

## Effects of Composite Material Layers on the Mechanical Properties for Partial Foot Prosthetic Socket

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### Abstract

In this work, nine types of laminated composite materials used for experimental study to investigate the tensile and fatigue properties of partial foot prosthetic socket which fabricated by using vacuum pressure system. The composite material matrix were Lamination 80:20 and reinforced with nine types of laminations (perlon, n-glass, fiber glass and carbon) by variation of thickness according to lamination. Results show that the mechanical properties were improved by increasing the two layers of carbon fiber, fiber glass and n-glass layers instead of zero layer with six layers of perlon lead to the increased in (yield strength  $\sigma_y$ , ultimate tensile strength  $\sigma_{ult}$  and modulus of elasticity  $E$  with (71% ,76% and 58%) respectively for carbon fiber, (20% , 19% and 40%) for fiber glass and ( 22% , 5.5% and 29% ) for n-glass. Results show that (3perlon+2carbon fiber+3perlon) gives the best value of mechanical properties and has higher Endurance limit stresses ( $\sigma_e$ ) which increase lifetime for the patient. It is recommend to use this type of lamination for the layup partial foot prosthetic socket because it meets the demand lamination layers for acceptable mechanical properties and its minimizing the cost of socket lamination to suitable costing value.

**Keywords:** Partial Foot Socket, Tensile, Fatigue, Laminated Composites.

### 1. Introduction

Prosthetic limbs are artificial devices which substitutes missing body parts (limbs) of the amputee. A person may face amputation due to disease or accidents. The amputee's limbs are hence replaced by prosthetic limbs which are designed to meet the performance level of natural human limbs equally providing comfort to the amputee. Prosthetic limbs allow amputees to continue their day to day life. Lower extremity prosthesis provides replacement of lower limbs at varying levels of amputation. Prosthetic foot helps the amputee to walk independently adapting amputee's gait [1] Prosthesis is an artificial device extension are generally used to replace parts lost by injury (traumatic) or missing from birth (congenital) or to supplement defective body

parts. Prostheses are specifically not orthotics, although under given certain circumstances prosthesis might end up performing some or all of the same functionary benefits as an orthotics. Prostheses are technically the complete finished item. Prostheses are technically the complete finished item. For instance, a C-Leg knee alone is not prosthesis, but only a prosthetic component. The complete prosthesis would consist of the attachment system to the residual limb - usually a "socket", and all the attachment hardware components all the way down to and including the terminal device. [2]

Many researches were interested the design and manufacturing of prosthetics and orthotics: Muhsin J. Jweeg et al. use (perlon 6, 9 and 12 layers) [3]. Muhsin J. Jweeg and Jana S. Jaffar worked on perlon-carbon-perlon (424) and perlon only [4]. S. S. Hasan, et al. used different composite material for laminations [5]. Muhsin J. Jweeg et al. used different types of laminations [6].

A. A. Ibrahim studied the structural strength of the syme by using two laminate with various reinforcement [7]. Sam L. Philips and William Creluis begins with a data base on mechanical properties of lamination sockets, which subjected to tensile and bending tests. [8]. H. F. Neama, investigated stress distribution for below knee prosthetic socket. They worked on polypropylene and composite material sockets [9]. S. H. Mohammed presented numerically and experimentally studying for ankle-foot orthoses by using perlon and carbon fiber materials instead of polypropylene [10].

In the ever-changing field of orthotics and prosthetics, recent advancements have been achieved with the use of new materials and resins. In the spring of 1981, a study project was initiated in an attempt to learn the proper use of these high-tech materials. Data was accumulated from various chemistry and physics texts on the characteristics of composite materials, specifically carbon, Kevlar, and fiberglass [11]. Prostheses and Orthoses prescribed for partial foot amputations vary in design and principle [12]. The main goals of orthotic and prosthetic devices in partial foot amputations are to restore stability, maintain support, and protect the function of the residual

limb. The materials and techniques used today have had significant positive effects on function and comfort of partial foot amputees [13].

In this work, tensile and fatigue test was applied for different samples of lamination from perlon, perlon with carbon fiber, perlon with fiber glass and perlon with n-glass in order to be used in manufacturing of prosthetic socket for partial foot to achieve the requirement of good socket design for acceptable mechanical properties and minimizing the cost.

## 2. Experimental procedures

### 2.1 Materials

The partial foot socket materials used in lamination for this study [14] as shown in Figure (1).

1. Perlon stockinet white.
2. Carbon fiber.
3. Fiber glass.
4. Nyle glass.
5. Lamination resin 80:20.
6. Hardening powder.
7. Polyvinylalcohol PVA.



Figure 1: prosthetics and orthotics materials.

### 2.2 Procedure of laminations

- a. Set the rectangular mold at the stand of vacuum pressure system as shown in Figure (2).



Figure 2: Positive mold.

- b. Use the Perlon stockinet, Perlon and fiber glass stockinet and Perlon and carbon fiber

stockinet Perlon and n- glass stockinet as indicated by the overlaying lay-up.

- c. Blend the overlay resin 80:20 polyurethane with the hardener.
- d. Maintain constant vacuum with pressure approximately (30-60 KPa) at room temperature until the laminations becomes cold and cut according to the dimension of samples as shown in Figure (3).



Figure 3: Positive mold with pressure system.

Universal instrument machine test (Testometric) for tensile as shown in Fig.(4). Three samples were prepared for each lamination according to ASTM D638 type I [15] while thickness varies according to the type of lay up. Fig.(5) shows the dimensions of tensile sample.



Figure 4: Tensile test device.

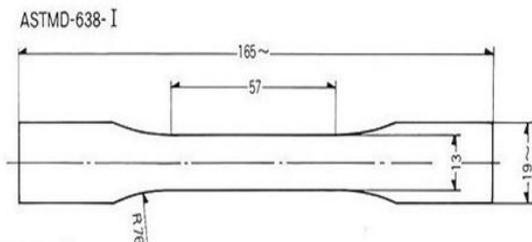


Figure 5: The dimensions of tensile specimen.

Material fatigue test for flat specimen as shown in Fig.6 were characterized. Eight samples for each lamination used for fatigue test. The dimensions of samples has length of 100mm and width 10mm according to the fatigue device test

while thickness varies with the type of layup. Fig. (7) shows the shape of fatigue samples.

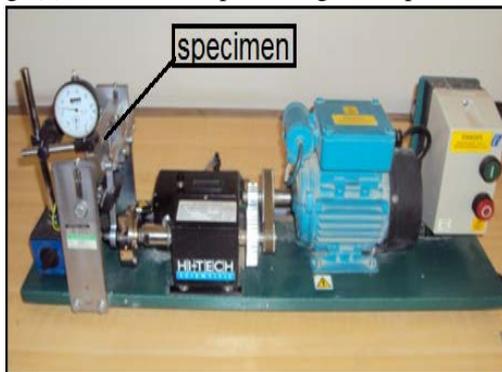


Figure 6: Fatigue test device.

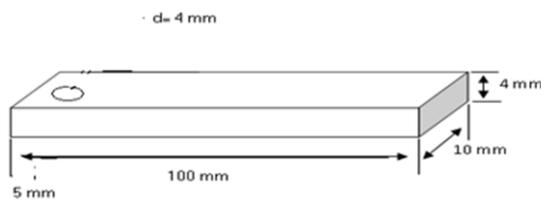


Figure 7: The shape of fatigue specimen.

The average thickness for the samples is measured and the laminations prepared are shown in Table 1.

Table 1: The lamination manufactured with different layup method

No	Total No of layers	Thickness (mm)	Lamination lay up procedures
Group A	7	3	(3Perlon +1 carbon fiber+3perlon)layers
Group B	7	3	(3Perlon +1 fiberglass+3perlon)layers
Group C	7	2.8	(3Perlon +1n-glass+3perlon)layers
Group D	8	3.5	(3Perlon +2 carbon fiber+3perlon)layers
Group E	8	3.7	(3Perlon +2 fiberglass +3perlon)layers
Group F	8	3.2	(3Perlon +2n-glass +3perlon)layers
Group G	4	1.9	4Perlon
Group H	6	2.5	6Perlon
Group I	8	2.9	8Perlon

### 3. Results and discussions

#### 3.1 Tensile properties results

The results of each laminations sample are shown in Table (2) and from Figs.(8 to 13) which can be determined by taking the average value of mechanical properties.

1. For Perlon lamination the mechanical properties are increasing about (yield strength  $\sigma_y$  70% and ultimate tensile strength  $\sigma_{ult}$  13%) with the increasing Perlon layers, but the mechanical properties(E) are decreasing about 30% with the increasing Perlon layers, especially for high number of Perlon layers because the matrix epoxy stronger than Perlon fiber these result agreement with.

- For lamination (Perlon+fiberglass+Perlon) these properties results for increasing fiber glass with constant Perlon, are increasing about (yield strength  $\sigma_y$  21% , ultimate tensile strength  $\sigma_{ult}$  16% and E 60% ) for (Group B) as compared with( Group H). and increasing about (yield strength  $\sigma_y$  20% , ultimate tensile strength  $\sigma_{ult}$  19% and E 40% ) for (Group E) as compared with (Group H).
- For lamination (Perlon+n-glass+Perlon) these properties results for increasing n-glass with constant Perlon, are decreasing yield strength  $\sigma_y$  66% and increasing about (ultimate tensile strength  $\sigma_{ult}$  about 0.9% and E 36% ) for (Group C) as compared with (Group H). and increasing about (yield strength  $\sigma_y$  22% , ultimate tensile strength  $\sigma_{ult}$  5.5% and E 29% ) for (Group F) as compared with (Group H). also the properties (yield strength  $\sigma_y$  73% and ultimate tensile strength  $\sigma_{ult}$  5%) are increasing with the increasing fiber glass layers these result agreement with [16].
- For lamination (Perlon + carbon fiber + Perlon) these properties results for increasing carbon fiber with constant Perlon, are increasing about (yield strength  $\sigma_y$  62% , ultimate tensile strength  $\sigma_{ult}$  62% and E 68% ) for (Group A) as compared with (Group H). and increasing about (yield strength  $\sigma_y$  71% , ultimate tensile strength  $\sigma_{ult}$  76% and E 58% ) for (Group D) as compared with (Group H). also the properties (yield strength  $\sigma_y$  are increasing about 24% and ultimate tensile strength  $\sigma_{ult}$  are increasing about 38%) with the increasing carbon fiber layers [16]. Due to increasing the ability of absorbing that can lead to increase in the thickness for each samples in plastic behavior for both materials. This addition of thickness come from the matrix material which was weaker than the fiber materials [17] This resulted in an optimum absorbing ability to the lamination 80:20 can give higher mechanical properties for sandwich layup lamination.

Table 2: Mechanical properties evaluated from stress -strain curves.

No. of Lam.	Total No of layers	Thickness (mm)	$\sigma_y$ MPa	$\sigma_{ult}$ Mpa	E GPa
Group A	7	3	89.1	108.5	2.5
Group B	7	3	42.5	48.6	2
Group C	7	2.8	11.4	41.37	1.25
Group D	8	3.5	117	175	1.9
Group E	8	3.7	42	50.4	1.32
Group F	8	3.2	43	43.4	1.13
Group G	4	1.9	10.12	38.8	1.16
Group H	6	2.5	33.6	41	0.8
Group I	8	2.9	34.45	44.4	1.01

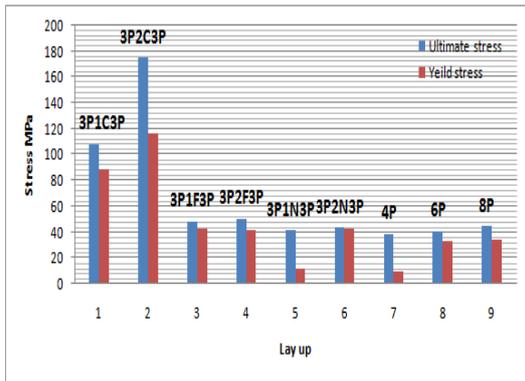


Figure 8: Variation of ultimate and yield stress with laminations.

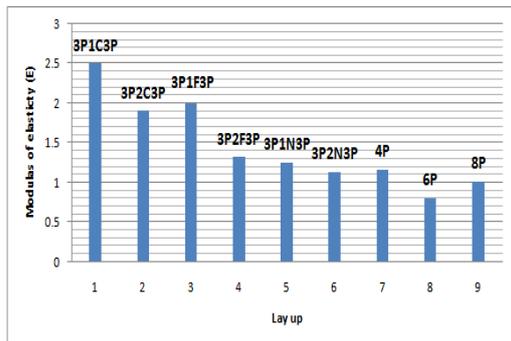


Figure 9: Variation modulus of elasticity with laminations.

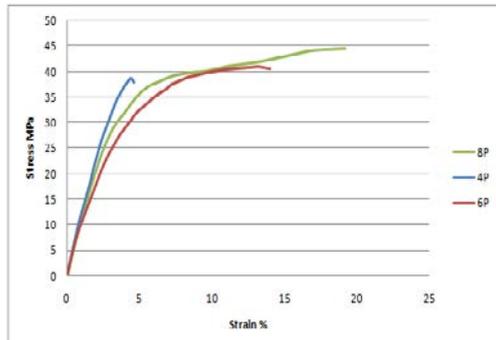


Figure 10: Stress-strain curve for one sample of each perlon lamination.

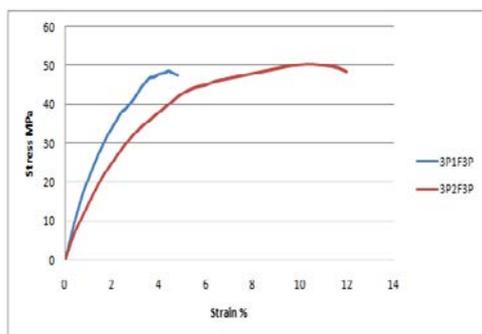


Figure 11: Stress-strain curve for one sample of each perlon fiber glass perlon lamination

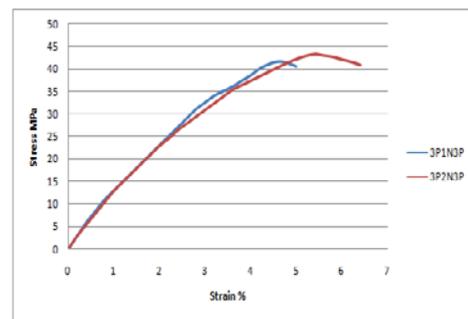


Figure 12: Stress-strain curve for one sample of each perlon n-glass perlon lamination

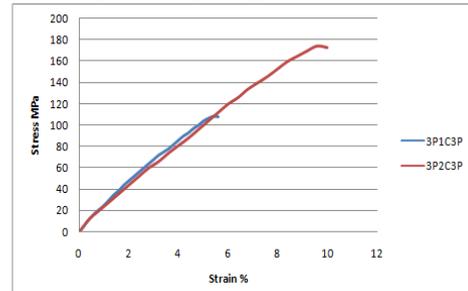


Figure 13: Stress-strain curve for one sample of each perlon carbon fiber perlon lamination

Also, it can be noticed that lamination which consisted of three layers of Perlon plus two layers of carbon fiber plus three layers of Perlon bound by the lamination (80:20) resin matrix, had the best mechanical properties.

### 3.2 Fatigue properties results

The failure of fatigue of flat specimen can be occur when the specimen fractures under alternating bending with high cycle fatigue. The readings were recorded by the fatigue tester machine give the number of cycles when the specimens were fractured. The S - N curves for each samples of all laminations as shown in Figures from Figure (14). to Figure (18). The failure stresses are decreasing and the number of cycles to reach to the failure is increasing at constant temperature.

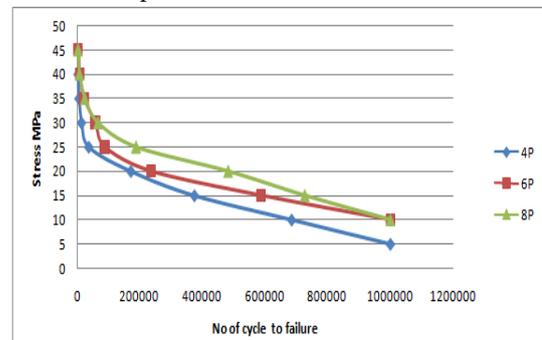


Figure 14: S-N curves for perlon laminations.

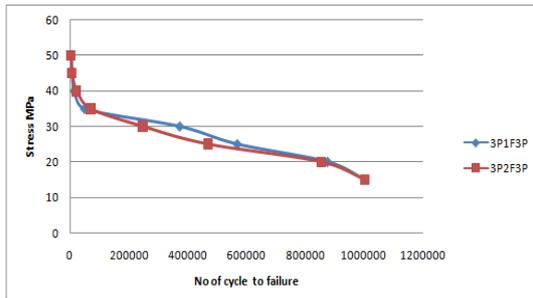


Figure 15: S-N curves for perlon fiber glass perlon laminations.

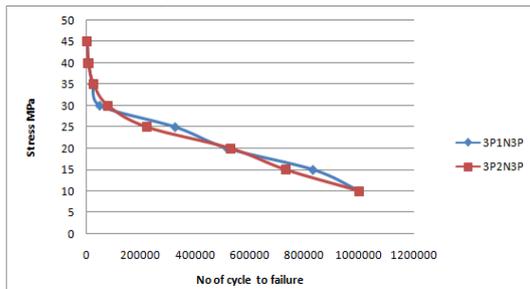


Figure 16: S-N curves for perlon n- glass perlon laminations.

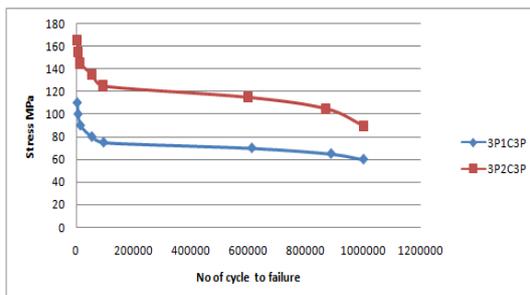


Figure 17: S-N curves for perlperlon laminations.

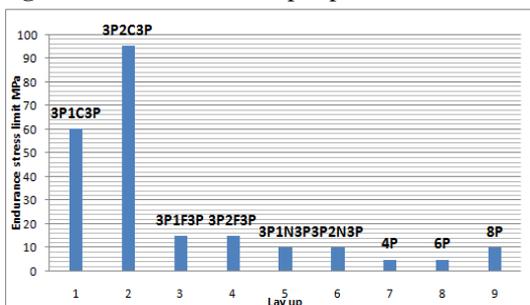


Figure 18: Fatigue endurance stress limit with various laminations.

#### 4. Conclusions

This study gives a good database for manufacturing suitable lamination of partial foot prosthetic socket for patients with below ankle amputee. The conclusions of this work are as follows:

1. The lamination which consists of (3P+2C+3P) are considered the best lamination lay up. It is recommend to use this type of lamination for the layup partial foot prosthetic socket because it meets the demand lamination layers of socket for acceptable mechanical properties

and its minimizing the cost of socket lamination to suitable costing value.

2. For constant layers of perlon the mechanical properties are improved when increasing of carbon fiber, fiber glass and n-glass layers. Using two layers of carbon fiber instead of zero layer with six layers of perlon lead to the increased in (yield strength  $\sigma_y$ , ultimate tensile strength  $\sigma_{ult}$  and modules of elasticity E with (51% ,75% and 58%) respectively for carbon fiber, (20% , 19% and 40%) for fiber glass and ( 22% , 5.5% and 29% ) for n-glass.
3. The lifetime for prosthesis depends on the applied stress and the composite material type. The lamination which consists of (3perlon+2carbon fiber+3 perlon) has Endurance limit stresses ( $\sigma_e$ ) is much longer than the other laminations. This increase in lifetime for the patient wearing partial foot prosthetic.

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## تأثير طبقات المواد المركبة على الخواص الميكانيكية لوقب طرف صناعي خلال القدم

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### الخلاصة

في هذا العمل، تم اختبار تسعة أنواع من المواد المركبة المستخدمة في الدراسة العملية لإيجاد الخواص الميكانيكية (الشدة والكلل) لوقب طرف صناعي خلال القدم لبتنر جزئي باستخدام نظام ضغط الهواء المفرغ. وباستخدام (20 : 80 lamination) وكذلك الألياف (بيرلون، نايل كلاس والزجاج والكربون) وبسبب كل مجموعة وفقاً لعدد الطبقات المستخدمة. أظهرت النتائج أن الخواص الميكانيكية تحسنت من خلال زيادة طبقتين من ألياف الكربون والألياف الزجاجية والطبقات الزجاجية وكذلك مادة النايل كلاس بين طبقات البيرلون التي تؤدي إلى زيادة في أجهاد الخضوع ( $\sigma_y$ ) ، أقصى أجهاد ( $\sigma_{ult}$ ) ومعامل المرونة (E) و (%71 و %76 و %58) على التوالي بالنسبة للألياف الكربونية (%20 و %19 و %40) للألياف الزجاجية و (%22 و %5.5 و %29) للنايل كلاس. كما بينت النتائج أن المجموعة 4 (3perlon + 2carbon + 3perlon) تعطي الخصائص الميكانيكية المثلى ولديه أعلى الضغوط التحمل ( $\sigma_e$ ) التي تزيد من عمر المريض. فمن المستحسن استخدام هذه المجموعة لصناعة وقب لطرف صناعي لبتنر جزئي خلال القدم ي لأنه ذو خصائص ميكانيكية مقبولة و تكلفة مقبولة مناسبة للمريض.