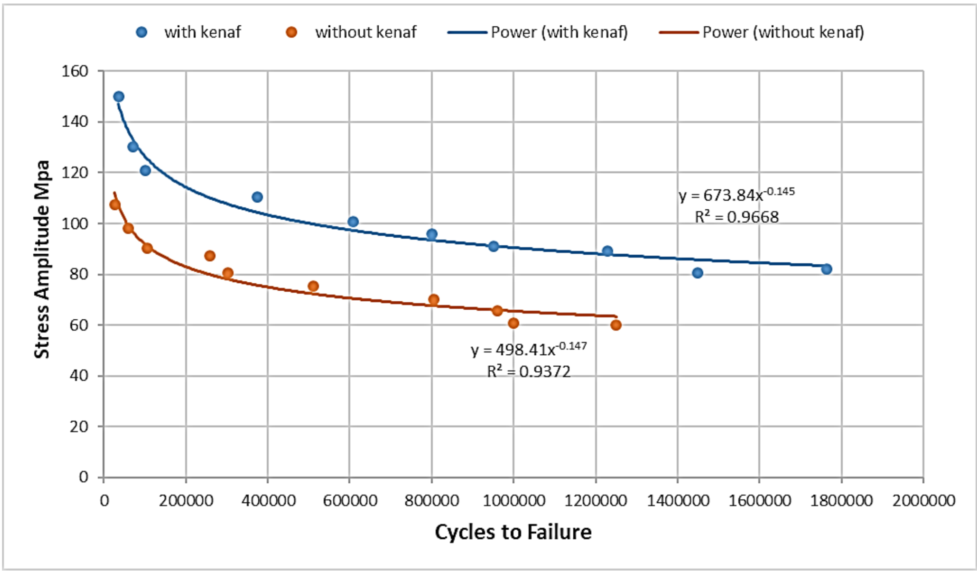

Figure 6. S-N curve for fatigue test.

Table 2. Fatigue life equations for all composite materials.

Name of lamination	Fatigue life equation	Endurance limits Mpa at 10^6	Fatigue ratio R_r	R^2
Group G/without kenaf	$Y = 498.41\, x^{-0.147}$	65.4	0.485	0.9372
Group D/ with kenaf	$Y = 673.84\, x^{-0.147}$	90.89	0.486	0.9668

4.2 Numerical Results

The aim of this analysis is to investigate the equivalent (Von-Mises) stress and safety factor of prosthetic socket. According to the Von-Mises theory that considers the yield stress as fatigue criteria,

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($\sigma_e < \sigma_y$, safe), ($\sigma_e = \sigma_y$, critical) and ($\sigma_e > \sigma_y$, failed).
Where, (σ_e) is the equivalent stress, and (σ_y) is the yield stress.
The safety factor for fatigue is safe in design if the safety factor about or more than (1.25) [73].

I. Fatigue Life Results

Fatigue life shows the available life for a given fatigue analysis. Counter plots were used to display the overall distribution of life throughout the socket for each type of composite used in this study the lamination without kenaf (group G) and with kenaf (group D_f) for analysis at 165 kpa and experimental f-socket as shown in Figures (7), (8) and (9), (10) respectively. In stress life analysis with constant amplitude, if the equivalent alternating stress is lower than the lowest alternating stress defined in the S-N curve, the life at that point will be used [6]. From the results, 165 kpa and for f-socket results, it was noticed that lamination with kenaf has a longer fatigue life than the lamination without kenaf.

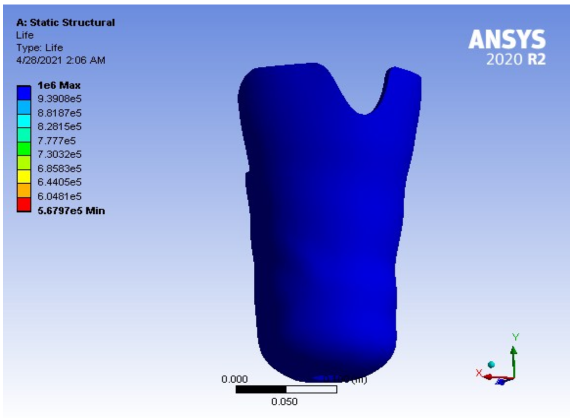

Figure 7. Contours of fatigue life distribution for the lamination without kenaf prosthetic socket, for group G at 165 kpa.

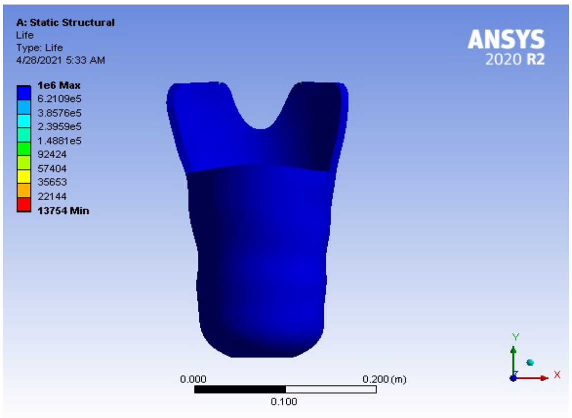

Figure 8. Contours of fatigue life distribution for the lamination with kenaf prosthetic socket, for group D at 165 kpa.

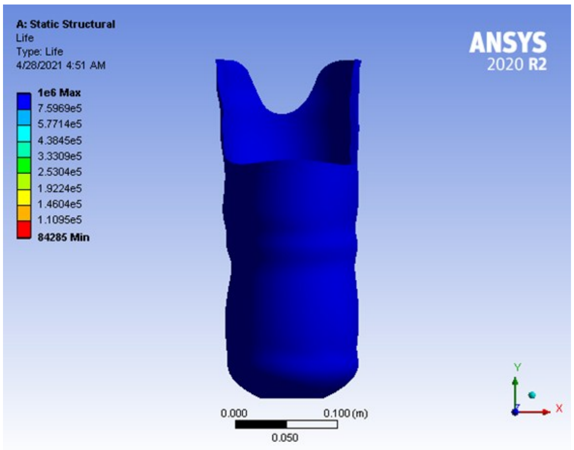

Figure 9. Contours of fatigue life distribution for the lamination without kenaf prosthetic socket, for group G with f-socket.

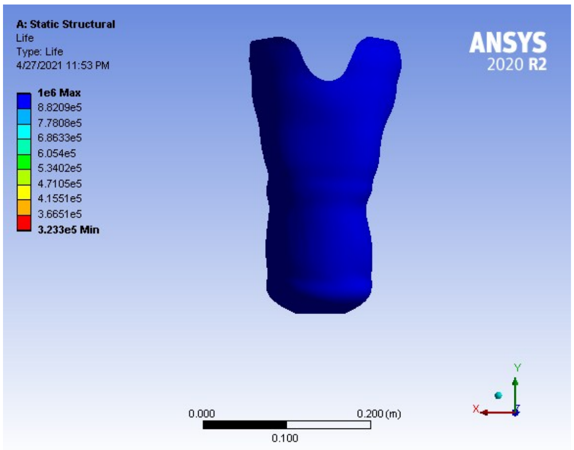

Figure 10. Contours of fatigue life distribution for the lamination with kenaf prosthetic socket, for group D with f-socket.

II. Fatigue factor of Safety Results

These are counter plots with respect to fatigue failure at a given design life. In Ansys, Maximum factor of safety displayed is 15, values less than one indicates failure before the design life has been reached [74-75]. The safety factor for the suggestion composite material groups of the socket model is passed in design, note that the value of safety factor varies from region to region depending on the distribution of stresses generated and the endurance stress for each group of composite materials. Each color indicates a certain gradient of values for the safety factor. The minimum safety factors are obtained at 165 kpa and f-socket for the lamination without kenaf (group G) and with kenaf (group D_f) of prosthetic socket respectively.

It can be noticed the distribution of safe and unsafe regions of the composites. At 165 kpa lamination without kenaf prosthetic socket (group G) are 1.43, and 1.58 with kenaf (group D_f) as shown in Figures (11) and (12) respectively.
At f-socket results lamination without kenaf (group G) the minimum safety factors were 1.75 and 2.52 with kenaf (group D_f) as shown in Figures (13) and (14) respectively. The fatigue analysis used in the present work is based on fully reversed bending R= -1 (tension– compression) life in case full reversal. In both investigations, 165 kpa and f-socket we note that the minimum safety factors are higher with kenaf lamination improved 10.4% at165 kpa and 44% for f-socket.

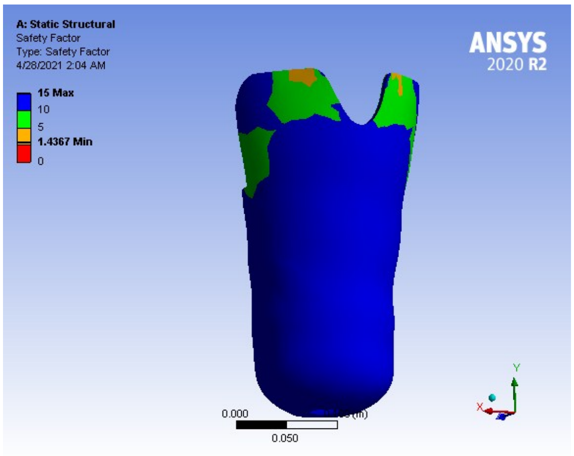

Figure 11. The minimum equivalent safety factor for the lamination without kenaf prosthetic socket (group G) at 165kpa.

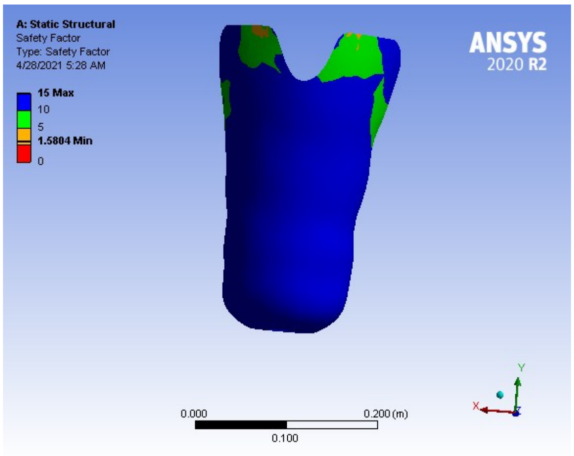

Figure 12. The minimum equivalent safety factor for the lamination with kenaf prosthetic socket (group D_f) at 165kpa.

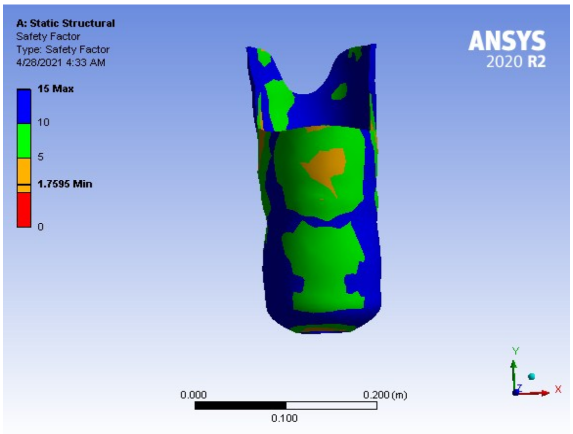

Figure 13. The minimum equivalent safety factor for the lamination without kenaf prosthetic socket (group G) for f-socket.

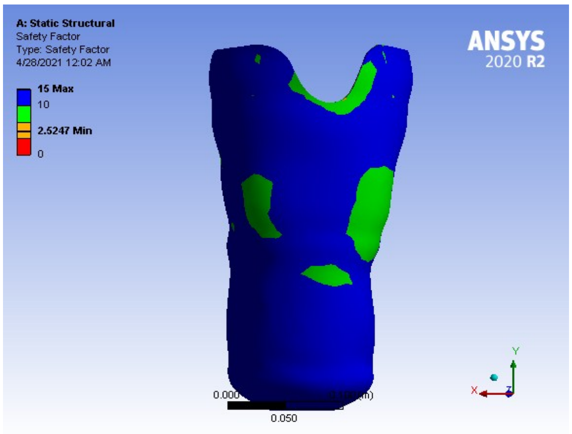

Figure 14. The minimum equivalent safety factor for the lamination with kenaf prosthetic socket (group D_f) for f-socket.

III. The effect of the stress ratio on the safety factor

The stress ratios were changed mathematically through FEA Ansys 2020R2to investigate the extent of its effect on the safety factor for both the analytical and experimental part of the lamination with kenaf (group D_f) and without kenaf (group G). Safety factor data collected by FEA under constant loading conditions based on various load ratios: R = (-1, - 0.5, 0, 0.25, 0.5) according Good Man Theory [21], these results are found for two laminations. It is found that the maximum fatigue safety factor. Figure 15 and 16 shows the minimum equivalent safety factor for the lamination without kenaf (group G) and for the lamination with kenaf prosthetic socket (group D_f) respectively, at 165 kpa with different values of stress ratio. And Table 3 explains the results. Figure 17 and 18 show the minimum equivalent safety factor without kenaf (group G) and with kenaf (group D_f) respectively, for f-socket with different values of stress ratio. Table (4) explains the results.

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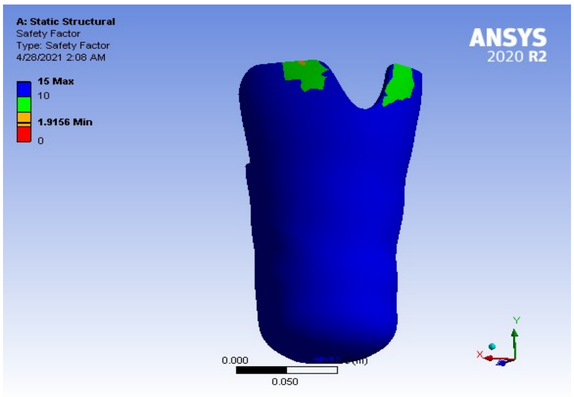
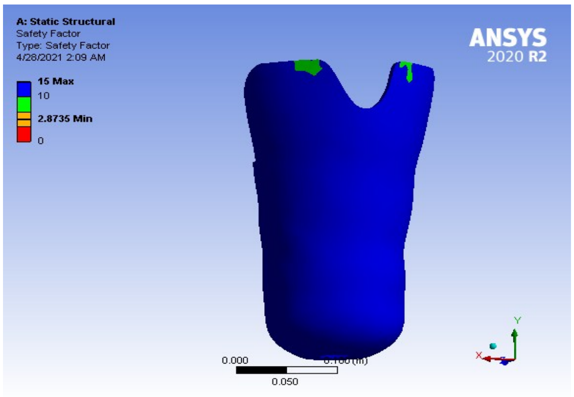
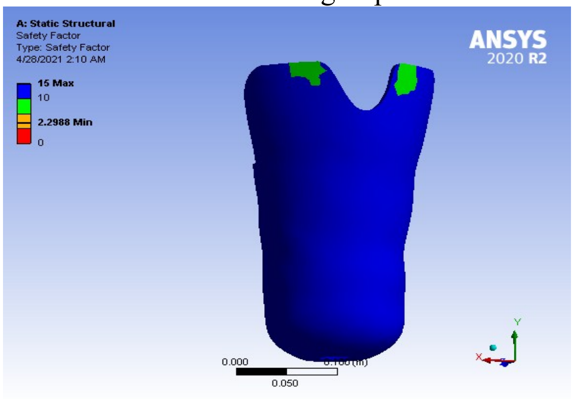


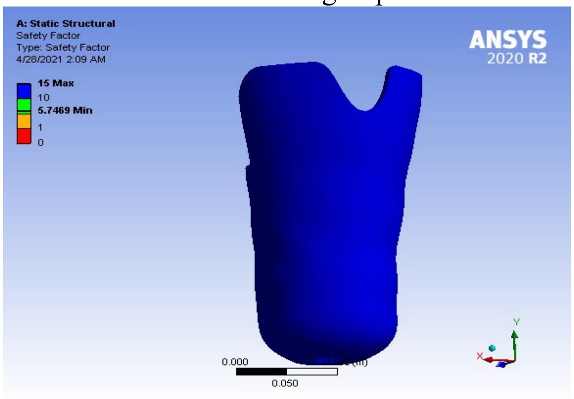
a. stress ratio group B



b. stress ratio group C

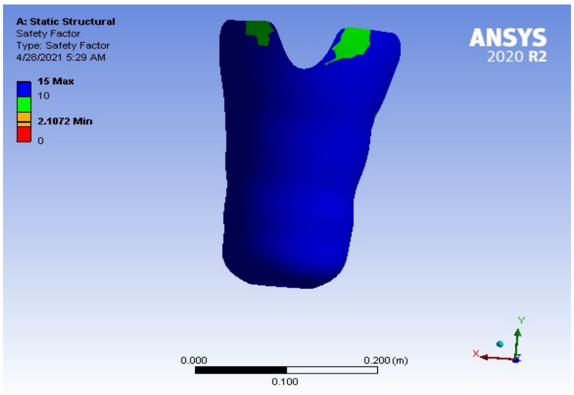


c. stress ratio group D

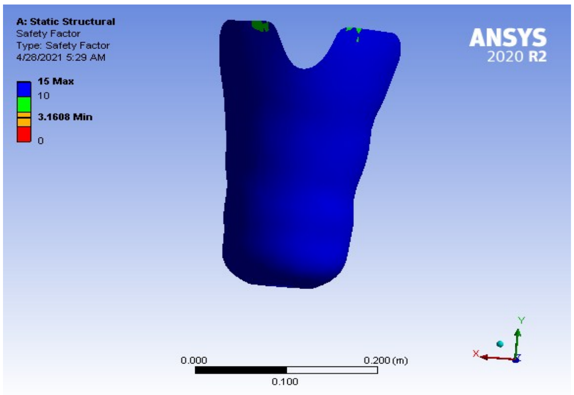


d. stress ratio group E

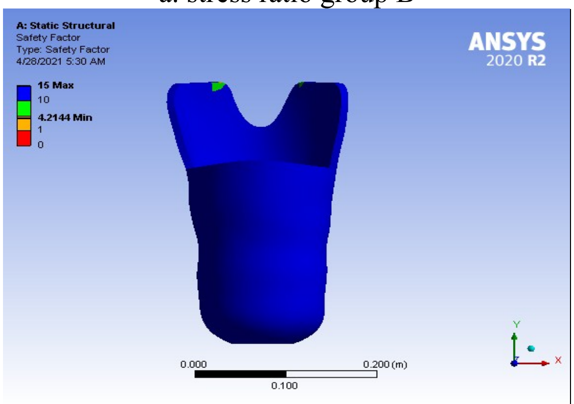
Figure 15. The minimum equivalent safety factor for the lamination without kenaf prosthetic socket (group G) at 165 kpa with different values of stress ratio.



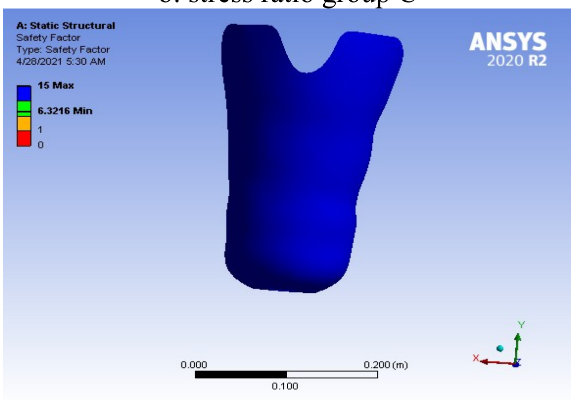
a. stress ratio group B



b. stress ratio group C



c. stress ratio group D



d. stress ratio group E

Figure 16. The minimum equivalent safety factor for the lamination with kenaf prosthetic socket (group D_f) at 165kpa with different values of stress ratio.

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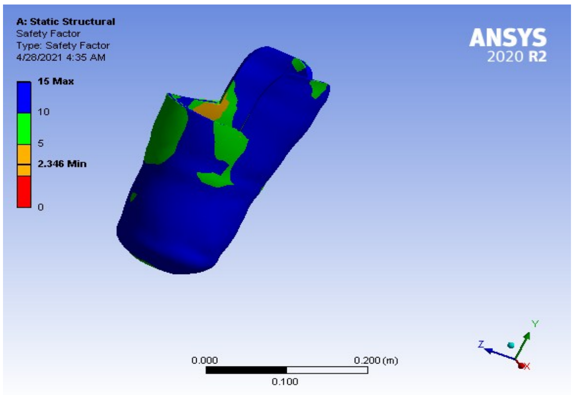
Table 3. The stress ratio values and minimum equivalent safety factor at165kpa.

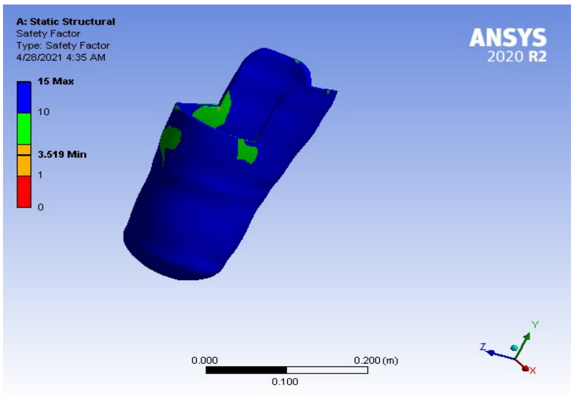
No.	Stress ratio	Safety factor	Group name
A	-1	1.436	(groupG) without kenaf
B	-0.5	1.915	
C	0	2.87	
D	-0.25	2.298	
E	0.5	5.476	
A	-1	1.508	(groupD) with kenaf
B	-0.5	2.108	
C	0	3.160	
D	0.25	4.214	
E	0.5	6.321	

Table 4. The stress ratio values and minimum equivalent safety factor for f-socket.

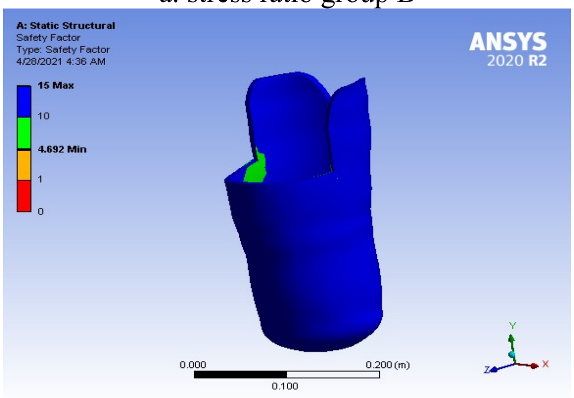
No.	stress ratio	safety factor	Group name
A	-1	1.759	(groupG) without kenaf
B	-0.5	2.346	
C	0	3.519	
D	0.25	4.692	
E	0.5	7.038	
A	-1	2.524	(groupD) with kenaf
B	-0.5	3.366	
C	0	5.049	
D	0.25	6.732	
E	0.5	10.099	



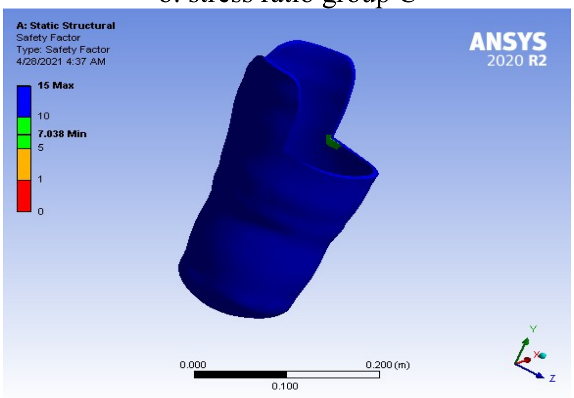
a. stress ratio group B



b. stress ratio group C



c. stress ratio group D



d. stress ratio group E

Figure 17. The minimum equivalent safety factor for the lamination without kenaf prosthetic socket (group G) for f-socket with different values of stress ratio.

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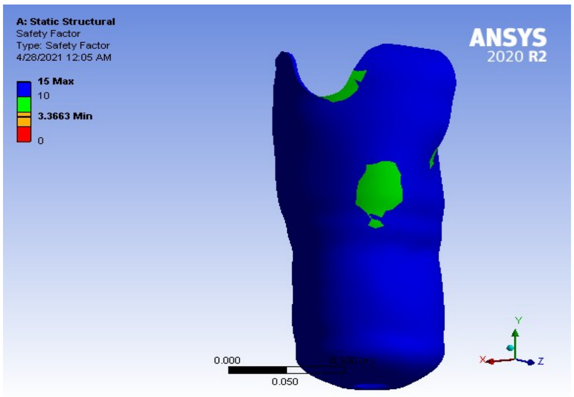
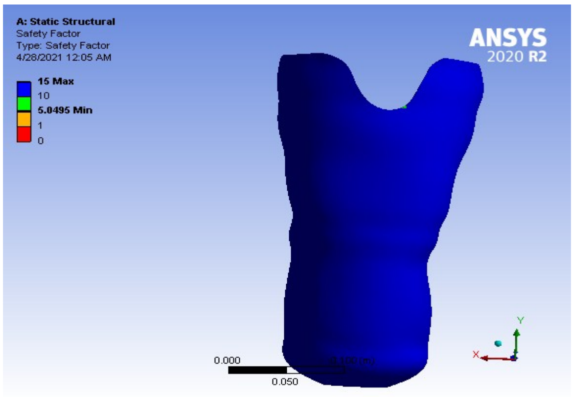
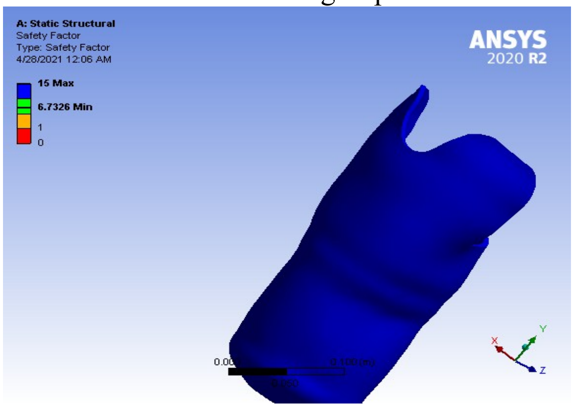


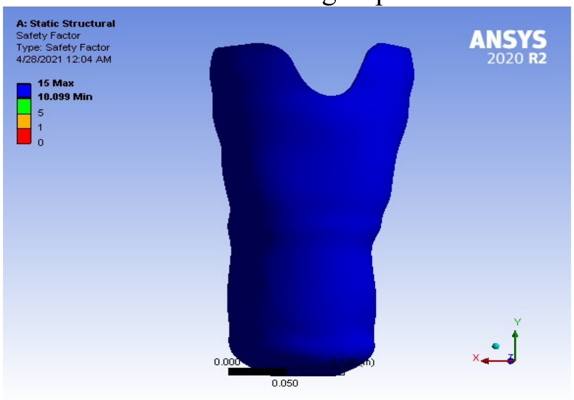
a. stress ratio group B



b. stress ratio group C



c. stress ratio group D



d. stress ratio group E

Figure 18. The minimum equivalent safety factor for the lamination with kenaf prosthetic socket (group D) for f-socket with different values of stress ratio.

5. Conclusions

From the experimental and numerical investigation for fatigue chrcatrization of composite materials with effect of natural reinforcement fiber, get the following important conclusion as,

1. Group D_f with kenaf show better results at the mechanical properties than group G, where the strength is increased by (39.35%) and modulus of elasticity (4.23%). The endurance limits were improved by (38.97%) this enhancement has advantages for kenaf lamination materials in manufacturing prostheses can be shown that the modifying for fatigue behavior for composite materials reinforcement with kenaf.
2. Safety factors are higher with kenaf lamination improved 22.3% at 165kpa and 59.49% for f- socket test, it was observed that the arrangement of the layers relative to the proposed material had a positive effect on the safety factor, the deformation of the material and the comfort of the patient during movement.
3. Notice that increasing the stress ratio leads to increasing safety factor at 165 kpa and at f-socket investigation.
4. The 165 kpa the analysis of patient's weight 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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Reference

[1] Daniel Felix, Selim Tanriverdi, Crystal Trivedi and Everett Wenzlaff 'Designing a Dynamic Prosthetic Socket for Transtibial Amputees' Faculty of Worcester Polytechnic Institute, 2016.
[2] Sumeia A. Mechi, Muhannad Al-Waily, Aseel Al-Khatat 'The Mechanical Properties of the Lower Limb Socket Material Using Natural Fibers: A Review' Materials Science Forum, Vol. 1039, pp. 473-492, 2021.
[3] Rajesh Kumar Mohanty, Sukanta Kumar Sabut, R. C. Mohanty 'Polycentric Prosthetic Knee Joint: Review' International Journal of Engineering, Science and Mathematics, Vol. 6, No. 8, 2017.
[4] Shireen Challoobi, Kadhim Resan and Yasir Ibrahim 'Stress Relaxation and Creep Effect on Polypropylene below Knee Prosthetic Socket' Journal of JSEM, Vol. 15, pp. 93-98, 2015.
[5] M. J. Jweeg, S. S. Hasan, J. S. Chiad 'Effects of Lamination Layers on the Mechanical Properties for Above Knee Prosthetic Socket' Eng.& Tech. Journal, Vol. 27, No. 4, 2009.
[6] Kahtan Al-Khazraji, Jawad Kadhim and Payman Sahbah Ahmed 'Tensile and Fatigue Characteristics of Lower-Limb Prosthetic Socket Made from Composite Materials' International Conference on Industrial Engineering and Operations Management, pp. 843-852, 2012.
[7] Saif M. Abbas, Kadhim K. Resan, Ahmed K. Muhammad, Muhannad Al-Waily 'Mechanical and Fatigue Behaviors of Prosthetic for Partial Foot Amputation with Various Composite Materials Types Effect' International Journal of Mechanical Engineering and Technology, Vol. 09, No. 09, pp. 383–394, 2018.
[8] A. K. Abdul Ameer, M. A. Al-Shammari 'Fatigue Analysis of Syme's Prosthesis' International Review of Mechanical Engineering, Vol. 12, No. 3, pp. 1970 - 8734, 2018.
[9] Ehab N. Abbas, Muhannad Al-Waily, Tariq M. Hammza, Muhsin J. Jweeg 'An Investigation to the Effects of Impact Strength on Laminated Notched Composites used in Prosthetic Sockets Manufacturing' IOP Conference Series: Materials Science and Engineering, 2nd International Scientific Conference of Al-Ayen University, Vol. 928, 2020.
[10] Ehab N. Abbas, Muhsin J. Jweeg, Muhannad Al-Waily 'Fatigue Characterization of Laminated Composites used in Prosthetic Sockets Manufacturing' Journal of Mechanical Engineering Research and Developments, Vol. 43, No. 5, pp. 384-399, 2020.
[11] Saif M. Abbas, Ayad M. Takhakh, Mohsin Abdullah Al-Shammari, Muhannad Al-Waily 'Manufacturing and Analysis of Ankle Disarticulation Prosthetic Socket (SYMES)' International Journal of Mechanical Engineering and Technology (IJMET), Vol. 09, No. 07, pp. 560-569, 2018.
[12] A. P. Irawan, T. P. Soemardi, K. Widjajalaksmi, A. H. S. Reksoprodjo 'Tensile and Flexural Strength of Ramie Fiber Reinforced Epoxy Composites for Socket Prosthesis Application' International Journal of Mechanical and Materials Engineering, Vol. 6, No. 1, pp. 46-50, 2011.
[13] Agustinus Purna Irawan, I. Wayan Sukania 'Gait Analysis of Lower Limb Prosthesis with Socket Made from Rattan Fiber Reinforced Epoxy Composites' Asian Journal of Applied Sciences Vol. 3, pp. 8-13, 2015.
[14] Bushra H. Musa 'Effect of Reinforcement with Kenaf Fibers on Some Mechanical Properties of Unsaturated Polyester Resin' Diyala Journal for Pure Sciences, Vol. 12, No.3, pp. 42–53, 2016.
[15] J. K. Odusote, A. T. Oyewo 'Mechanical Properties of Pineapple Leaf Fiber Reinforced Polymer Composites for Application as Prosthetic Socket' Journal of Engineering and Technology, Vol. 6, No. 1, pp. 24-32, 2016.
[16] Jumaa S. Chiad and Muhammad Safa al-Din Tahir 'A Suggested New Material to Manufacture Above-Knee Prosthetic Socket Using the Lamination of Monofilament, Cotton and Perlon Fibers' Al-Nahrain Journal for Engineering Sciences, Vol. 20, No. 4, pp. 832-837, 2017.
[17] Ali S. Hammood, Muhannad Al-Waily, Ali Abd. Kamaz 'Effect of fiber Orientation on Fatigue of Glass-Fiber Reinforcement epoxy Composite Material' The Iraqi Journal for Mechanical and Material Engineering, Vol.11, No.2, 2011.
[18] Ameer A. Kadhim, Muhannad Al-Waily, Zaman Abud Almalik Abud Ali, Muhsin J. Jweeg, Kadhim K. Resan 'Improvement Fatigue Life and Strength of Isotropic Hyper Composite Materials by Reinforcement with Different Powder Materials' International Journal of Mechanical & Mechatronics Engineering, Vol. 18, No. 02, 2018.
[19] Muhannad Al-Waily, Moneer H. Tolephih, Muhsin J. Jweeg 'Fatigue Characterization for Composite Materials used in Artificial Socket Prostheses with the Adding of Nanoparticles' IOP Conference Series: Materials Science and Engineering, 2nd International Scientific Conference of Al-Ayen University, Vol. 928, 2020.

ISSN 2076-2895 (Print), ISSN 2076-2909 (Online) ©2021 International Energy & Environment Foundation. All rights reserved.

[20] Nesreen Dakhil Fahad, Ameer A Kadhim, Rasha Hayder Al-Khayat, Muhannad Al-Waily 'Effect of SiO2 and Al2O3 Hybrid Nano Materials on Fatigue Behavior for Laminated Composite Materials Used to Manufacture Artificial Socket Prostheses' Materials Science Forum, Vol. 1039, pp. 493-509, 2021.
[21] Emad K. Njim 'Notches effect on mechanical and fatigue behavior of steel alloys beams' M.Sc. Thesis, University of Babyon, 2015.
[22] Mohsin Al-Shammari and Ahmed Kh. Abd Alameer 'Material Characterization and Fatigue Analysis of Lower Limb Prosthesis Materials' Association of Arab Universities Journal of Engineering Sciences, Vol. 25, No. 3, pp. 137-154, 2018.
[23] Ali S. Humod, Muhannad Al-Waily 'Experimental and Analytical Study of Tensile Properties for Hyper Composite Material' The Iraqi Journal For Mechanical And Material Engineering, Vol.10, No.1, 2010.
[24] Muhsin J. Jweeg, Ali S. Hammood, Muhannad Al-Waily 'Analytical Solution to Oblique Crack Effect in Different Types of Composite Plates' ARPN Journal of Science and Technology, Vol. 2, No. 8, 2012.
[25] Muhsin J. Jweeg, Ali S. Hammood, Muhannad Al-Waily 'A Suggested Analytical Solution of Isotropic Composite Plate with Crack Effect' International Journal of Mechanical & Mechatronics Engineering, Vol. 12, No. 5, 2012.
[26] Muhsin J. Jweeg, Muhannad Al-Waily 'Analytical Investigation of Time Dependent Tensional Loading of Stiffened and Un-Stiffened Composite Laminated Plates' International Journal of Mechanical and Production Engineering Research and Development, Vol. 3, No. 4, 2013.
[27] Muhsin J. Jweeg, Muhannad Al-Waily 'Determination of Inter-Laminar Shearing Stresses Using a Suggested Analytical Solution in the Composite Laminated Plates' International Journal of Mechanical Engineering, Vol. 2, No. 5, 2013.
[28] Muhsin J. Jweeg, Muhannad Al-Waily, Alaa Abdulzahra Deli 'Theoretical and Numerical Investigation of Buckling of Orthotropic Hyper Composite Plates' International Journal of Mechanical & Mechatronics Engineering, Vol.15, No. 4, 2015.
[29] Muhannad Al-Waily 'Dynamic Analysis Investigation of Stiffened and Un-Stiffened Composite Laminated Plate Subjected to Transient Loading' International Energy and Environment Foundation, 2015.
[30] Muhannad Al-Waily 'Analytical and Numerical Thermal Buckling Analysis Investigation of Unidirectional and Woven Reinforcement Composite Plate Structural' International Journal of Energy and Environment, Vol. 6, No. 2, 2015.
[31] Muhsin J. Jweeg, Muhannad Al-Waily 'Experimental and numerical analysis of cross-ply and angle-ply composite laminated plates having various shapes of cut outs' International Journal of Energy and Environment, Vol. 7, No. 6, 2016.
[32] Ehab N. Abbas, Muhsin J. Jweeg, Muhannad Al-Waily 'Analytical and Numerical Investigations for Dynamic Response of Composite Plates Under Various Dynamic Loading with the Influence of Carbon Multi-Wall Tube Nano Materials' International Journal of Mechanical & Mechatronics Engineering, Vol. 18, No. 06, pp. 1-10, 2018.
[33] Muhannad Al-Waily, Mohsin Abdullah Al-Shammari, Muhsin J. Jweeg 'An Analytical Investigation of Thermal Buckling Behavior of Composite Plates Reinforced by Carbon Nano Particles' Engineering Journal, Vol. 24, No. 3, 2020.
[34] Ameer A. Kadhim, Esraa A. Abbod, Ahmed K. Muhammad, Kadhim K. Resan, Muhannad Al-Waily 'Manufacturing and Analyzing of a New Prosthetic Shank with Adapters by 3D Printer' Journal of Mechanical Engineering Research and Developments, Vol. 44, No. 3, pp. 383-391, 2021.
[35] Muhannad Al-Waily 'Analysis of Stiffened and Unstiffened Composite Plates Subjected to Time Dependent Loading' M.Sc. Thesis, University of Kufa, Faculty of Engineering, Mechanical Engineering Department, 2005.
[36] Muhsin J. Jweeg, Ali S. Hammood, Muhannad Al-Waily 'Experimental and Numerical Study of Oblique Crack Effect on Natural Frequency of Different Composite Plate Structure Types' AT, Asian Transactions on Engineering, Vol. 2, No. 5, 2012.
[37] Muhsin J. Jweeg, Ali S. Hamood, Muhannad Al-Waily 'A Suggested Analytical Solution of Orthotropic Composite Plate Structure with Crack Effect' International Journal of Mechanical Engineering, Vol. 1, No. 2, 2012.

ISSN 2076-2895 (Print), ISSN 2076-2909 (Online) ©2021 International Energy & Environment Foundation. All rights reserved.

[38] Muhannad Al-Waily 'Experimental and Numerical Vibration Study of Woven Reinforcement Composite Laminated Plate with Delamination Effect' International Journal of Mechanical Engineering, Vol. 2, No. 5, 2013.
[39] Muhannad Al-Waily 'Theoretical and Numerical Analysis Vibration Study of Isotropic Hyper Composite Plate Structural' International Journal of Mechanical and Production Engineering Research and Development, Vol. 3, No. 5, 2013.
[40] Mohsin Abdullah Al-Shammari, Muhannad Al-Waily 'Theoretical and Numerical Vibration Investigation Study of Orthotropic Hyper Composite Plate Structure' International Journal of Mechanical & Mechatronics Engineering, Vol. 14, No. 6, 2014.
[41] Muhannad Al-Waily 'Theoretical and Numerical Study of Natural Frequency Investigation for Orthotropic Unidirectional and Woven Hyper Composite Materials Beam' First International Conference on Engineering Sciences' Applications, 2014.
[42] Muhannad Al-Waily, Zaman Abud Almalik Abud Ali 'A Suggested Analytical Solution of Powder Reinforcement Effect on Buckling Load for Isotropic Mat and Short Hyper Composite Materials Plate' International Journal of Mechanical & Mechatronics Engineering, Vol.15, No. 4, 2015.
[43] Muhannad Al-Waily 'Analytical and Numerical Buckling and Vibration Investigation of Isotropic and Orthotropic Hyper Composite Materials Structures' International Energy and Environment Foundation, 2015.
[44] Muhannad Al-Waily 'Numerical Analysis Investigation Study of Deflection and Stresses with Size and Number Holes Effect of Different Composite Laminated Plate Structures Types' Engineering Applications of Computational Fluid Dynamics, Vol. 3, Chapter 3, International Energy and Environment Foundation, 2015.
[45] Abdulkareem Abdulrazzaq Alhumdany, Muhannad Al-Waily, Mohammed Hussein Kadhim 'Theoretical analysis of fundamental natural frequency with different boundary conditions of isotropic hyper composite plate' International Journal of Energy and Environment, Vol. 7, No. 3, 2016.
[46] Mohsin Abdullah Al-Shammari, Muhannad Al-Waily 'Analytical Investigation of Buckling Behavior of Honeycombs Sandwich Combined Plate Structure' International Journal of Mechanical and Production Engineering Research and Development, Vol. 08, No. 04, pp. 771-786, 2018.
[47] Esraa A. Abbod, Muhannad Al-Waily, Ziadoon M. R. Al-Hadrayi, Kadhim K. Resan, Saif M. Abbas 'Numerical and Experimental Analysis to Predict Life of Removable Partial Denture' IOP Conference Series: Materials Science and Engineering, 1st International Conference on Engineering and Advanced Technology, Vol. 870, 2020.
[48] Emad Kadum Njim, Sadeq H. Bakhy, Muhannad Al-Waily 'Analytical and Numerical Investigation of Free Vibration Behavior for Sandwich Plate with Functionally Graded Porous Metal Core' Pertanika Journal of Science & Technology, Vol. 29, No. 3, pp. 1655-1682, 2021.
[49] Muhsin J. Jweeg, H. A. Hamzah, Muhannad Al-Waily, Mohsin Abdullah Al-Shammari 'A Finite Element Simulation of Nano Effects on Stress Distribution in a Below Knee Prosthetic' 4th International Conference on Engineering Sciences, IOP Conference Series: Materials Science and Engineering, Vol. 1067, 2021.
[50] Emad Kadum Njim, Sadeq H. Bakhy, Muhannad Al-Waily 'Analytical and Numerical Investigation of Buckling Behavior of Functionally Graded Sandwich Plate with Porous Core' Journal of Applied Science and Engineering, Vol. 25, No 2, pp. 339-347, 2022.
[51] Ali Abdul Ameer Najm 'Study of Failure Mode in Bolt Adapter of prosthesis SACH foot' M.Sc. Thesis, AlNahrain University, 2013.
[52] American Society for Testing and Materials International 'Standard Test Method for Tensile Properties of Plastics' D 638, 2000.
[53] Muhsin J. Jweeg, Ali S. Hammood, Muhannad Al-Waily 'Experimental and Theoretical Studies of Mechanical Properties for Reinforcement Fiber Types of Composite Materials' International Journal of Mechanical & Mechatronics Engineering, Vol. 12, No. 4, 2012.
[54] Abdulkareem Abdulrazzaq Alhumdany, Muhannad Al-Waily, Mohammed Hussein Kadhim 'Experimental Investigation for Powder Reinforcement Effect on Mechanical Properties and Natural Frequency of Isotropic Hyper Composite Plate with Various Boundary Conditions' International Journal of Energy and Environment, Vol. 6, No. 5, 2015.
[55] Abdulkareem Abdulrazzaq Alhumdany, Muhannad Al-Waily, Mohammed Hussein Kadhim Al-Jabery 'Theoretical and Experimental Investigation of Using Date Palm Nuts Powder into

ISSN 2076-2895 (Print), ISSN 2076-2909 (Online) ©2021 International Energy & Environment Foundation. All rights reserved.

Mechanical Properties and Fundamental Natural Frequencies of Hyper Composite Plate' International Journal of Mechanical & Mechatronics Engineering, Vol. 16, No. 1, 2016.
[56] Muhannad Al-Waily, Kadhim K. Resan, Ali Hammoudi Al-Wazir, Zaman Abud Almalik Abud Ali 'Influences of Glass and Carbon Powder Reinforcement on the Vibration Response and Characterization of an Isotropic Hyper Composite Materials Plate Structure' International Journal of Mechanical & Mechatronics Engineering, Vol.17, No.6, 2017.
[57] Muhannad Al-Waily, Thaier J. Ntayeesh 'Influence of Multi Wall Carbon Nanotube (MWCNTs) Reinforcement on the Mechanical Properties and Vibration Behavior of Composite Plates' 1st International Conference on Recent Trends of Engineering Sciences and Sustainability, 2017.
[58] Muhannad Al-Waily 'Analytical and Experimental Investigations Vibration Study of Isotropic and Orthotropic Composite Plate Structure with Various Crack Effect' International Energy and Environment Foundation, 2017.
[59] Muhannad Al-Waily, Muhsin J. Jweeg, Mohsin Abdullah Al-Shammari, Kadhim K. Resan, Ayad M. Takhakh 'Improvement of Buckling Behavior of Composite Plates Reinforced with Hybrids Nanomaterials Additives' Materials Science Forum, Vol. 1039, pp. 23-41, 2021.
[60] Sumeia A. Mechi, Muhannad Al-Waily 'Manufacturing and mechanical behavior investigation of prosthetic below knee socket by using natural kenaf fiber' International Journal of Energy and Environment, Vol. 12, No. 1, pp. 45-62, 2021.
[61] Ameer Alaa Alewi 'Investigation of fatigue strength and stiffness/weight ratio of knee disarticulation prosthetic socket' M.Sc. Thesis, University of Karbala, 2018.
[62] Muhsin J. Jweeg, Muhannad Al-Waily 'Dynamic Analysis of Stiffened and Unstiffened Composite Plates' The Iraqi Journal For Mechanical And Material Engineering, Vol. 13, No. 4, 2013.
[63] Muhannad Al-Waily, Alaa Abdulzahra Deli, Aziz Darweesh Al-Mawash, Zaman Abud Almalik Abud Ali 'Effect of Natural Sisal Fiber Reinforcement on the Composite Plate Buckling Behavior' International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS, Vol.17, No.1, 2017.
[64] Mahmud Rasheed Ismail, Zaman Abud Almalik Abud Ali, Muhannad Al-Waily 'Delamination Damage Effect on Buckling Behavior of Woven Reinforcement Composite Materials Plate' International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS, Vol. 18, No. 05, pp. 83-93, 2018.
[65] Hawraa Ahmed Hamzah 'Theoretical and Experimental Analysis of Cut-Out Shapes for Syme's prostheses' M.Sc. Thesis, University of Kerbala, 2018.
[66] Ali Munther Jaafar, Muhannad Al-Waily 'Calculation of Elastic Deformation Under the Influence of High Velocity Impact on Composite Plate Structures' International Journal of Energy and Environment, Vol. 10, No. 06, pp. 359-372, 2019.
[67] Emad Kadum Njim, Muhannad Al-Waily, Sadeq H. Bakhy 'A Review of the Recent Research on the Experimental Tests of Functionally Graded Sandwich Panels' Journal of Mechanical Engineering Research and Developments, Vol. 44, No. 3, pp. 420-441, 2021.
[68] Zaman Abud Almalik Abud Ali, Ameer A. Kadhim, Rasha Hayder Al-Khayat, Muhannad Al-Waily 'Review Influence of Loads upon Delamination Buckling in Composite Structures' Journal of Mechanical Engineering Research and Developments, Vol. 44, No. 3, pp. 392-406, 2021.
[69] H. M. Akil, M. F. Omar, A. A. M. Mazuki, S. Safiee, Z. A. M. Ishak and A. Abu Bakar 'Kenaf fiber reinforced composites: A review' Materials and Design, Vol. 32, pp. 4107-4121, 2011.
[70] Muhannad Al-Waily 'Investigation of Health Monitoring of Composite Plate Structures-Using Vibration Analysis' Ph. D. Thesis, Alnahrain University, College of Engineering, Mechanical Engineering Department, 2012.
[71] Jumaa S. Chiad, Muhannad Al-Waily, Mohsin Abdullah Al-Shammari 'Buckling Investigation of Isotropic Composite Plate Reinforced by Different Types of Powders' International Journal of Mechanical Engineering and Technology, Vol. 09, No. 09, pp. 305–317, 2018.
[72] Sumeia A Mechi, Muhannad Al-Waily 'Impact and Mechanical Properties Modifying for Below Knee Prosthesis Socket Laminations by using Natural Kenaf Fiber' 3rd International Scientific Conference of Engineering Sciences and Advances Technologies, Journal of Physics: Conference Series, Vol. 1973, 2021.
[73] Ali Abdul Ameer Najm 'Study of Failure Mode in Bolt Adapter of prosthesis SACH foot' M.Sc. Thesis, AlNahrain University, 2013.

ISSN 2076-2895 (Print), ISSN 2076-2909 (Online) ©2021 International Energy & Environment Foundation. All rights reserved.

[74] Muhsin J. Jweeg, Muhannad Al-Waily, Ahmed K. Muhammad, Kadhim K. Resan 'Effects of Temperature on the Characterisation of a New Design for a Non-Articulated Prosthetic Foot' IOP Conference Series: Materials Science and Engineering, 2nd International Conference on Engineering Sciences, Vol. 433, 2018.

[75] Emad Kadum Njim, Muhannad Al-Waily, Sadeq H Bakhy 'A Critical Review of Recent Research of Free Vibration and Stability of Functionally Graded Materials of Sandwich Plate' IOP Conference Series: Materials Science and Engineering, Vol. 1094, 2021.

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