Material Characterization and Fatigue Analysis of Lower Limb Prosthesis Materials

Asst.Prof. Dr. Mohsin Al-Shammari
Ahmed Kh. Abd Alameer
Engineering College
University of Baghdad \ Iraq

Abstract:-

Fiber reinforced plastics (FRP) have been widely used as one of the most interesting materials for structural engineering applications due to their excellent mechanical and physical characteristics for example, high specific strength and high specific stiffness. One of the most successful applications of FRP is the fabrication of prosthetic socket because of its lightweight and high strength to weight ratio. In this work, the influence of volume fraction and lay-up of layers on the fatigue and mechanical properties (Tensile and flexural test) were investigated for composite materials. Woven carbon fibers, knitting perlon stockinet as reinforcement layers and acrylic resin as a matrix used in this investigation with different volume fractions. Two proposed composite materials were manufactured by vacuum molding techniques and matrix material fabricated by pouring mixture of resin with 2% of hardener into a shallow flat container and compared effect of fiber volume fraction on tensile mechanical properties of matrix resin where the first proposed laminate have eight layers with lay-up (3-perlon + 2-carbon fiber + 3-perlon) and the other have ten layers with different lay-up (2-perlon + 1-carbon fibers + 1-perlon + 2-carbon fiber + 1-perlon + 1-carbon fibers + 2-perlon). The second proposed composite material gave an excellent results in tensile, flexural and fatigue tests. The ultimate tensile strength and Young's modulus increased by approximately factors 3.77 and 2.61 respectively with increasing fiber volume fraction into 40.63% and by approximately factor 1.96 and 1.36 respectively for 26.2% fiber volume fraction of first proposed composite if they compared with matrix material and the endurance limit of the second composite material was about twice the endurance limit for the first where it was a positive indication.

Keywords: Syme's prosthetic limb, Composite materials, volume fraction, mechanical tests, composite fatigue, laminated plate.

1. Introduction

A composite materials are the combination of any two or more constituents, one of which has superior mechanical properties but it is in a difficult to be used form e.g. fiber. This superior constituent is usually the reinforcement, while the other constituent (the matrix) serves as the medium in which the reinforcement is dispersed and serves to transmit external loads from reinforcing fiber to fiber. The actual magnitude in composite strength and stiffness can be controlled over a significant range by controlling the volume fraction of reinforcements and by selecting reinforcements with the desired levels of strength and stiffness. Therefore the volume fraction plays a great role in manipulation of the mechanical properties for a composite material[2].Most researchers concentrated their investigations on the type of materials that used in fabrication of prosthetic socket and its influence on mechanical properties by increasing or reducing numbers of reinforced layers whether carbon fibers, glass fiber, hybridization (carbon +glass fibers), perlon, Nyglass or natural fiber such as bamboo, banana, corn, cotton and others thus improvement of strength to weight ratio and life of prosthesis without taking into account the effect of increasing or decreasing the volume fraction of both amount of resin and reinforced fibers on the mechanical and fatigue properties .Virgil Faulkner et al.,1987,[6] studied the strength of common composite material where they used most reinforced fibers that used in prosthetics (carbon fiber , aramid fiber , glass fiber , nylon) with resins (acrylic , epoxy , polyester) . They made more than 300 laminated coupons with length (5) cm and width (2.5) cm and determined the strength and the weight for everyone therefore it can consider this searcher reference for many researchers in prosthetics field. T. A. Current et al.,1999,[4] evaluated ten of composite materials that used in trans-tibial sockets five of them made from five different reinforced materials (unidirectional carbon, carbon-fiberglass stockinet, fiberglass stockinet, carbon cloth, fiberglass cloth) with acrylic . The others are manufactured the same reinforced materials but with carbon acrylic resin. They concluded that carbon reinforcements performed better than fiberglass reinforcements of similar weave type and they observed that the greatest ultimate strength and strength-to-weight ratio was with the unidirectional carbon reinforcement. Ibrahim., 2001, [1] fabricated and tested the standard laminate (6-perlon, 4-fiberglass, 2-perlon) and also suggested two composite materials, one of them he increased the fiberglass content and other he hybridized fiberglass with carbon fiber. He got a good enhancement strength for proposed composite materials.

A.P. Irawan et al., 2011,[8] used Ramie fiber once with epoxy (RE) and again with polyester (RP) in addition of using the fiberglass polyester composite material and compared among them. They concluded that (RE) have the highest mechanical properties. The tensile strength, Young's modulus and flexural strength has the higher than the tensile strength, Young's Modulus and Flexural strength of (RE) and fiberglass polyester respectively. M.J. Jweeg et al., 2012, [9] investigated the interactions between creep and fatigue of the materials used in prosthetic sockets. Their investigation covers the determinations of the fatigue failure limit at room temperature using the results of the endurance diagram in addition to the 50ºC temperature which is compatible to the summer environment in hot climate countries. M.J. Jweeg et al., 2012, [10], presented an experimental and theoretical study of composite materials reinforced by different types of fiber. Their study investigated the modulus of elasticity for the tested material with different types of reinforcement and different values of volume fraction. They showed that the results indicated the unidirectional and woven reinforcement gave the best values of modulus of elasticity.

2. Experimental Works

2.1. Materials

In this work, the materials used in the laminated composite materials are as follows and shown in **Fig.1**.

1. Woven carbon fiber (0/90).
2. Knitting perlon stockinette white.
3. Acrylic resin.
4. Polyvinylalcohol PVA bag (Otto bock health care).
5. Hardening powder (Otto bock health care).
6. Gypsum material for making the mould.
7. Glass for making the mould of acrylic specimens.

Fig. 1 Materials are used

2.2 Fabrication of material specimens

Specimens of the matrix material and the two proposed laminated composite materials for tensile, flexural and fatigue test were fabricated. Perlon layers were in the form of stockinettes while the woven carbon fibers which were in the form

Table .1 Constituent of the plastic laminates

Type of lamination	Lamination I	Lamination II
Number of reinforcement layers	8	10
Type of Layers	6-Perlon, 2-Carbon fiber	6-Perlon, 4-Carbon fiber
Lay-Up	3-Perlon 2-Carbon fiber 3-Perlon	2-Perlon 1-Carbon fiber 1-Perlon 2-Carbon fiber 1-Perlon 1-Carbon fiber 2-Perlon

of cloth. The constituents of each type of laminated composite materials including the number of reinforced layer and lay-up of layers are summarized in above **Table .1**.

The laminated composite materials specimens were manufactured by using vacuum moulding technique where it has prepared the suitable rigs as shown in the **Fig .2** for this purpose.

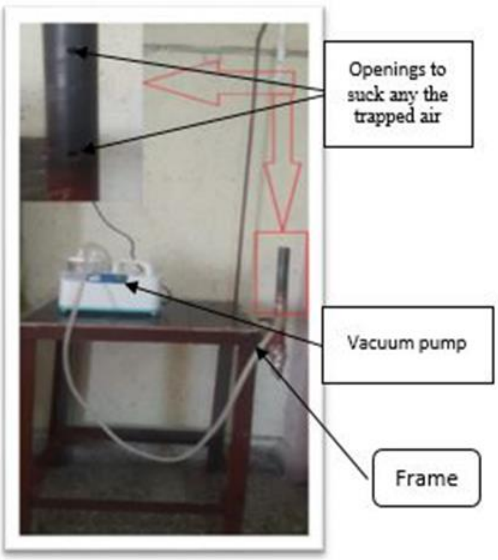

Fig. 2. Vacuum moulding technique

A parallelepiped plaster cast is prepared through making wooden mould with internal dimensions (30× 15 × 4) cm³ where this mould gives two thin plates with dimensions (30×15) cm² and the thickness of it according to volume fraction.The procedure of fabrication the laminated composite materials including firstly connect the positive mould at the stand of frame after modified the sharp edges and made it fillet to prevent the PVA bags from rupture. An internal bag of PVA fitted over the plaster mould and connected firmly below the upper opening of the stand and top of the plaster mould by using cord and then run the vacuum pump to check any leaks that may be taken place in connection areas after that the reinforcement layers were consecutively stacked according to lay-up for each one of proposed laminated composite materials. Another external PVA bag was fitted over the reinforcement layers and connected below the lower opening of the stand such that reinforcement layers were stacked between the two PVA bags and check the leaks as the same manner. The lamination resin was mixed thoroughly with 2% of hardener powder and the mixture was poured into the top opening of the outer PVA bag. The resin was rolled down evenly by using an elastic cord to ensure its thorough absorption by the reinforcement layers. Through this process the vacuum pump was run to suck any the trapped air in the laminated composite materials.

Acrylic resin passed four states before the perfect solidness during fabrication process of suggested materials. It is started with liquid state and then arise the temperature of the resin to reach warm state after that resin rapidly reach a Gel state where the chemical curing process would continue on the solid state where this process took about (30) minute when the room has heated at (25-30) ℃[3]. After curing, the laminated composite material was cut into two parts by a vibrating circular saw in preparation to cut them to strips that have the same shape of standards of tensile, flexural and fatigue specimens by using CNC machine. As for the specimens of the matrix resin were fabricated by pouring the resin-hardener mixture into a shallow flat container then after curing the lamination is cut to suit tensile strips as the same manner to the one followed with laminated composite materials. The stages of preparation for samples can be summarized as shown in the **Fig.3**.

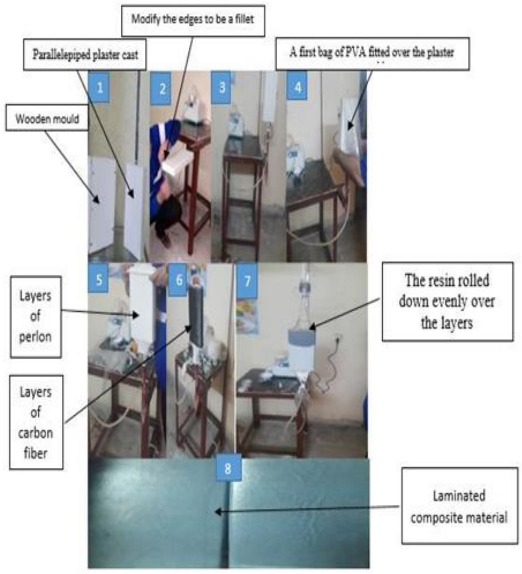

Fig. 3 The stages of preparation of samples

2.3 Calculation of volume fraction

The volume fraction is defined as the volume of fiber that present in a composite material and was achieved by changing the fiber to matrix ratio by using vacuum moulding technique. For determination the fiber volume fraction of two proposed laminated composite materials, it is necessary to calculate practically the density of the perlon, woven carbon fiber and acrylic resin by taking a piece of each woven carbon fiber and perlon in addition to an amount of acrylic resin to weight each one separately by using Digital sensitive balance and then submerge each one in scalar cylindrical flask filled with water to find the volume of woven carbon fiber and perlon according to Archimedes base as for acrylic resin, the scalar cylindrical flask filled with weighted acrylic resin to calculate the volume and can find density according to the following law [5]:-

$$\rho = \frac{m}{v} \quad \text{.........} \quad (1)$$

Table .2 gives the magnitudes of density for all materials used in this investigation.

Table .2 Density of the used materials

Material	Density (g/cm³)
Carbon fibers	1.4
Perlon	1.083
Acrylic resin	1.24

Before starting the fabrication process of composite materials, reinforcement fibers and matrix material must be weighed for calculating volume fraction where the following formulas had depended to find volume fraction of the laminated composite materials [11]:

$$mI = mc + mp + mr \quad \text{.........} \quad (2)$$

$$v_f = \left(\frac{m_c}{\rho_c}\right) + \left(\frac{m_p}{\rho_p}\right) \quad \text{..........} \quad (3)$$

$$v_r = \frac{m_r}{\rho_r} \quad \text{..........} \quad (4)$$

$$vI = v_f + v_m \quad \text{..........} \quad (5)$$

$$V_f = \frac{v_f}{v_I} \quad \text{..........} \quad (6)$$

$$V_m = \frac{v_r}{v_I} \quad \text{..........} \quad (7)$$

$$V_p = \frac{m_p/\rho_p}{v_f} \quad \text{..........} \quad (8)$$

$$V_c = \frac{m_c/\rho_c}{v_f} \quad \text{..........} \quad (9)$$

The volume fraction that was calculated after fabrication process considers primary ratios where it re-calculated after completing of the sample which cut and weighted in order to determine the volume fraction. Fiber volume fractions of 26.2% and 40.63% are achieved in the present study. Table (3) gives volume fraction for two suggested laminations with respect to woven carbon fiber and knitting perlon in addition to matrix volume fraction.

2.4 Physical and mechanical testing

I. Physical properties test

Density is the material's mass per unit of volume. It is an important determinant of energy consumption during functional activities when an amputee wears a prosthetic socket. Although the goal is to provide as lightweight a prosthesis as possible, but strength and fatigue resistance may necessitate a denser material. Practically, the procedures which is followed to calculate the density of suggested materials according to Archimedes principle where manufactured sample has been cut into strips and weighted them by using digital sensitive balance and then submerge each one in scalar cylindrical flask filled with water to find the volume where the density has calculated according to the density formula 1.

Table .3 Volume fraction of suggested laminations

Type of Lamination	Carbon fiber volume fraction (%)	Perlon volume fraction (%)	Matrix volume fraction (%)
Lamination I	26.2		73.8
	7.88	18.32	
Lamination II	40.63		59.37
	18.78	21.85	

As well as, it has calculated the magnitude of density of the two proposal laminated composite materials theoretically according to mixture rule which shown in the following equation [10]:

$$\rho_{comp} = (\rho_c \times V_c) + (\rho_p \times V_p) + (\rho_m \times V_m)$$

………. (10)

II. Tensile test

Testing of materials is a powerful design tool for structural engineering application. It gives design data to improve the quality, reliability and performance of structures. The tensile test of material specimens was carried out on Tinius Olsen test machine with a capacity of 50 KN as shown in the **Fig.4**.

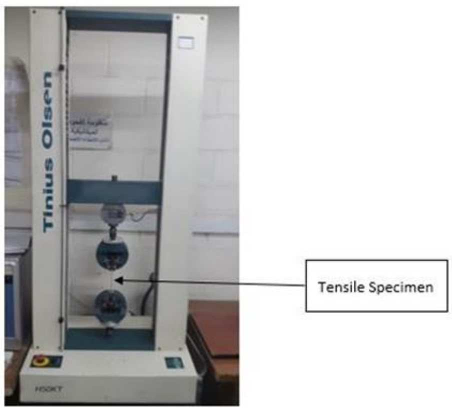

Fig. 4 Tensile test machine

All of tensile specimens manufactured according to standard test method for tensile properties of plastic D638 as shown in **Fig.5.** Each specimen was loaded to failure at constant rate of 2 mm\min. Four specimens were taken and tested to ensure reproducibility of the results where the average of four replicates of each matrix material and proposed lamination was taken. Most of tensile specimens failed at the reduced section of specimen where the cross section area is minimum.

III. Flexural test

Flexural properties, such as flexural strength and modulus, are determined according to the standards of used test machine as shown in the **Fig.6** that include the shape and dimensions of flexural bending specimens.

In this test, a composite specimen of rectangular cross section is loaded a three point bending mode. The maximum fiber stress at failure on the tension side of a flexural specimen is considered the flexural strength of the material

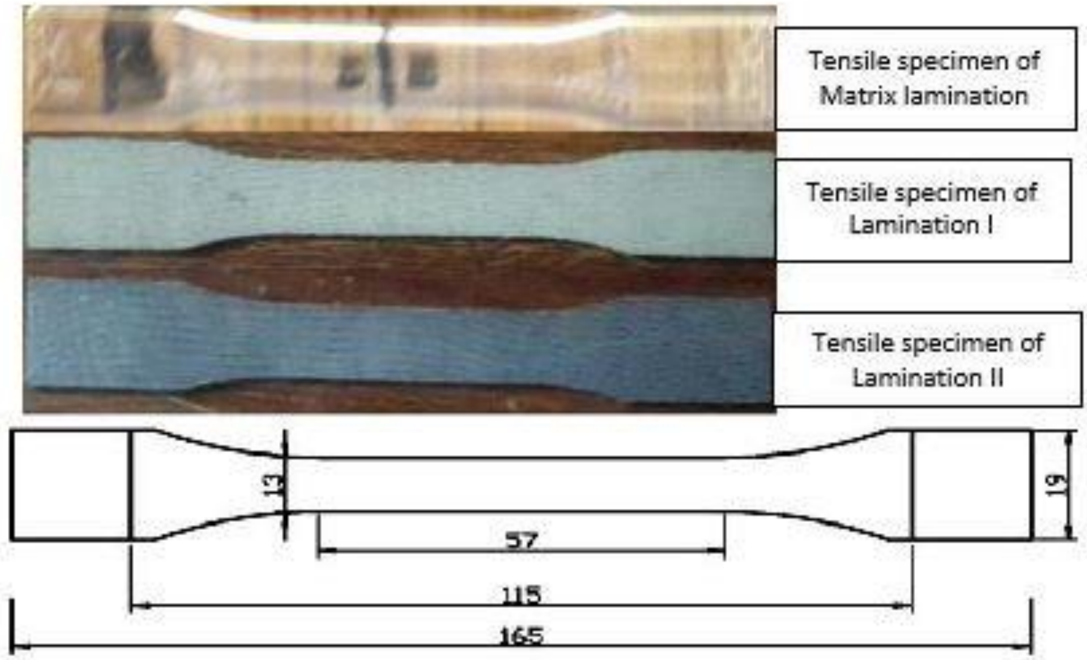

Fig. 5 Tensile specimens

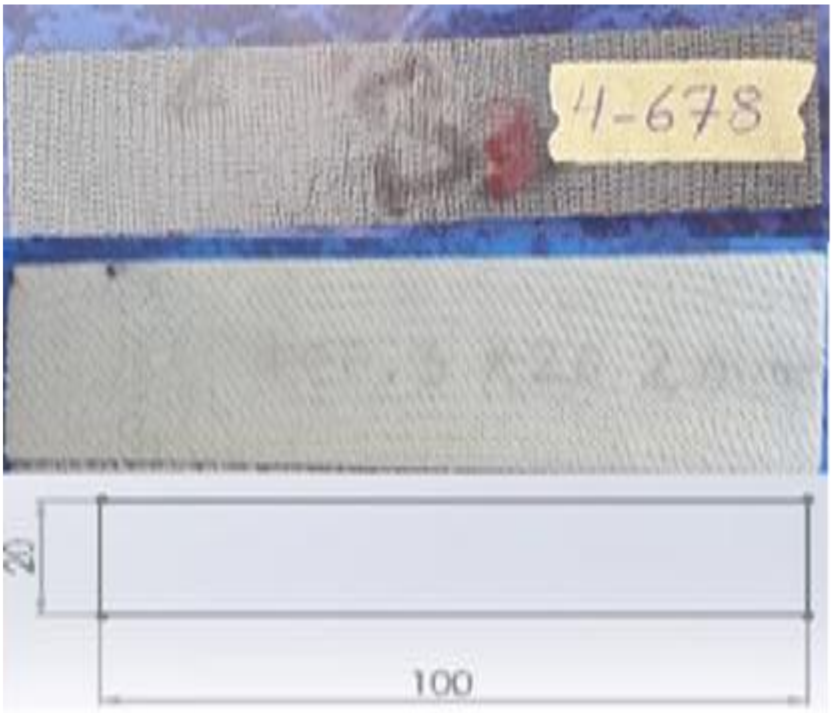

Fig. 6 Flexural specimens

[13]. For flexural bending test the samples for each lamination is carried out by using the Tinius Olsen bending test machine. Flexural testing specimens were machined in a similar manner that adopted in tensile test, several specimens were tested for each type of lamination and the average of three replicates was taken.

IV. Fatigue test

Fatigue test can be provided useful information for finding the durability (service life) for the proposed material where the socket exposed to dynamic and fluctuating stresses during gait cycle. Fatigue test of composite material is a very important tool for structural engineering application that represents the ability of material to resist repeated cycles of loading or unloading during functional activities. Repeated loading weaken the strength of material and increases risk of failure or fracture of the material. Fatigue resistance is especially problematic that faces materials with different properties.

HSM20 alternating bending fatigue machine (Speed of motor 1440 rpm , Voltage 230 V, Frequency 20Hz, Power 400w), as shown in **Fig.7** has been used to test eight specimens for lamination.

Fig.7 Alternating bending Fatigue Machine

The shape of the specimen was machined according to standards of used test machine as shown in the **Fig.8**.This test carried out at room temperature with constant amplitude and completely reversed tension–compression cycling. The length and limits of deflections specified by using nomogram according to ultimate tensile stress and bending Young's modulus that has gotten from the previous tests.

Fatigue ratio has calculated theoretically according to the following equations [7]:-

$$\text{Fatigue ratio } (R_r) = \frac{\text{Endurance limit } (\sigma_e)}{\text{ultimat tensile strength } (\sigma_{ts})} \quad \text{……….} (11)$$

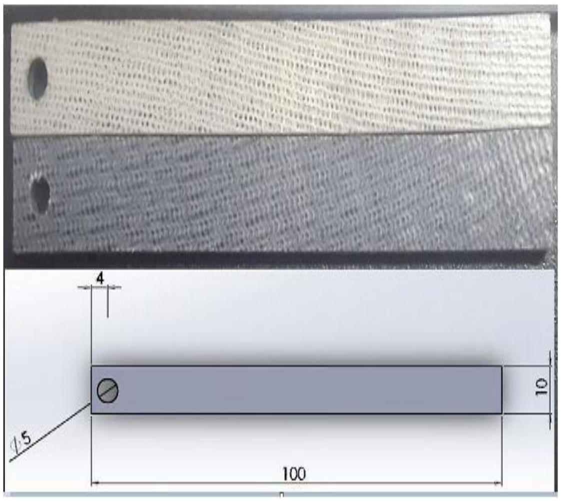

Fig.8 Fatigue specimens

3. RESULTS ANALYSIS AND DISCUSSION

3.1 Effect of fiber volume fraction on density and thickness

The density of laminated composite material mainly depends on the three main factors density of matrix, density of fiber and fiber volume fraction. The density for each lamination has calculated theoretically by using equation (10) and practically under Archimedes principles as shown in **Table .4**

The results showed that density of (Lamination II) is higher than density of (Lamination I) but by slight percentage approximately (0.98%) and the density of both suggested material is less than density of matrix material. Of course the reason is clear as mentioned above where reinforcement of acrylic resin by low carbon fiber volume fraction (7.88% for Lamination I and 18.78% for Lamination II) will be decreased from magnitude its density that considers higher value of density than others in addition to density of carbon fiber is not so high if it has compared with densities of perlon and acrylic resin therefore the results showed in this form. For the thickness of laminated composite materials for each lamination, it has seen that the thickness of (Lamination II) is less than thickness of (Lamination I) because the high matrix volume fraction of the lamination I that led to increase the thickness.

3.2 Effect of fiber volume fraction on tensile strength and Young's modulus

Most of specimens failed at reduced section of the specimen because the minimum cross section area. The stress-strain curve for the matrix and two suggested materials are shown in the **Fig.9**. It has noticed that acrylic resin is a brittle behavior material to failure under tension as shown in Fig.9 .Lamination I is acrylic resin reinforced by 18.32% of perlon and 7.88% of carbon fiber where this reinforcement gives a good result when compared with the results of acrylic resin. This fiber volume fraction is increased the ultimate tensile strength and Young's modulus 195% and 136.2% respectively higher than of the ultimate tensile strength and Young's modulus of matrix material.

This increasing belongs to high strength and stiffness of carbon fibers. With respect to lamination II, the carbon fiber layers is increased keeping the same number of perlon layers where the carbon fibers and perlon volume fraction become 18.77% and 21.85% respectively.

The ultimate tensile strength and Young's modulus of lamination II is increased by approximately percentage 61.4% and 52.7% respectively higher than lamination I.

Table. 4 Density and thickness of the lamination

Type of Lamination	Theoretical density (g/cm^3)	True density (g/cm^3)	Thickness (mm)
Matrix material	1.24	1.24	2.5
Lamination I	1.2238	1.21	3.5
Lamination II	1.235	1.235	2.9

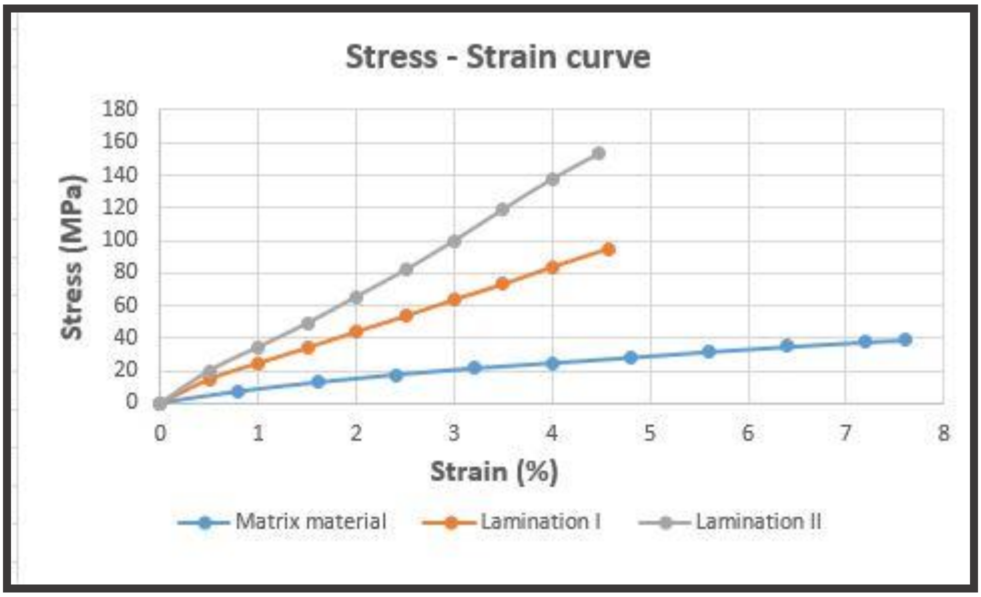

Fig. 9 Typical strain – stress curve for matrix material and two suggested lamination

Table. 5 Mechanical properties for the matrix material and two suggested lamination

Type of Lamination	Ultimate tensile strength (MPa)±SD	Young's Modulus (GPa)±SD	Specific Strength (KJ/kg)	Specific Modulus (MJ/kg)
Matrix material	32.1225±8.14	1.295±0.439	26	1.04
Lamination I	95.066±4.25	3.06±0.235	77.7	2.5
Lamination II	153.43±11.47	4.675±0.96	124.164	3.78

3.3 Effect of fiber volume fraction on flexural strength and bending modulus

In flexural test, the specimen of lamination I does not break even after being greatly deflected due to their ductile behavior under flexural but it has found the opposite in lamination II where it has noted that they in a purely elastic manner until failure as shown in the Fig.10 because of increasing carbon fiber volume fraction therefore it has a brittle behavior under flexural. The fracture of Lamination II took place on the compression and tensile sides. Increasing of carbon fiber volume fraction and modified the lay-up of ten layers improved the flexural properties of lamination II where moving away the added carbon fiber from the neutral axis, the moment of inertia is increased subsequently increasing of bending stiffness because the moment of inertia can express the ability to resist bending [12]. The magnitudes of flexural strength for two suggested materials are 66.7 MPa and 170 MPa respectively and bending Young's modulus are 1,925 GPa and 8.493 GPa respectively. Increasing carbon fiber volume fraction led to increase flexural strength and Young's modulus by approximately percentage 154.9% and 341.2% respectively higher than (Lamination I). Also, it has seen that bending Young's modulus of (Lamination I) was reduced by approximately percentage 37% which was less than tensile Young's modulus at same lamination in contrast to lamination II where the bending Young's modulus was increased by approximately percentage 81.7% higher than tensile Young's modulus where this increasing is attributed to the high carbon fiber content and modify of lay-up. Table 6 gives the magnitudes of flexural strength and bending Young's modulus.

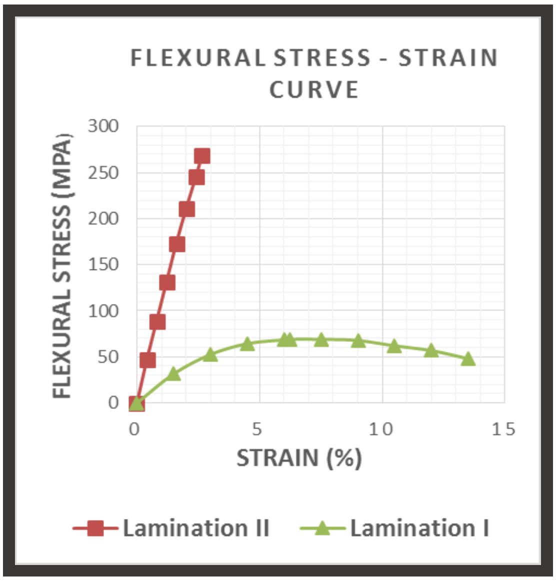

Fig. 10 Typical strain – stress curve for two suggested lamination

Table .6 Flexural strength and Young's modulus of lamination

Type of lamination	Ultimate flexural strength (MPa)±SD	Young's modulus (Gpa)±SD
Lamination I	66.7±1.9925	1,925±0.1565
Lamination II	170±85.6	8.493±2.225

3.4 Effect of fiber volume fraction on fatigue strength

The results of all fatigue tests are graphically displayed in the form of S-N curves as shown in **Fig.11** where it gives indications about Fatigue stress and number of cycles for lamination I and Lamination II in addition to **Table 7** gives magnitudes of fatigue ratio and endurance limit for both of them. These results showed that lamination II are higher than lamination I because increasing of carbon fiber volume fraction and consequently increases the bending stiffness of the laminated composite material against the fatigue loading. In general, the fatigue strength of materials is proportional to its tensile strength hence materials with higher ultimate tensile strength possesses higher fatigue limit. Also the cause of failure that has seen for most specimens of lamination I were formed a multiple cracking on the surface of specimen (matrix failure) in contrast to lamination II where initiating of micro-cracks and delamination were the most cases of failure. **Table 8** gives the fitting equation of stress and a correlation coefficient (R^2) 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 R^2 to 1, the stronger is the relationship between σ and N.

Table .7 The magnitudes of endurance limit and fatigue ratio of lamination

Type of Lamination	Endurance Limit (MPa)	Fatigue Ratio
Lamination I	30.6	0.322
Lamination II	54.15	0.352

Table .8 The curve fitting equation of stress of the lamination

Type of Lamination	Curve fitting equation	R^2
Lamination I	$S = 308.73 \times N^{-0.164}$	0.9764
Lamination II	$S = 365.85 \times N^{-0.135}$	0.9949

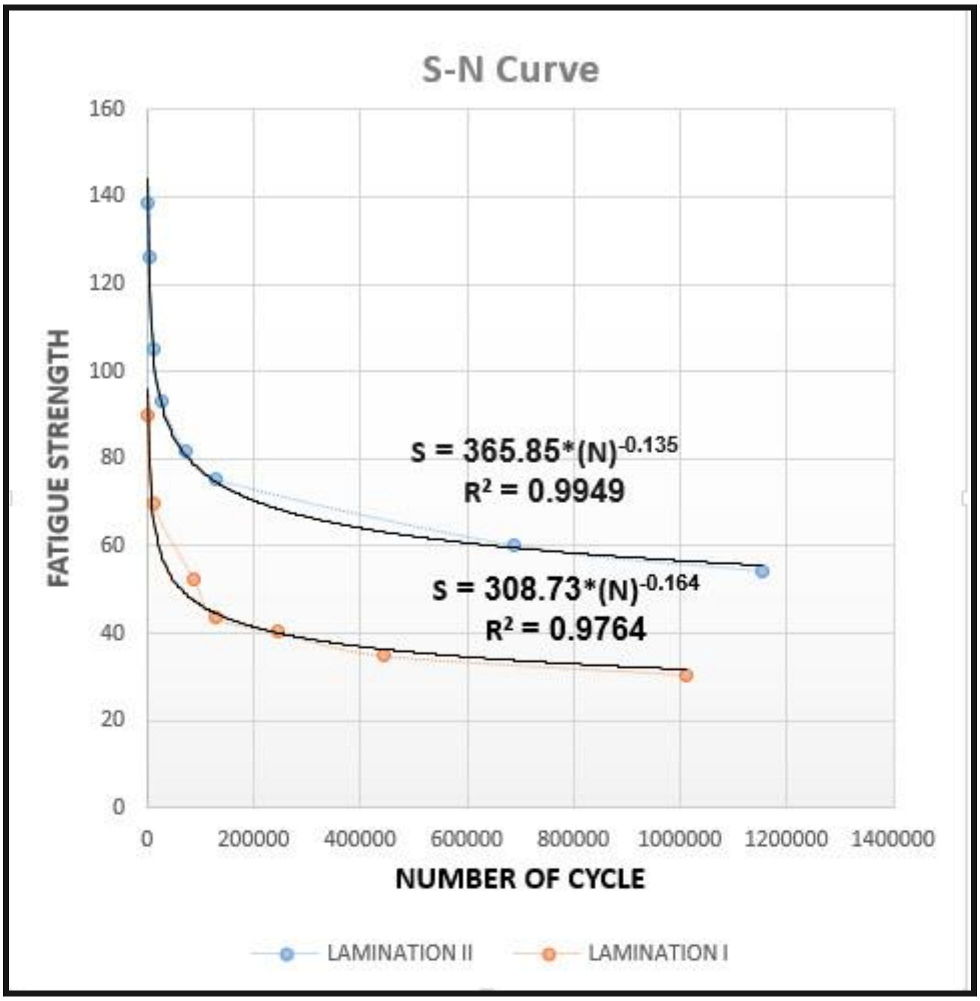

Fig.11 S-N curve for lamination I & lamination II

4. Conclusions

The major conclusions can be summarized as follows:

1. Fiber volume fraction plays an excellent role for improvement the mechanical properties and characteristics of fatigue where the tensile strength and flexural stiffness of the plastic laminated depend on the types, number and lay-up of reinforcement layers that means fiber volume fraction.
2. Increasing of carbon fiber volume fraction led to improve the magnitudes ultimate tensile strength and Young's modulus but by a varying percentages where there is a slight increasing in value of Young's modulus compared with high increasing of ultimate tensile strength.
3. In the poor fiber volume fraction (26.2%), the flexural strength and bending Young's modulus are less than tensile strength and Young's modulus but for (40.63%) fiber volume fraction and modify the lay-up made them higher than the value of tensile strength and Young's modulus.
4. Increasing of fiber volume fraction into (40.63%) and

modify of lay-up increased the life of laminated composite material through increasing fatigue strength and endurance stress.

5. The most important characteristics of composite material are specific strength and specific modulus where the two suggested composite material gives high specific modulus and high specific strength but the high fiber volume fraction (40.63%) gives excellent specific strength with high increasing about (60%) but specific modulus give an increasing about (51.2%) if it compared with the low fiber volume fraction (26.2%).

Notation

ρ: Density of material in (g\cm³)

ρ_c; Density of woven carbon fiber in (g/cm³)

ρ_p: Density of perlon stockinette in (g/cm³)

ρ_r: Density of acrylic resin in (g/cm³

m: Mass of material in (g)

v : Volume of material in (cm³)

m_I: Mass of laminated composite material in (g)

m_c: Mass of woven carbon fiber in (g)

m_p: Mass of knitting perlon stockinette in (g)

m_r: Mass of acrylic resin in (g)

v_f : Volume of reinforcement layers in (cm³)

v_r : Volume of matrix in (cm³)

V_f : Volume fraction of fiber (%)

V_m: Volume fraction of matrix (%)

V_p: Volume fraction of perlon stockinette (%)

V_c: Volume fraction of woven carbon fiber (%)

References

[1]A.A.Ibrahim,(2001). "Development and Testing of Syme Prosthesis with Enhanced Structural Strength", Ph.D. Dissertation, university of technology.pp.79-99

[2] ASM International, (2001) Handbook. "Vol. 21: Composites."

[3] Berry, C.P. (C). (1987) "Composite Materials for Orthotics and Prosthetics" American orthotic and prosthetic Association Vol. 40, No. 4, pp. 35-43,

[4] Current, Kogler and Earth.(1999) "Static Structural Testing of Trans-Tibial Composite Sockets." Prosthetics and Orthotics International: pp.113-122.

[5] Cardarelli, François. Materials handbook: a concise desktop reference. Springer Science & Business Media, 2008.pp.1

[6] Faulkner, V., Field, M., Egan, J. W., & Gall, N. G. (1987) "Evaluation of High Strength Materials for Prostheses." Orthotics Prosthetics 40.4: 44-58.

[7] Harris, Bryan, ed. Fatigue in Composites: Science and Technology of the Fatigue Response of Fibre-

Reinforced Plastics. Woodhead Publishing, (2003).pp.622

[8] Irawan, A. P., Soemardi, T. P., Widjajalaksmi, K., & Reksoprodjo, A. H. S. (2011). Tensile and Flexural Strength of Ramie Fiber Reinforced Epoxy Composites for Socket Prosthesis Application.pp.46-50

[9] M.J. Jweeg, K.K. Resan and M.Tariq, (2012) "Study of Creep – Fatigue Interaction in Prosthetic Socket below Knee" ASME International Mechanical Engineering, November 9-15, Houston, Texas, USA.pp.1-6.

[10] Jweeg, Ali. Hammood and M.Al-Waily., (2012) "Experimental and Theoretical Studies of Mechanical Properties for Reinforcement Fiber Types of Composite Materials" International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS Vol: 12 No: 04, pp.62-75

[11] Kaw, Autar K. Mechanics of Composite Materials. CRC press, (2005).pp.204-210

[12] Klasson, (1995): "Carbon Fiber and Fiber Lamination in Prosthetics and Orthotics: Some Basic Theory and Practical Advice for the Practitioner." Prosthetics and Orthotics International 19.2, pp 74-91.

[13] Mallick, Pankar, (2007) " Fiber-Reinforced Composites: Materials, Manufacturing, and Design". CRC press, pp.270-277

توصيف المواد وتحليل الكلال للمواد المستخدمة في صناعة الأطراف الاصطناعية السفلية

د. محسن عبد الله الشمري
أستاذ مساعد
أحمد خليل عبد الأمير
قسم الهندسة الميكانيكية / كلية الهندسة
جامعة بغداد

الخلاصة

تعتبر المواد اللدنة المركبة التي تستخدم بشكل واسع كواحدة من أكثر المواد الجديدة بالاهتمام في التطبيقات الهندسية الهيكلية بسبب خصائصها الفيزيائية و الميكانيكية العالية واهم تلك الخصائص المتانة و الجساءة. الأطراف الإصطناعية هي احدى التطبيقات الهندسية التي تستخدم فيها المواد اللدنة المركبة لكونها خفيفة الوزن وتمتلك متانة عالية نسبة الى وزنها.

سيتم خلال هذه الدراسة معرفة تاثير المحتوى الحجمي للالياف و ترتيب الطبقات على الخواص الميكانيكية (فحص الشد و فحص الانحناء) و خواص الكلال للمواد المركبة المصنعة كذلك فحص الخواص الميكانيكية للمادة الرابطة .استخدمت في هذه الدراسة كل من الياف الكاربون النسيجية و الياف البيرلون و مادة الرانتيج الصناعي لغرض تصنيع مواد مركبة بمحتوى حجمي متغير باستخدام تقنية القولبة المفرغة وكذلك تصنيع عينات للمادة الرابطة من خلال سكب المادة الرابطة داخل حاوية بابعاد محددة بعد خلطها بنسبة 2% من المادة المصلبة.

تم تصنيع مادتين مركبتين بترتيب و بمحتوى حجمي متغير الاولى بمحتوى حجمي للالياف (26.2%) ((8 طبقات) و بتنضيد (3-بيرلون + 2- الياف الكاربون + 3- بيرلون)) و المادة المقترحة الثانية بمحتوى حجمي للالياف (40.63%) ((10 طبقات وبتنضيد (2- بيرلون + 1- الياف الكاربون + 1- البيرلون + 2- الياف الكاربون + 1- البيرلون + 1- الياف الكاربون + 2- بيرلون) و مقارنة خواصها الميكانيكية بخواص المادة الرابطة و خواص المادتين كلا على انفراد.

أظهرت النتائج أفضلية المادة المركبة المقترحة الثانية ذات المحتوى الحجمي العالي (40.63%) حيث زاد الإجهاد الاقصى و معامل المرونة بمعامل تقريبي مقداره 3.77 و 2.61 على التوالي وبخصوص المادة المركبة الاولى ذات المحتوى الحجمي (26.2%) فقد زاد الإجهاد الاقصى و معامل المرونة بمعامل تقريبي مقداره 1.96 و 1.36 على التوالي مقارنة مع نفس الخواص للمادة الرابطة وكان حد التحمل للمادة الثانية تفوق تقريبا مرتين حد التحمل للمادة الاولى وهو مؤشر إيجابي.

الكلمات المفتاحية: - طرف صناعي نوع سايم , المواد المركبة , المحتوى الحجمي , أختبارات ميكانيكية , الكلال للمواد المركبة , الصفيحة الطبقية