Impact and Mechanical Properties Modifying for Below Knee Prosthesis Socket Laminations by using Natural Kenaf Fiber

Sumeia A Mechi *, Muhannad Al-Waily **
Department of Mechanical Engineering, Faculty of Engineering, University of Kufa, Iraq

* sumiaa.maji@uokufa.edu.iq, ** muhanedl.alwaeli@uokufa.edu.iq

Abstract. The main issue of this research to improve and develop the mechanical properties of the socket composite material for below-knee (BK) prosthesis; several composite materials were proposed, consisting of perlon, Kevlar and carbon fibers, and natural fibers were added as a new idea for the research. Making the theory calculations were for several layers of materials, by using mathematical model, to obtain the best lamination with and without kenaf by calculating the best modulus of elasticity and the best E /ρ ratio. So the experimental tests were carried out on the lamination with a total of 12 layers for thickness (4 mm) each of them, (Group G/withot kenaf ) and (Group D/ with kenaf). The experimental part included examining the samples by tensile test, bending test, impact test. The results of the tensile test results were for the first lamination and the second lamination for the ultimate tensile strength (134.47 MPa) and (187.39 MPa) respectively. As for the elasticity modulus, it was as follows (16.78 GPa) without kenaf and (17.49 GPa) for kenaf lamination. Through the theoretical and experimental results, it was found that the use of natural kenaf fibers led to the improvement of the maximum tensile strength 39.35% and modulus of elasticity 4.23%. The impact resistance was improved by using kenaf by 8.8% due to its durability higher than perlon fiber.

Keywords: Below Knee, Prosthetic Socket, impact test, Natural Fibers, Mechanical Properties.

1. Introduction
The modified for mechanical properties and behavior for below knee prosthesis and socket part investigated from many researchers at previous years. Therefore, more study aims to increase strength for materials which used for manufacturing the socket. Then, can be using many ways to modified the mechanical properties, such as change the reinforcement fiber types, change the reinforcement fiber volume fraction, change the number of laminated layers … etc. Therefore, shown many researchers to modified the properties for materials used, the reason for chose the natural fibers reinforced polymer matrix is because of its low cost, low effect on environment and also its shows good mechanical properties compared to polymer resins. Natural fibers reinforced composites are advantageous over the metals that can be recycled, more environmentally friendly, potentially abundant, less costly than synthetic fibers and green composites when excellent corrosion resistance is required. This works published on the kenaf fiber composites is usually reinforced with synthetic based polymer resin such as polypropylene to reduce the negative impact on human health, extensively in order to obtain the maximum composite performance. Results indicated that the mechanical properties; tensile strength and modulus, are improved as the kenaf fiber was used. [1].
As, Firstly, Muhsin J. J. et. al. (2009) [2] investigated the properties of a materials used in the manufacture of above knee prosthetic socket. They used perlon, fiberglass as a material, and acrylic resin. It has been manufacturing fourteen sockets each one different from the other either at lamination or materials used, and Also Studied increase and decrease the number of layers fibres on the mechanical properties. Results show that the lamination that made of (2perlon+2fiberglass+2perlon) gives the optimum mechanical properties. A.P. Irawan et.al (2011)[3], They chose natural ramie fiber reinforced with epoxy composite (RE) instead of glass fiber (FGP) reinforced with polyester composite, and they examined the flexural and tensile strength of the reinforced ramie fibers and produced the socket prosthesis by using the filament winding method, the results showed that a specimens made of (RE) has mechanical properties (tensile strength and Young’s Modulus) higher than the specimens made From RP and FGP composites. Irawan et.al. (2011)[4] at same year proved that natural use of fiber-reinforced compounds (NFRCS) in orthotics and prosthetics lighter weight, more cost-effective and widely available materials at biomedical purposes. Tensile, compressive, impact, and flexural test have done. Fracture surface of samples were observed on a scanning electron microscope (SEM).

A. P. Irawan et al (2012) [5] used epoxy with reinforced fiber(bamboo) to manufacturing composite socket, which is cheap and have good strength. Laminated composites are made of knitted bamboo at 0.3 ± 0.05 mm thickness and 3 ± 0.5 mm width with volume fraction (10%, 20%, 30%, 40%, and 50%). Compression, tensile, and impact tests have done. The results of epoxy with reinforced fiber bamboo composite at (40%) volume fraction is better than from other percentage (tensile strength is 78.09 ± 1.97 Mpa, modulus of elasticity is 8.96 ± 0.33 Gpa, impact strength is 1.3 KJ/m2, and compressive strength is 87.1 ± 4.3 KN. Y.A.El-Shekeil et.al (2012)[6], have studied the effect of reinforcing Kenaf fibers with thermoplastic polyethylene composites (TPU) on the mechanical resistance to tensile, stiffness, flexion, abrasion, and impact and thermal properties (i.e. TGA). The sample was prepared by smelting and mixing of the materials, then a pressing process in molds to form samples, followed by the process of loading the fibers of different proportions. By mechanical tests samples examined, the results showed the fiber content 30% gave the highest tensile strength and bending, as the modulus increased with the increase in the content of the CNF fibers, and deterioration in the impact values, with increased loading and decreased corrosion rate and thermal stability.

Jumaa S. Chiad, (2014)[7], studied the impact properties of lamination composites materials used in the manufacture (BK) prostheses socket at low speed Impactor. He made three gropes of samples from perlon and carbon. The Impact test was performed and the impact characteristics were estimated by rig designed, he concluded analytical and theoretical that all types of lamination absorbed energy and that lamination with the addition of two perlon layers is better used for its lower cost, weight and more safety. Agustinus Puma Irawan et.al (2015)[8], developed the production of the (BK)Sockets prosthesis by adding natural fibers (Rattan) with epoxy (RFREC).as a composite material of good strength and light weight and available in Indonesia. Many tests, including a 6-minute gait analysis (6MWT), pressure test to determine the maximum socket load, and a physiological analysis test by measuring the pulse rate before and after gait done. After analyzing the results of the three tests, the socket product can be an alternative that can be used more comfortably and safely, in addition to the advantages of using natural fibers that can be recycled as environmentally friendly.

Hassanein Salih Hussain et.al (2017)[9], have made a theoretical and experimental comparison between the conventional plastic materials (polyethylene and polypropylene) and the composite materials (perlon - glass fibers- hybrid carbon fibers) in the long life partial synthetic foot industry. They selected composite materials having good mechanical properties, light weight and low cost, tested samples from both materials and they conducted the (tensile ,fatigue and flexural test) and the results of the experiment showed that the mechanical properties were improved with a very large percentage, since the long life of any prosthesis depends on the applied load and the type of material it is made of, so their results proved that the composite materials (Gf-Hybrid Cf and PCP) have the longest life through the fatigue test of the materials compared with plastics (PE and PP). S. M. Abbas (2017)[10], In the same year, has investigated the mechanical properties through his experimental study in the use nine types of laminated composite (perlon, carbon, fiber glass and n-glass) fabricated the Partial Foot Socket by using the vacuum pressure system and matrix were Lamination 80:20 in
different thicknesses. His results showed improving the mechanical properties through (tensile and Fatigue and flexural test) by increasing two layers of carbon fiber, n glass fiber and perlon, yield strength, maximum tensile strength and flexibility, increasing use (3P+2C+3P) it provides the best values of mechanical properties, and reduces cost.

Jumaa S. Chiad et.al (2017)[11], presented a study on improving the mechanical properties of materials used in orthotics of lower prostheses by using nanomaterials and chosen the optimum mechanical properties of the lamination materials depending on the high yield, bending stress, fatigue characteristics and ultimate stresses. Response surface (RSM) to achieve accurate mechanical properties with Max, the error ratio was small compared to the mechanical experimental. Where the materials were selected by a method of response surface methodology (RSM) and the samples were made by vacuum, the addition of the proposed MWCNTs led to the improvement of the mechanical properties. Mohsin Al-Shammari et.al (2018)[12].They investigated the use of woven carbon fiber reinforced with knitted perlon as reinforcing material and acrylic resin in the manufacture of prosthetic socket. Instead of using fiber reinforced plastics (FRP) they proposed to manufacture two models of composite material with the technique of vacuum forming by mixing the matrix material resin, adding 2% of the hardener and pouring the mixture into a shallow flat container and proceeding flexural and tensile Testing, with difference in the volume fractions. Their results showed that increasing of fiber volume fraction lead to increase the lifespan of the socket with the increase in the stress strength and the Young’s Modulus, i.e. improving the mechanical properties to a large extent.

Ayad M. Takakh et.al (2018)[13], they presented an experimental study of mechanical properties (tension and fatigue) and Parameter for( BK) Prosthetic Socket.from multiple layers sample manufactured by vacuum molding, consisting of two groups, the first of (8 carbon) fiber layers and the second 11 layers consisting of (4 perlon + 3carbon fiber + 4 perlon) and the experimental results showed that the values of the maximum stress and the fatigue limit are higher than polypropylene because it has high hardness. Muhsin J. Jweeg et.al (2019)[14], have investigated the experimentally and numerically improving the mechanical properties of the composite materials of the socket prosthesis for below-knee (BK). They used a composite material of 7 layers from (Kevlar and perlon) with 3.5 mm thickness, by mechanical experimental tests, the values of the maximum stress and elastic modulus of the proposed material were determined, as well as (GRF) was measured. And developed using the CT –Scan method and exported to ANSYS. The (DLF) that did not exceed (1.188) was calculated for the proposed socket. They concluded that the mechanical properties of the proposed composite material are much better than the traditional material (polypropylene) with a large ratio, as well as using the CT –Scan method is very strong and much better in FEL modeling. Decrease the difference between the healthy leg and the injured by suggesting socket prostheses.

Ehab N. Abbas et.al (2020)[15], have investigated the effects of the impact strength Laminated Notched Composites used for the manufacture of prosthetic socket. they selected different types of fibers (kevlar, glass fiber and carbon fiber) with three types of araldite Polyester, Orthocryl and a hardener. Samples were prepared according to 12 layers and 4 mm thickness. The toughness and the impact energy of different types were experimentally determined. Samples consisting of Kevlar and Perlon gave the maximum strength and the best results compared using carbon or glass fibers and that increasing the crack depth reduces the energy consumed by the fracture, and adding Kevlar to the composite material gives high strength and durability.

Finally, Muhammad Al-Waily et.al (2020)[16-17], have modified the mechanical properties and Fatigue Characterization of the composite materials used in the manufacture of prosthetic socket by adding nanoparticles using the experimental and artificial ANN technique. They studied the effect of adding different nanoparticles with different volume fraction on fatigue behavior of the composite, And by using the experimental technique, fatigue testing samples were prepared by a mechanical fatigue device, where they added nanoparticles (Nano Al2O3 and Nano SiO2) with (0% to 2%) volume fraction for each type of nanoparticle, and using the neural network technique, the experimental results were calculated and compared in calculating the fatigue strength and life of the composite materials. They concluded that increasing the reinforcement with nanoparticles leads to improved mechanical properties, strength and fatigue limits, especially when reinforced with (Nano SiO2), and without relying on the experimental program, the results are predicted by the ANN technique.
In this work, different types of materials (Kevler, perlon, carbon, natural kenaf) fibers were used with lamination resin 80:20 to get the best results that can be used to manufacture a below socket prosthetics to achieve a good design and acceptable mechanical properties with long life.

2. Theoretical Investigation

2.1. Structural Laminated of the Socket

The following section is devoted to presenting the fundamentals of this strategy including a mathematical calculation method by programming the equations in an Excel 2016 program to calculate the best values of the elastic modulus of the layers according to the proposed sequence, [18-27]. Note that the thickness of the layers (h = 4mm) was taken and the number of layers 12 layers depending on the most previous researches as show in Table 1, and many groups were created in a different arrangement of the composite, and after the introduction of the elastic modulus and Poisson ratio for each material and for all layers \((E_1, E_2, \ldots , E_{12}), (\nu_1, \nu_2, \ldots , \nu_{12})\). The elastic modulus suitable for the socket design was calculated through program, as shown in the Figure 1.

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

| Group name               | Lamination Lay–up Procedures                  |
|--------------------------|-----------------------------------------------|
| Group G/without kenaf    | (1)perlon+(2)carbon fiber+(1) Kevlar fiber+(4)perlon + (1) Kevlar fiber+(2)carbon fiber+(1)perlon |
| 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 |

![Geometry of an n-layered lamina](image)

The height of the \(i\)th layer is \(z_i\). Thus, the expression of \(z_i\) is shown in Equation below,

\[ z_i = \sum_{j=1}^{i} h_j \]  

(1)

The Young’s modulus \(E_i\) should be substituted by the effective Young’s modulus \(E\). The moment of inertia of the \(i\)th layer, \(I_i\), with respect to the neutral axis of the layers lamina is expressed,

\[ EI = \sum_{i=1}^{n} \frac{E}{I_i}, I_i = \frac{1}{3} W(z_i^3 - z_{i-1}^3), I = \frac{1}{12} W h^3 \]  

(2)

2.2. Mechanical Properties of Composite Materials

The mechanical properties of the composite material can be obtained after knowing the properties for both the fiber and the matrix, both the mass and the density, in addition to the mechanical properties, defined the fiber mass fraction is, [29],

\[ \text{Fiber of matrix} = M_f = \frac{\text{mass of fiber}}{\text{total mass}} \]  

(3)

\[ \text{The mass of matrix} = M_m = \frac{\text{mass of matrix}}{\text{total mass}} \]  

(4)

\[ \text{The total mass} = M_f + M_m = 1 \]  

(5)

\[ \text{Fiber volume fraction} = \forall_f = \frac{\text{volume of fiber}}{\text{total volume}} \]  

(6)
Volume of matrix = \( \gamma_m = \frac{\text{volume of matrix}}{\text{total volume}} \) (7)

Total volume = \( \gamma_f + \gamma_m = 1 \) (8)

The mass density = \( \rho = \frac{\text{total mass}}{\text{total volume}} \) (9)

Total density = \( \rho_f \gamma_f + \rho_m \gamma_m \) (10)

### I. Mechanical properties for unidirectional ply,

The mechanical properties for unidirectional ply is, modulus of elasticity along the direction of the fiber \( E_1 \) is given by, [29],

\[
E_1 = E_f \gamma_f + E_m \gamma_m
\] (11)

And Modulus of elasticity in the transverse direction to the fiber axis \( E_2 \) by,

\[
E_2 = \frac{1}{\frac{\gamma_f}{E_f} + \frac{\gamma_m}{E_m}} \text{ or } E_2 = \frac{\gamma_f}{E_f} + \frac{\gamma_m}{E_m}
\] (12)

The Poisson coefficient = \( \nu_{12} = \frac{\gamma_f}{E_f} + \frac{\gamma_m}{E_m} \) (13)

### II. Woven Fabrics

The fabrics are woven in two orthogonal directions. The first is called the warp and the second is called the weft and the weaves are woven together, they can be considered cross-section 90°, the first perpendicular to the second, calculate the modulus of elasticity for bidirectional by, [29],

\[
E_{1w} = kE_1 + (1-k)E_2, \quad E_{2w} = (1-k)E_1 + kE_2, \quad \nu_{12w} = \nu_{12} = \frac{\gamma_f}{E_f} + \frac{\gamma_m}{E_m}
\] (14)

Where, \( k = \frac{n_1}{n_1 + n_2} \), \( n_1 \) =number of warp yarns per meter, \( n_2 \) =number of fill yarns per meter.

Depending on the programming of the equations through which the Elastic modulus was calculated, the arrangement of the layers was chosen as follows,

\[
W_R = 0.55 * \rho_R * a * b * h, \quad W_f = 0.45 * \rho_f * a * b * t
\] (15)

Where, \( W_R \), is the weight of lamina risen, \( h = 4 \text{mm} \) thickness of total layers, \( t = 0.333 \text{ thickness of one layer} \) Density for each layer = \( 0.55 * \rho_R + 0.45 * \rho_f \). Several layers were also calculated by adding natural kenaf fibers, depending on the specifications attached to the imported product from Malaysia, and the best layer was found with the best mechanical properties. The best layer of the selected materials was calculated with kenaf fibers and without addition kenaf fibers. Where the best layer was chosen from each of the two groups after entering the specifications of the materials that were used by the companies producing the materials according to the Table 2.

### Table 2. The mechanical properties for using materials from the company and approved [30].

| Materials       | Density (g/cm³) | Elastic Modulus (GPa) | Poisson ratio |
|-----------------|-----------------|-----------------------|---------------|
| Perlon Fiber    | 1.083           | 2.6-3                 | 0.39          |
| Carbon Fiber    | 1.76            | 122.5                 | 0.3           |
| Kevlar fiber    | 1.44            | 67.7                  | 0.4           |
| kenaf fiber     | 1.45            | 53                    | 0.38          |
| lamination resin| 1.04            | 3.24                  | 0.35          |

### 3. Experimental Investigation

Different materials were used for socket lamination for preparing samples from composite materials and for conducting mechanical tests, in order to compare the experimental results with the results obtained from the theoretical part, [31-40].

#### 3.1. The physical properties of the materials used

Two groups of materials were used to manufacture prosthetic socket Samples. First group G without kenaf fiber consists from (perlon, kevlar fabric, woven carbon, laminations resin 80:20 polyurethane and Hardening powder) and the second group D with kenaf for socket consists from (perlon, woven carbon fiber, kevlar fabric, kenaf fiber was knitted at 0°-90°, laminations resin 80:20 polyurethane...
and Hardening powder). The thickness of each piece of fiber was measured by a vernier, and the pieces of fiber were cut with the required dimensions, after which the required weight for each material was calculated in the layered lamina according to the required ratio and the final thickness of the arrangement as in the Eq. 15, [41-51]. The Table 3 shows the physical properties of the materials from the fitted company and reference, [30], and Weight required for each material for one layer shown in Table 4.

**Table 3. The physical properties of the materials.**

| Materials             | Density (g/cm$^3$) | State               | Thickness (mm) |
|-----------------------|--------------------|---------------------|----------------|
| Perlon Fiber          | 1.083              | Knit                | 0.1            |
| Carbon Fiber          | 1.75               | woven               | 0.18           |
| Kevlar fiber          | 1.44               | woven fabric        | 0.6            |
| kenaf fiber           | 1.45               | woven fabric        | 0.6            |
| Orthocryl lamination 80:20 | 1.04             | Liquid(resin)       |                |
| Hardener              | 1.08               | Powder              |                |

**Table 4. Weight required for each material for one layer.**

| Materials             | Weight required (g) | Measured weight( g) |
|-----------------------|---------------------|---------------------|
| Perlon Fiber          | 4.13                | 4.432               |
| Carbon Fiber          | 6.6                 | 7                   |
| Kevlar fiber          | 5                   | 12.23               |
| kenaf fiber           | 5.54                | 6                   |
| lamination resin      | 58.244              | 65                  |

3.2. Sample Preparation

Samples are prepared using the hand lay-up method, [52], which is easy and successful. The perlon, carbon, Kevlar and kenaf fibers are cut into square pieces (21*17) cm and measuring weight as Table 4. The Orthocryl lamination 80:20 mixed with hardener. By using a plate of steel as a base (lower) and putting a PVA or a film nylon over it, to prevent the resin adhesion to the mold. The fiber layers are placed one after the other, starting with the perlon and placing the resin between them according to the sequence of (12) layers that have been chosen as Figure 2. After the layering is finished, put a piece of nylon or PVA. Then we put the top cover of the steel mold with applied pressure by using the hydraulic jack. In order for the bubbles to remove and distribute the resin evenly on all layers, and leave the sample to dry for 24 hours at room temperature, [53-62].

**Figure 2. Sample manufacture by Hand Layup technique**

3.3. Tests for Composites Materials

I. Tensile Tests

Three specimens of two samples were prepared using a CNC machine based on the recommendation of ASTM D638 [63] as Figure 3, and examined using the tensile test machine, for determined yield strength ($\sigma_y$), yield point elongation, tensile strength(UTS), elongation ($\Delta L\%$), elastic modulus
(E), tensile properties may vary with specimen preparation, with speed (feed speed = 5 mm/min.) and environment of testing. Figure 4, shows for samples before and after fracture.

**Figure 3.** Standard of tensile test specimen according to ASTM D-638 (mm-dim.), [63].

**Figure 4.** Tensile samples before and after test.

### II. Flexural Test

The bending samples were prepared according to the machine's manual as shown in Figure 5 according to ASTM- D790 Standard, [64]. By using test machine (Tinus Olsen), bending stress, flexural bending strain and modulus of elasticity have been done by using equations below, [65] The load was applied midway between the supports with a crosshead speed of 5 mm/min,

\[
\sigma_f = \frac{3FL}{2bd^2}
\]  

(16)

Where: \(\sigma_f\): flexural bending stress, \(F\), \(L\), \(b\) and \(d\) represent load, support span, width of sample and depth of samples respectively. Modulus of elasticity of hybrid composites was calculated based the slope (m) of load- displacement curves using the following equation,

\[
E_f = \frac{L^2m}{4b+4d^3}
\]

(17)

\(E_f\): bending Modulus. Figure 6 shows the samples before and after fracture.

**Figure 5.** The dimensions for bending specimen **Figure 6.** Samples before and after bending test. according to ASTM- D790 Standard, [64].

### III. Impact Test

The impact test samples are prepared according the machine's manual with dimension 10mm×5mm x 55 mm respective thickness from each composition were tested, according to ASTM ASTM E23, [66], as shown in Figure 7. The impact test is carried out in a charpy impact, this device mainly consists of pendulum and energy gauge where the hammer of the device and which is raised .It holds a capacity of 30 joules to the maximum height and is well fixed and the specimen is placed in the place designated for it horizontally between the two pillars the device , The energy gauge is reset first (on zero position), then the pendulum is released using the lever fixed to the scale with a swinging motion that turns potential energy into kinetic energy part of which is lost in the fracture of the sample, so the scale indicator reads the fracture energy of the specimen (Uc) and impact Strength was calculated from the relationship (20) [67], also Figure 8 show the samples before and after fracture,

\[
I.S = \frac{Uc}{A}
\]

(18)

Where, (I.S) Impact Strength; (Uc) fracture energy of the specimen (KJ) ; (A) The cross-sectional area of the specimen measured in units (m²).
4. Results and Discussion

4.1. Theoretical Results
Theoretical and experimental results are presented, the theoretical results included the calculation of the physical properties and mechanical properties as the elastic modulus of the composite materials of the manufacture of the socket for the amputation below the knee and for all sequences lamination without kenaf and with kenaf. The arrangement of layers was chosen randomly from the selected materials. After programming the equations for calculating the most important mechanical and physical properties in the Excel2016 program to obtain the best results for the lamination. Depending on the results obtained for best sequences. Finally, the experimental results of the mechanical properties (tensile, bending and impact) tests for the best the lamination which has best mechanical properties are discussed, as shows in Tables 5 to 8.

Table 5. Prosthetic and Orthotics Composite Materials without Reinforcement kenaf.

| Group Lamination | Lay-up Samples | Laminate stacking sequence | elastic modulus of the layers E Gpa |
|------------------|----------------|---------------------------|-----------------------------------|
| Group A          | 2-3-2-3-2      | (2)Perlon+(3)Kevlar fiber+(2)Perlon+(3)carbon fiber | 9.95                              |
| Group B          | 3-2-2-2-3      | (3)Perlon+(2)Carbon fiber + (2)Perlon+(2) Kevlar  | 6.23                              |
| Group C          | 3-1-3-2-3      | (3)Perlon+(1)Kevlar fiber +(3)Perlon+(2)Carbon fiber | 8.59                              |
| Group D          | 2-2-1-2-1      | (2)Perlon+(2)Kevlar fiber + (1)Perlon+(2)Carbon fiber | 7.79                              |
| Group E          | 1-1-2-4-2      | (1) Perlon+(1) Carbon Fiber + (2) Kevlar fiber + (4) | 15.38                              |
| Group F          | 1-3-4-3-1      | (1) Perlon+(3) Kevlar fiber+(4) Perlon+(3) Carbon Fiber+(1) Perlon | 15.38                              |
| Group G          | 1-2-1-4-1      | (1)perlon+(2)carbon fiber+(1) Kevlar fiber+(4)perlon+(1) Perlon (2)carbon fiber | 17.68                              |
| Group H          | 1-2-1-4-1      | (1)perlon+(2) Kevlar fiber +(1) carbon fiber +(4)perlon+(1) carbon fiber+(2)Kevlar fiber+(1)perlon | 13.13                              |
| Group I          | 2-1-1-4-1      | (2)Perlon+(1)Kevlar fiber +(1) Carbon fiber +(4) Perlon+(1) Carbon fiber+(2)Perlon | 8.74                              |
| Group J          | 1-1-2-1-2      | (1) Perlon+(1)Kevlar fiber +(2) Carbon Fiber +(1) Perlon+(2) Carbon Fiber+(1) Kevlar fiber+(1) Perlon | 15.36                              |
| Group K          | 1-2-2-2-2      | (1)perlon+(2) Kevlar fiber +(2) Carbon fiber+(2) Kevlar fiber+(1)perlon | 14.04                              |
### Table 6. Prosthetic and Orthotics Composite Materials with Reinforcement kenaf.

| Group Lamination | Lay–up Samples | Laminate stacking sequence | Elastic modulus of the layers E Gpa |
|------------------|----------------|---------------------------|-----------------------------------|
| Group A          | 3-2-2-2-3      | (3)Perlon+(2)Kevlar fiber +(2)kenaf fiber + (2)carbon fiber +(3)Perlon | 6.29 |
| Group B          | 1-2-1-1-2-1-2-1 | (1)Perlon+ (2) Kevlar fiber +(1)Carbon fiber + (1) kenaf fiber +(2) Perlon+( 1) kenaf fiber + (1) Carbon fiber + (2) Kevlar fiber +(1)Perlon | 13.53 |
| Group C          | 1-1-1-1-4-1-1-1 | (1)Perlon+(1) kenaf fiber +(1)Kevlar fiber+ (1)Carbon fiber + (4)Perlon+ (1) Carbon fiber + (1)Kevlar fiber+ (1) kenaf fiber +(1)Perlon | 12.20 |
| Group D          | 1-2-1-1-2-1-2-1 | (1)Perlon+(2) Carbon fiber +(1) Kevlar fiber+ (1) kenaf fiber +(2) Perlon+(1) kenaf fiber +(1) Kevlar fiber+(2) Carbon fiber+ (1)Perlon | 18.01 |
| Group E          | 2-1-1-1-2-1-1-2 | (2)Perlon+(1)kenaffiber+(1)Kevlar fiber+ (1)Carbon fiber + (1) kenaf fiber +(2) Perlon+ (1)Kevlar fiber+(1)kenaf fiber +(2) Perlon | 7.22 |
| Group F          | 3-1-1-2-1-1-3   | (3) Perlon+(1) Kevlar fiber +(1)Carbon fiber + (2) kenaf fiber+(1)Carbon Fiber + (1) Kevlar fiber + (3) Perlon | 5.95 |
| Group G          | 1-1-2-4-2-1-1   | (1)Perlon+(1) Kevlar fiber +(2)carbon fiber + (4) kenaf fiber +(2)carbon fiber +(1) Kevlar fiber + (1)perlon | 15.69 |
| Group H          | 1-2-1-1-1-1-1-2-1 | (1)Perlon+ (2)Carbon Fiber +(1)kenaf fiber + (1)Kevlar fiber +(1) perlon+(1) kenaf fiber +(1) Kevlar fiber+(2) Carbon Fiber+ (1)Perlon | 17.83 |
| Group I          | 1-2-1-1-2-1-1-2-1 | (1)Perlon+ (2) Kevlar fiber +(1)Carbon Fiber +(1)Kevlar fiber +(1) kenaf fiber + (2) Carbon Fiber+(1)Perlon | 11.46 |
| Group J          | 4-2-2-2-4       | (4)Perlon+(2)Kevlar fiber + (2) kenaf fiber + + (2)carbon fiber+ (4)Perlon | 4.16 |
| Group K          | 2-2-2-2-2-2-2   | (2)Perlon+(2)kenaffiber+(2)Carbonfiber+(2)Kevlarfiber+(2) kenaf fiber +(2) Perlon | 7.60 |

### Table 7. Mechanical properties for Groups Lamination without Reinforcement kenaf

| Group Lamination | Elastic modulus of the layers E Gpa | Density (g/cm³) | Poisson ratio | Elastic modulus/Density (E/ρ) |
|------------------|-------------------------------------|----------------|---------------|-------------------------------|
| Group A          | 9.95                                | 1.176          | 0.23          | 8.46                          |
| Group B          | 6.23                                | 1.137          | 0.27          | 5.48                          |
| Group C          | 8.59                                | 1.124          | 0.32          | 7.65                          |
| Group D          | 7.79                                | 1.164          | 0.23          | 6.69                          |
| Group E          | 15.38                               | 1.176          | 0.23          | 13.08                         |
| Group F          | 15.38                               | 1.176          | 0.23          | 13.08                         |
| Group G          | 17.62                               | 1.188          | 0.22          | 14.83                         |
| Group H          | 13.13                               | 1.164          | 0.23          | 11.29                         |
| Group I          | 8.74                                | 1.137          | 0.27          | 7.68                          |
| Group J          | 15.36                               | 1.238          | 0.17          | 12.40                         |
| Group K          | 14.04                               | 1.214          | 0.18          | 11.56                         |
Table 8. Mechanical properties for Groups Lamination with Reinforcement kenaf

| Group Lamination | Elastic modulus of the layers E Gpa | Density (g/cm$^3$) | Poisson ratio | Elastic modulus / Density (E/ρ) |
|------------------|------------------------------------|-------------------|--------------|-------------------------------|
| Group A          | 6.29                               | 1.164             | 0.23         | 5.40                          |
| Group B          | 13.53                              | 1.191             | 0.19         | 11.36                         |
| Group C          | 12.20                              | 1.164             | 0.23         | 10.48                         |
| Group D          | 18.01                              | 1.215             | 0.18         | 14.82                         |
| Group E          | 7.220                              | 1.075             | 0.23         | 6.72                          |
| Group F          | 5.95                               | 1.164             | 0.23         | 5.11                          |
| Group G          | 15.69                              | 1.243             | 0.14         | 12.62                         |
| Group H          | 17.83                              | 1.215             | 0.18         | 14.67                         |
| Group I          | 11.46                              | 1.192             | 0.19         | 9.61                          |
| Group J          | 4.16                               | 1.126             | 0.28         | 3.70                          |
| Group K          | 7.60                               | 1.192             | 0.19         | 6.38                          |

After presenting the results obtained from the program, the best results were obtained for elastic modulus (E) without reinforcement kenaf in the group G and with reinforcement kenaf in the group D, as the choice of the symmetrical arrangement gives the best results, and the inner layers of the lamination composite not affect much on the values of the elastic modulus compared to the surface layers, as noted in Tables 5 and 6. And when replacing the 4 perlon layers in group G with two layers of natural fibers of kenaf and two layers of perlon, best results were obtained due to the mechanical properties (e.g. σ$_{	ext{ult}}$ and E), kenaf that it has higher than perlon in addition to its lightness as noted in Tables 7 and 8.

4.2. Experimental Results

I. Tensile Test Results

After the tensile test was done, the average value for three specimens were calculated. The ultimate stress (σ$_{	ext{ult}}$) for Group G/without kenaf (134.47Mpa) and the modulus of elasticity (16.78Gpa), The ultimate stress (σ$_{	ext{ult}}$) for Group D/with kenaf (187.39Mpa) and the modulus of elasticity (17.49Gpa).

Figure 9 show stress–strain curves for group G/without kenaf & group D/ with kenaf respectively.

![Figure 9. The stress-strain curve for tensile composite](image)

a. group G/ without kenaf, S3
b. Group D/ with kenaf, S1.

The high mechanical properties of groups) G & D (is due to symmetrical arrangement of layers in a composite material lead to increasing the number of carbon fiber layers leads to an increase modulus of elasticity because it has a high of modulus of elasticity (122.5Gpa). Arrangement of strong fibers in the surface layers gives superior strength to the composite material such as carbon, Kevlar, and weak layers such as perlon are placed in the inner four layers. Through the theoretical calculations, it was noticed that the inner layers did not affect the values of the results, improvement of the mechanical
properties by reinforcing with kenaf fibers in addition to the Kevlar fibers because these fibers possessed high mechanical properties where the rate of improvement with ultimate stress was 39.35% and the increasing in the elastic modulus was 4.23%. It is noting that there is a convergence between the experimental results and the theoretical, where the error rate was very acceptable when applying the following equation,

\[
\text{Percentage error} = \left( \frac{\text{Theoretical value} - \text{measured value}}{\text{Theoretical value}} \right) \times 100\% \quad (19)
\]

For elastic modulus (E) without reinforcement kenaf percentage error was (4.7%), and (2.8%) with reinforcement kenaf.

II. Flexural Test Results

Flexural strength is required in a socket prosthesis to support body weight and extreme movement. The average values of the modulus of elasticity and the flexural strength for group G/without kenaf is (15.66 Gpa), (179MPa) respectively and for group D/ with kenaf is (18.70 Gpa), (204.5 MPa) having obtained the plot of the load- deflection in Figure 10.

![Figure 10](image_url)

**Figure 10.** The plot of the load- deflection for flexural test

Group D was higher than flexural properties for the Group G, the flexural strength for reinforcement natural fibers bidirectional mat kenaf composite possess was better due to elongation at break for long fiber (2.6-6.9) % [30] As for fabric elongation at break may reach 15.37% [65]. Whereas, synthetic fibers kevlar and carbon (2.5-3.7) % and (1.4-1.8) % have less elasticity [68]. which results in higher strains with respect to the applied loading Then, the deflection occurs until the specimen rupture. This is seen through the results of the modulus of elasticity of the Group G were observed less than in the tensile test these. As in a Tables 9 and 10 showing the comparison of results with the percentage of increase and discrepancy in them.

| Table 9. Average results of Tensile strength from tensile and bending tests. |
| Name of lamination | Tensile strength (MPa) (Tensile Test) | Tensile strength (MPa) (Bending Test) | Percentage (%) |
|-------------------|--------------------------------------|--------------------------------------|---------------|
| Group G/without kenaf | 134.47 | 179.03 | 33% (Increasing) |
| Group D/ with kenaf | 187.39 | 204.5 | 9.13 % (Increasing) |

| Table 10. Average results of modulus of elasticity from tensile and bending tests. |
| Name of lamination | Modulus of elasticity (Gpa) (Tensile Test) | Modulus of elasticity (Gpa) (Bending Test) | Percentage (%) |
|-------------------|------------------------------------------|------------------------------------------|---------------|
| Group G/without kenaf | 16.78 | 15.66 | 6.67% (Decreasing) |
| Group D/ with kenaf | 17.49 | 18.7 | 6.91% (Increasing) |
III. Impact Test Results
Charpy impact test was conducted to analyses the effect of woven fiber layering sequence on the energy absorption capability of the composites. The results for three sample shown in Table 11 for the Group G&D and show in Figure 11.

Table 11. Impact test results.

| Name of lamination | Impact energy (J) | Impact Strength (KJ/m²) | Average values (KJ/m²) |
|--------------------|------------------|-------------------------|-----------------------|
| Group G/without kenaf | 2.2 | 55 | 61.88 |
|                     | 2.7 | 67.5 | |
|                     | 2.4 | 63.15 | |
| Group D/ with kenaf | 3.1 | 77 | 67.33 |
|                     | 2.4 | 60 | |
|                     | 2.6 | 65 | |

![Figure 11](image1.png)  
![Figure 11](image2.png)

a. group G/ without kenaf  
b. Group D/ with kenaf

That the highest value of impact resistance was when reinforcing with kenaf fibers. Despite kenaf fails more quickly than Kevlar, it is stronger than perlon fiber and more toughness. So the percentage was improved 8.8%. Where the fibers bear the largest part of the shock stress as the energy is distributed over a larger area, therefore the fibers in the compound act to impede the growth of the fracture. This is because that the Kevlar fibers have the applicability in responding to the impact loading and instead of that the fracture occurs across its section, the Kevlar fibers will absorb the energy in two directions which results in increasing Impact Strength. This may give an indication of ductile behavior of kenaf and Kevlar in opposite to the other types of fibers. The contribution of the Kevlar fibers is clear in responding to the impact loading compared to the other types of fibers, because the patient may face impact loading in his motion during daily life. Therefore, the sockets manufacturers ask for the toughness of the laminate before taking action in manufacturing in the rehabilitation centers for the people of special needs.

5. Conclusion
In this study assumes that the mechanical properties are calculated by using mathematical and experimental techniques. There, some conclusion can be listing as,

1. Two parameters have been use to evaluate the mechanical properties the ultimate stress (σult) and the modulus of elasticity (E), the best results of (E) and physical properties were obtained without reinforcement kenaf in the group G and with reinforcement kenaf in the group D.
2. The results of experimental test for two groups which gives the best mechanical properties with the best values of ultimate, and bending stress are 134.47 Mpa, 179 Mpa respectively for Group G/without kenaf, and 187.39 Mpa, 204.5 Mpa respectively for Group D/with kenaf.

3. Accurately with maximum error value of elastic modulus (E) without reinforcement kenaf percentage error was (4.7%), and (2.8%) with reinforcement kenaf, from comparison with the theoretical and experimental testing results.

4. Reinforcing with kenaf fibers where the rate of improvement with ultimate stress was 39.35% and the increasing in the elastic modulus was 4.23%. Also, that the highest value of impact resistance was when reinforcing with kenaf fibers, so the percentage was improved. 8.8%.

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