Eng.&Tech.Journal,Vol.27,No.4,2009

Effects of Lamination Layers on the Mechanical Properties for Above Knee Prosthetic Socket

Dr.M.J.jweeg*, Dr.S.S.Hasan**&J.S.Chiad***

Received on: 1/6/2008
Accepted on:6/11/2008

Abstract

In order to initiate a database on materials properties of typical lamination used in above knee prosthetic limb socket fourteen group of different lamination materials layers are manufactured using perlon and fiber glass and acrylic resin .The effect of increasing and decreasing of perlon and fiber glass layers on mechanical and physical properties are examined subjected the eighty two manufacturing sample of the different fourteen group of lamination to tensile and flexural test .

Results show that the lamination which was layup from three layers of perlon plus two layers of fiber glass plus three layers of perlon gives the optimum mechanical properties . Comparing this lamination with the standard lamination used in Baghdad center of five layers of perlon plus two layers of fiber glass plus five layers of perlon it can be seen that ,in spite of the big reduction in perlon layers form ten to six layers the yield stress increased with 14.75% while ultimate strength remains at the same value and bending stress decreased with 1.3% only . It is recommend to use this type of lamination for the layup the above knee socket because it meets the requirement of good socket design for acceptable mechanical properties and its minimizing the cost of socket lamination to suitable cost value.

Also it was found that increasing the fiber glass layers from zero to two layers with fixing perlon layers leaded to increased in($s_y, s_{ult}, E, s_{flex}, E_{flex}$) with (40%,30.4%,110.5% 36.4%and 20.4%) respectively. At the same time the results show that the lamination group of sandwich lay up during which the layers of perlon distributed equally (homogeneously) on each side of the central fiber glass layers improved the mechanical properties set ($s_y, s_{ult}, E, s_{flex}, E_{flex}$) with ((21-59)%,(12.4-66.4)%,(46.6-150)%,(5.2-60.2)%,(27.5-44.8)%) respectively compared with the others group of unequally distributed lamination .

Keywords: Transfemoral, Socket Material, Fiberglass, Perlon , Mechanical Properties

تاثير عدد الطبقات المستخدمة في تصنيع الوقب على المواصفات الميكانيكية لوقب بتر فوق الركبة

الخلاصة

لغرض انشاء قاعدة بيانات لخصائص المواد المستخدمة في تصنيع وقـب(Socket) لبتـر فوق الركبة للاطراف السفلية فقد تم تصنيع اربع عشر وقب باسـتخدام قالـب تـم تـصنيعة خصيصا لدراسة المواصفات الميكانيكية بحيث ان كل وقب يختلف عن الاخر اما بعدد الطبقـات او بنوع المادة المستخدمة في التصنيع.وايضا تم دراسة تاثير زيادة عدد طبقـات كـل مـن ال (Perlon) و (Fiber glass)على المواصفات الميكانيكية والفيزيائية للوقب بتثبيت احدهما وزيادة

* Collage of Engineering , University of Al-Nahrain /Baghdad.
** Mechanical Engineering Department, University of Technology/Baghdad
*** Collage of Engineering, University of Al-Mustansiriya /Baghdad

https://doi.org/10.30684/etj.27.4.12
2412-0758/University of Technology-Iraq, Baghdad, Iraq

الاخر ولتحقيق هذا الهدف فقد تم تصنيع اثنان وثمانون عينة فحصية تم فحصها فحصي الشد والانحناء.
اظهرت النتائج ان الوقب المصنع باستخدام ثلاث طبقات من ال (Perlon) وطبقتين من ال (Fiber glass) وثلاث طبقات من ال (Perlon) يحقق المواصفات الميكانيكية المثالية وبمقارنة هذا الوقب مع الوقب المصنع في مركز بغداد للاطراف الاصطناعية والذي يتالف من خمس طبقات من ال (Perlon) وطبقتين من ال (Fiber glass) وخمس طبقات من ال (Perlon) نجد انه بالرغم من تقليص عدد طبقات ال (Perlon) من عشرة الى ستة فان اجهاد الخضوع ازدادت قيمتة بنسبة 14.75% بينما حافظ اجهاد مقاومة الشد على قيمتة وانخفض اجهاد الانحناء بمقدار 1.3% فقط وعلية يوصى باستخدام هذا الوقب طالما انة يحقق متطلبات التصميم الناجح للوقب بمواصفات ميكانيكية مقبولة بالاضافة الى انة يقلل كلفة التصنيع.
وجد ايضا انة بزيادة عدد طبقات ال (Fiber glass) من الصفر الى اثنين وتثبيت عدد طبقات ال(Perlon) فان هذا يقود الى زيادة في المواصفات الميكانيكية $(s_{flex}, E_{flex}, s_y, s_{ult}, E)$ بنسبة (40%,30.4%,110.5% 36.4%and 20.4%) . وبنفس الوقت اظهرت النتائج ان الوقب الذي يصنع من عدد طبقات ال (Perlon) الموزعة بالتساوي على جانبي طبقات ال (Fiber glass) المركزية يتميز بمواصفات ميكانيكية $(s_{flex}, E_{flex}, s_y, s_{ult}, E)$ تزداد قيمتها بنسبة تتراوح ((21-59)%,(12.4-66.4)%,(46.6-150)%,(5.2-60.2)%,(27.5-44.8)%) على التوالي مقارنة مع الوقب الذي يكون توزيع الطبقات فية غير متساوي او غير متجانس .

Notations

Symbols	Defination	Units
A	Area	mm^2
ASTM	American society for testing and materials	
B	Width	mm
E	Young's modulus	Gpa
$E_{flexural}$	Flexural young's modulus	Gpa
FG	Fiber glass	
L	Length	mm
p	Force	n
PVA	Polyvinyalcohol	
t	thickness	mm
V	Volume	mm^2
v_f	Fiber volume fraction	
v_m	Matrix volume fraction	
w	Weight	g
w_f	Weight of fiber	g
w_m	Weight of matrix resin	g
W_f	Fiber weight fraction	
W_m	Matrix weight fraction	
s_y	Yield strength	Mpa
s_{ult}	Ultimate strength	Mpa
r	Density	g/cm^3
e	strain	
d	Extension	mm
$s_{b\max}$	Maximum bending strength	Mpa
r_c	Density of sample	g/cm^3
r_m	Density of matrix resion	g/cm^3

1. Introduction

In 1946 [1] U.S. Army made a study of general prosthetic manufacturing technology ,a major recommendation of this commission was for introduction of new technique which called suction socket .This technique used different type of fiber stockinet with acrylic resin matrix to manufacturing a quadrilateral lamination socket .. The period 1955-1960 [2] saw the introduction of thermosetting lamination resin into lower limb prosthetics technology ,first as substitute for rawhide in the reinforcement of wooden prostheses ,later as basic materials for plastic socket molded over plastic stump . the remarkable success of laminated plastic socket used with patellar tendon bearing below knee prosthetic led to the use of similar techniques with above knee quadrilateral suction socket .

The type of the laminated socket used in the above knee prosthetic depends upon shape, size and condition of the residual limb[3].if a patient has a small residual limb a suction suspension socket will not be effective to used while it is preferred to use this socket for patient with long residual limb this due to the large ,evenly size and relatively scar free residual limb over which the suction forces can be evenly distributed. The actual socket material must meet certain demands ,these are economy ,durability ,tightness and non toxicity; also must be capable of local adjustment either by grinding or local heating [4]

Through time artificial limbs have been made with various materials .From wood and aluminum of yesterday, to perlon , nylon, carbon fiber and fiber glass today[5]. Physical properties of individual layers in lamination lay up are important because they help to determine the physical properties of the entire lamination [6].These properties were yield stress, ultimate strength, young's modulus, tensile stiffness ,flexural stress, bending stiffness and brittleness and ductility .Published values of materials properties for typical fabrication materials were presented in table (1) [6]and[7].

Both carbon fiber and fiber glass are very strong ,but they don't have lamination as properties socket materials because of their brittleness they break, rather than stretch during post fabrication modification significant strength is lost .Characterizing properties of socket themselves are difficult because of their complex shapes and dynamics irregular nature of their stress pattern consequently ,it has been difficult to establish expected stress or loads or prosthetic and orthotic devices .Establishing expected values is the next stepping optimizing socket design [6].

The effect of type of acrylic resin on the mechanical properties of the socket materials were studied using three types of lamination resins[6].The first was 80:20 ottobock acrylic resin while the second was epoxy acrylic resin and the last was resin 80:0 IPOS .It was found that the third type gives maximum ultimate strength compared with other two types of resins .The effect of the amount of resin on fiber stockinet were studying through three samples of lamination using normal amount of resin for the first and rich resin for the second while the third was using rich fiber .It was found that using rich fiber lamination gives maximum stiffness and ultimate strength[8].

In this work different lamination were used in order to get the optimum lamination can be used in manufacturing socket which achieving the requirement of good socket design for acceptable mechanical properties and minimizing the cost

2. Experimental procedures

2-1.Materials

The materials of the socket chosen were laminated randomly[6],[8].This means that the material is Isotropic [9],[10].In this work the material needed in lamination of the above knee socket for this study are as follows and shown in fig (1-a).

●Perlon stockinet white (ottobock health care 623T3) [11].

●Fiberglass stockinet (ottobock health care 616G3) [11].

●Lamination resin 80:20 polyurethane (proter hand icap technology) [11].

●Hardening powder (ottobock health care 617P37) [11].

●Polyvinyalcohol PVA bag (ottobock health care 99B71) [11].

● Materials for Jepson mold

2-2.Equipment

●Jepson mold (positive mold rectangular cuboids in shape with size 10*10*24 cm^3 .As shown in fig (1-b) (manufactured).

●vacuum forming system including vacuum pump and different types of stands, pipes and tubes as shown in fig (1-b)(available in Baghdad center for prosthetic and orthetic).

●mechanical workshop including different types of cutting and forming and measuring machine as shown in fig (1-c))(available in Baghdad center for prosthetic and orthetic).

●universal instrument machine test for tensile and flexural test as shown in fig (2-a)(available in the laboratories of the materials science department in the ministry of science and technology).

●sensitive weighting device for measuring weight of specimen as shown in fig(2-b) available in the laboratories of the materials science department in the ministry of science and technology).

2-3.Procedure

All laminations were performed under vacuum with the following procedures

●Mount the positive mold at the laminating stand and complete the connection with the vacuum forming system through the pressure tubes and pull the inner (PVA)bag in the positive mold and open the pressure valves to value of approximately 30 mm Hg at room temperature.

●Put the perlon stockinet and fiber glass stockinet according the laminating layup table (2)and pull the outer (PVA) keeping the smaller end positioned over the value area using cotton string to tie off the (PVA) bag.

● Mixed the lamination resin 80:20 polyurethane with the hardener according the standard ratio for each 100 part of acrylic resin mixed (2-3)part of hardener [11]and then putting the resulting matrix mixture inside the outside (PVA)bag and distributing the matrix homogeneously over all area of lamination stockinet.

● Maintain constant vacuum until the composite materials becomes cold and then left the resulting lamination as shown in fig (3)

●The tensile specimens machined at the (Baghdad center for prosthetic and orthetic workshop).Three samples for each lamination were machined according ASTM D638[12]with 50mm original length and 13mm width while thickness various with the type of lay up .At the same manner the flexural samples machined according ASTM D790[13]with 125 mm in length and 13mm in width .So the total sum of tensile and flexural specimens reach to 82 sample. Fig (4)shows the shape of each tensile and flexural samples.

●All the above 82 samples tested using the universal testing instrument for tensile and flexural testing at (the materials laboratories of the ministry of the science and technology).Fig (5) shows samples under tensile and flexural testing

3.Results

3-1Samples physical features

The average thickness and weight for the Sample set were measured using digital Vernier and digital sensitive weighting device while sample density and volume fraction were calculated according to [8].The physical properties are shown in table (3) and fig (6)

3-2.Tensile properties results

All 42 specimens were tested using Tinius olsen instrument for tensile testing .Three specimens for each lamination were tested to get load-extension curve for each sample. Fig(7) shows load- extension curve for one of three sample of the lamination 8 .After plotting the load-extension curve, the mechanical properties of each sample can be calculated and by taking the average value of the mechanical properties ($s_y, s_{ult}, E, Stifness$ and percent of elongation) the mechanical properties for all lamination can be found as shown in table (4)

The effects of increasing perlon layers with constant value of fiber glass layers on mechanical properties are shown in fig (8)while the effects of removing fiber glass layers from lamination layup on the mechanical properties were showing in fig(9)

Also the effects of increasing fiber glass layers with fixing No. of perlon layers are shown in figures (10and11).

3-3.Flexural properties

The flexural properties can be calculated from the bending curves of three samples for each lamination and by averaging the results , the mechanical bending properties of the all lamination lay up are listed in table (5)

The effects of the increasing of perlon layers on the bending properties ($s_{b\max}$ and $E_{flexural}$) with two layers of fiber glass were shown in fig(12),while the effects of removing fiber glass layers from lamination on the flexural properties are shown in fig(13) .also the effect of increasing of fiber glass layers on the bending properties with fixing perlon layers were shown in fig (14)and fig(15).

4.Discussions

4-1.Physical properties

Table (2) and fig(6) show that with increasing perlon layers of the laminations ,the thickness is increased at the same time the weight increased too. This increasing of thickness and weight was due to the increasing of fiber layers and matrix acrylic resin ,but the increasing in its maximum coming from the matrix acrylic resin .Also it can be seen that the absorbing ability in the lamination increased with the increasing the number of perlon layers .The values of the fiber volume fraction supporting strongly this analysis .

4-2.Tensile properties

Table(3) and fig(8) show that with constant fiber glass layer in the lamination the mechanical properties($s_y, s_{ult}, E, Stifness$)are increasing slowly with the increasing of perlon layers especially for the high number of perlon layers .This is due to increasing the absorbing ability which leads to increasing the lamination thickness of samples .This addition of thickness consist of fiber and matrix materials ,but the greater part of this addition thickness coming from matrix material which is certainly weaker than fiber material [14].For that reason the higher strength coming from increasing fiber material facing with weakness coming from matrix material . Also it can be noticed that lamination which consists of three layers of perlon plus two layers of fiber glass plus three layers of perlon binding by acrylic resin matrix having optimum mechanical properties .By comparing this lamination with the lamination used in Baghdad center for prosthetic and orthetic which consist five layers of perlon plus two layers of fiber glass plus five layers of perlon binding by acrylic resin matrix ,the yield stress increased with 14.75%while ultimate strength keeping its value for both laminations while young's modulus is decreased by about 10% .This is certainly related to the homogenously distributed of fiber for both perlon and fiber glass resulting optimum absorbing ability to acrylic matrix which gives strong binding to sandwich lay up lamination which leads to high mechanical properties . In addition to that this lamination achieved economy goal by reducing the costing of the socket lamination to optimum value with keeping the mechanical properties with acceptable values .

Fig(9) shows with absences the fiber glass layers ,the mechanical properties set ($s_y, s_{ult}, E, Stifness$) are improved with increasing the perlon layers in the lamination lay up. By compared the lamination of twelve perlon layers with lamination of six perlon layers, the (yield ,ultimate strength and young's modulus) increased with(6.6%,25.4%and 121% respectively .This is certainly due to increasing the binding forces with the increasing the fibers layers .Also figures (10and11) shows that for the fixing perlon layers ,the mechanical properties set ($s_y, s_{ult}, E, Stifness$) are improved with increasing the fiber glass layers. By comparing the lamination of two fiber glass layers with the lamination of zero fiber glass layes with six perlon layers for both laminations , the (yield ,ultimate strength and young's modulus) increased with(40%,30.4%,110.5%)respectively. The reason for this was the binding forces increasing with increasing fiber glass layers .

Finally table (5) shows that lamination numbers (2,5and13)having better mechanical properties set ($s_y, s_{ult}, E, Stifness$) compared with lamination numbers(3,6and14) ,in spite of both lamination (2and3),(5and6)and (13and14)having the same number of fiber layers (same number of perlon layers and fiberglass layers).By comparing the properties of the lamination (2 with 3), the (yield ,ultimate strength and young's modulus) are increased by(21%, 40%and 46.6%)respectively while comparing the properties of the lamination (5 with 6)and (13 with 14) shows that the above properties increased by(59%, 66.4%and150%)and(23.4%,12.4%and55.8%). The reason for this difference is related to the method of sandwich lay up for the first group. The layers of perlon are distributed equally (homogeneously) on each side of the central fiber glass layers. This means that the resulting binding forces is stronger compared with second group which lies up unequally (non homogenously) on each side of central fiber glass layers.

4-3.Flexural testing

Table(6)and fig(12)shows that flexural set of mechanical properties (s_{flex}, E_{flex} and flexural stiffness)are increasing slowly with the increasing layers of perlon for constant two layers of fiber glass of the lamination lay up especially for the high number of perlon layers .The reason for this behavior is related to the addition thickness resulting form the increasing in fiber material and acrylic resin matrix material surely the great part of addition thickness comes from acrylic resin matrix material ,so the more strength comes from fiber material facing with weakness of acrylic resin materials. This explains the above behavior. Fig (13)shows that the mechanical properties set (s_{flex}, E_{flex} and flexural stiffness)are improved with the increasing of perlon layers with absence the fiberglass layers in the lamination. By comparing the lamination of twelve perlon layers with lamination of six perlon layers, the s_{flex}, E_{flex} increased with (25.5%and 14.6%)respectively .Also figures (14,15)show that mechanical properties set(s_{flex}, E_{flex} and flexural stiffness) are increased with the increasing of fiber glass layers for constant layers of perlon. By comparing the lamination of two fiber glass layers with the lamination of zero fiber glass layers with six perlon layers for both laminations, s_{flex}, E_{flex} increased with (36.4%and 20.4%)respectively .The reason of this behavior is related to the bonding forced which are increased with the increasing of fiber layers in the lamination lay up.

Results in table (6) show that the lamination which consist of three layers of perlon plus two layers of fiber glass plus three layers of perlon binding by acrylic resin matrix may be considered the optimum lamination lay up. Comparing this lamination with the lamination used in Baghdad center for prosthetic and orthetic which consists five layers of perlon plus two layers of fiber glass plus five layers of perlon binding by acrylic resin matrix shows that inspite of big reduction in number of perlon layers ,the s_{flex}, E_{flex} are decreased by only (1.3%and 7%)respectively. This is certainly is related to the homogenously distributed of fiber for both perlon and fiber glass resulting optimum absorbing ability to acrylic matrix which gives strong binding to sandwich lay up lamination which leads to high mechanical properties. It is recommend to use this type of lamination for the layup the above knee socket because it achieved the requirement of good socket design for acceptable mechanical properties set (s_{flex}, E_{flex} and flexural stiffness) and its minimizing the cost of socket lamination to suitable cost value. Finally table (6) shows that the mechanical properties set(s_{flex}, E_{flex} and flexural stiffness) of the lamination (2,5,13) were better than the lamination (3,6,14) .It can be seen that the (s_{flex}, E_{flex}) are increased with (39.8%,44.8%), (60.2%,38.9%)and(5.2%,27.5%)when compared laminations (2 with 3),(5with 6)and (13 with 14) respectively. The reason for this difference is related to the method of sandwich lay up for the first group the layers of perlon are distributed equally (homogeneously) on each side of the central fiber glass layers. This means that the resulting binding forces will be stronger compared with second group of unequally (non homogenously) on each side of central fiber glass layers.

5.Conclusion

This study give a very good database for the manufacturers which can help them in choosing the suitable lamination lay up especially for the above knee socket lamination .These are as follows.

1- For constant perlon layers the mechanical properties are improved clearly with the increasing of fiber glass layers. Using two layers of fiber glass instead of zero layer with six layers of perlon lead to the increased in($s_y, s_{ult}, E, s_{flex}, E_{flex}$)with (40%,30.4%,110.5% 36.4%and 20.4%) respectively.

2-The lamination which consists of three layers of perlon plus two layers of fiber glass plus three layers of perlon may be considered the optimum lamination lay up .Comparing this lamination with the standard lamination used in Baghdad center it can be seen that in spite of the big reduction in perlon layers form ten to six layers the yield stress is increased by 14.75% while ultimate strength remain at the same value and bending stress decreased with 1.3% only. It is recommend to use this type of lamination for the layup the above knee socket because it meets the requirement of good socket design for acceptable mechanical properties and its minimizing the cost of socket lamination to suitable costing value.

3-The lamination group(2,5,13) of sandwich lay up during which the layers of perlon are distributed equally (homogeneously) on each side of the central fiber glass layers give mechanical properties better than the others group of unequally distributed lamination (3,6,14). .It can be seen that the ($s_y, s_{ult}, E, s_{flex}, E_{flex}$) are increased with (21%,40%,46.6%,39.8%,44.8%), (59%,66.4%,150%,60.2%,38.9%)and (23.4%,12.4%,55.8%,5.2%,27.5%)when compared laminations (2 with 3),(5with 6)and (13 with 14) respectively.

References

[1]-C.w radcliffe "above –knee prosthetic" the Knud Jansen lecture ,new-yourk,1977.

[2]-J. foort "Innovation in prosthetic and orthotic" the Knud Jansen lecture,copenhsgen,1986.

[3]-J.A. Cambell "material selection in an above knee prosthetic leg " apart of course requirement for ENGN4601 Engineering materials, Australian national university, Canberra ,2002 .

[4]-J.A.E. Gleave "A plastic socket and stump casting technique for above knee prosthetics" the journal of bone

and joint surgery ,Hong Kong ,vol47B,No.1,February ,1965.
[5]-R. Stewart "socket stress distribution " Monash rehabilitation technology research ,Monash Australian international university ,1998 .
[6]-C.P. Saml Phillips, William Craelius "material properties of selected prosthetic lamination "journal of prosthetic and orthotic ,JPO,vol17,No.1,2005.
[7]-R.A. Flinn.,Trojan PK"Engineering materials and their application "4 thed Bostan ,Houghton Mifflin, 1990.
[8]-K. Smith"laminated socket properties " Monash rehabilitation technology research ,Monash Australian international university ,1998 .
[9]-K.K.Resan "analysis and design optimization of prosthetic BK"Ph.D. thesis ,university of technology ,Baghdad,2007.
[10]-Z. Gurdal,Rapharel T. Haftka and Praht Hajela"Desgin and optimization laminated composite materials "john Wiley &sons,INC.1999.
[11]-Ottobock quality for life " orthotic- prosthetic materials catalog",2007
[12]-American society for testing and materials information ,Handing series "standard test method for Tensile properties ",2000.
[13]-American society for testing and materials information ,Handing series "standard test method for flexural properties ",2000.
[14]- J.N.Reddy "mechanics of laminted composite plates and shells "third edition ,Crc press.

Table (1) Materials properties typically used in orthotics and prosthetic fabrication[6]and[7]

Materials	Ultimate strength(Mpa)	Stiffness E(Gpa)	Strain to failure%
Carbon fiber	2070-2750	10-380	1.6-2
Fiber glass	1700	68	5-5.5
Nylon	55-83	1.2-2.4	>5
Polyethylene	7-41	0.13-1.3	>5
Poly propylene	28-41	1.3	>5

Table (2) The lamination manufactured with different lay up method

No. of Lamination.	Lay up symbol	Total No. of layers	Lamination lay up procedures
Lamination 1	626	14	(6Perlon +2fiber glass +6perlon)layers
Lamination 2	525	12	(5Perlon +2fiber glass +5perlon)layers
Lamination 3	624	12	(6Perlon +2fiber glass +4perlon)layers
Lamination 4	424	10	(4Perlon +2fiber glass +4perlon)layers
Lamination 5	323	8	(3Perlon +2fiber glass +3perlon)layers
Lamination 6	422	8	(4Perlon +2fiber glass +2perlon)layers
Lamination 7	222	6	(2Perlon +2fiber glass +2perlon)layers
Lamination 8	606	12	(6Perlon + zero fiber glass +6perlon)layers
Lamination 9	505	10	(5Perlon +zero fiber glass +5perlon)layers
Lamination 10	404	8	(4Perlon + zero fiber glass +4perlon)layers
Lamination 11	303	6	(3Perlon + zero fiber glass +3perlon)layers
Lamination 12	414	9	(4Perlon +1fiber glass +4perlon)layers
Lamination 13	313	7	(3Perlon +1fiber glass +3perlon)layers
Lamination 14	412	7	(4Perlon +1fiber glass +2perlon)layers

Table (3) physical properties for each lamination samples

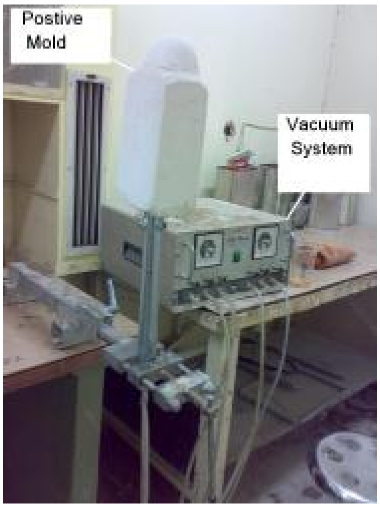
No. of Lam.	Lay up	Thickness mm	W_c g	r_c g/cm^3	v_f
Lamination 1	626	5	9.78	1.2	0.292
Lamination 2	525	4.6	8.82	1.18	0.294
Lamination 3	624	4.4	8.85	1.23	0.262
Lamination 4	424	3.4	6.8	1.23	0.32
Lamination 5	323	3.2	6.12	1.176	0.33
Lamination 6	422	3.2	6.4	1.23	0.274
Lamination 7	222	2.5	4.8	1.18	0.35
Lamination 8	606	4.7	9.45	1.23	0.13
Lamination 9	505	4.2	8.1	1.186	0.167
Lamination 10	404	3.3	6.3	1.17	0.175
Lamination 11	303	2.7	4.98	1.135	0.19
Lamination 12	414	3.3	6.5	1.21	0.2
Lamination 13	313	2.8	5.4	1.186	0.25
Lamination 14	412	2.7	5.1	1.16	0.12

Table(4) Mechanical properties calculated from tensile load -extension curves

No. of Lam.	Lay up	σ_Y Mpa	σ_{Ult} Mpa	E Gpa	Stiffness N/mm	Percent of Elongation %
Lamination 1	626	18.3	28	2.37	3081	72
Lamination 2	525	18	26	2.2	2631	40
Lamination 3	624	14.86	18.56	1.5	1716	40
Lamination 4	424	19.5	26.2	2.1	1856.4	15
Lamination 5	323	21	26	2	1664	13
Lamination 6	422	13.2	15.62	0.8	665.6	30
Lamination 7	222	18.5	22	1.9	1235	10
Lamination 8	606	16	25	2.1	2566.2	78
Lamination 9	505	15.6	23	1.5	1638	75
Lamination 10	404	15.1	20.97	1.2	1029.6	16
Lamination 11	303	15	19.94	0.95	666.9	14
Lamination 12	414	16.3	22.14	1.4	1201.2	16
Lamination 13	313	16	20.8	1.2	873.6	12
Lamination 14	412	12.96	18.5	0.77	540.5	25

Table (5) Mechanical properties calculated from flexural testing

No. of Lam.	Lay up	$\sigma_{b\max}$ Mpa	$E_{flexural}$ Gpa
Lamination 1	**626**	**52.28**	**3.5**
Lamination 2	**525**	**49.31**	**3.1**
Lamination 3	**624**	**35.25**	**2.14**
Lamination 4	**424**	**48.7**	**2.85**
Lamination 5	**323**	**48.65**	**2.89**
Lamination 6	**422**	**30.36**	**2.08**
Lamination 7	**222**	**37.52**	**2.26**
Lamination 8	**606**	**44.75**	**2.75**
Lamination 9	**505**	**42.62**	**2.6**
Lamination 10	**404**	**35.86**	**2.5**
Lamination 11	**303**	**35.66**	**2.4**
Lamination 12	**414**	**38.2**	**2.63**
Lamination 13	**313**	**36**	**2.5**
Lamination 14	**412**	**34.2**	**1.96**



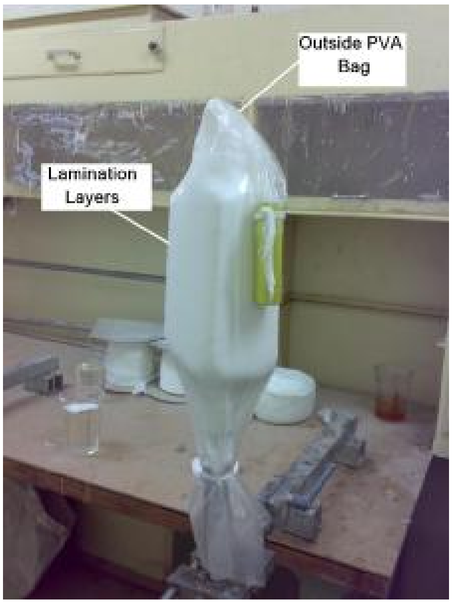
a)Materials used for above knee socket lamination **b)Positive mold with vacuum system**

c)Mechanical workshop for forming and manufacturing samples

Fig(1) Material and equipment used in above knee socket lamination

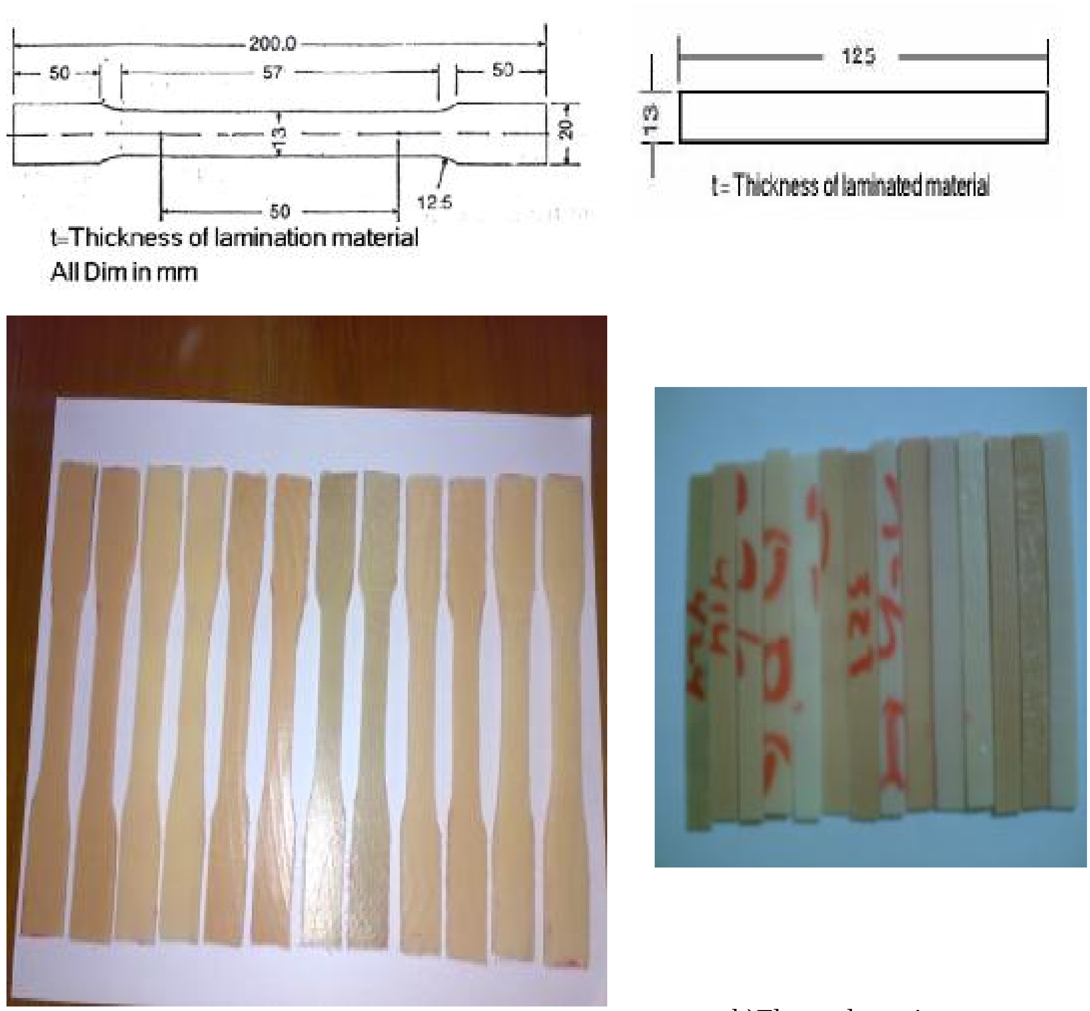
a)Universal testing instrument **b)Sensitive weighting device**

Fig(2) Universal testing machine with sensitive weighting device



a) Positive mold ready for lamination **b)Two lamination layup one of them was cold and other were under constant vacuum pressure**

Fig(3) Positive mold before and after lamination lay-up



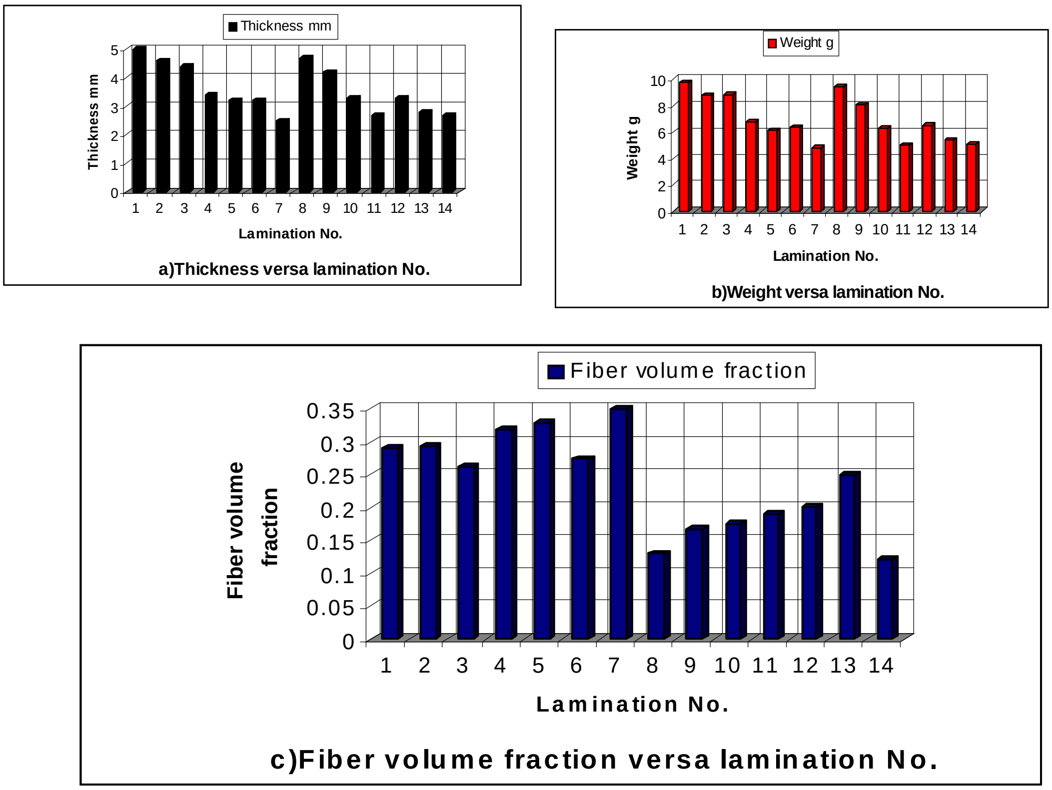
a)Tensile specimens

b)Flexural specimens

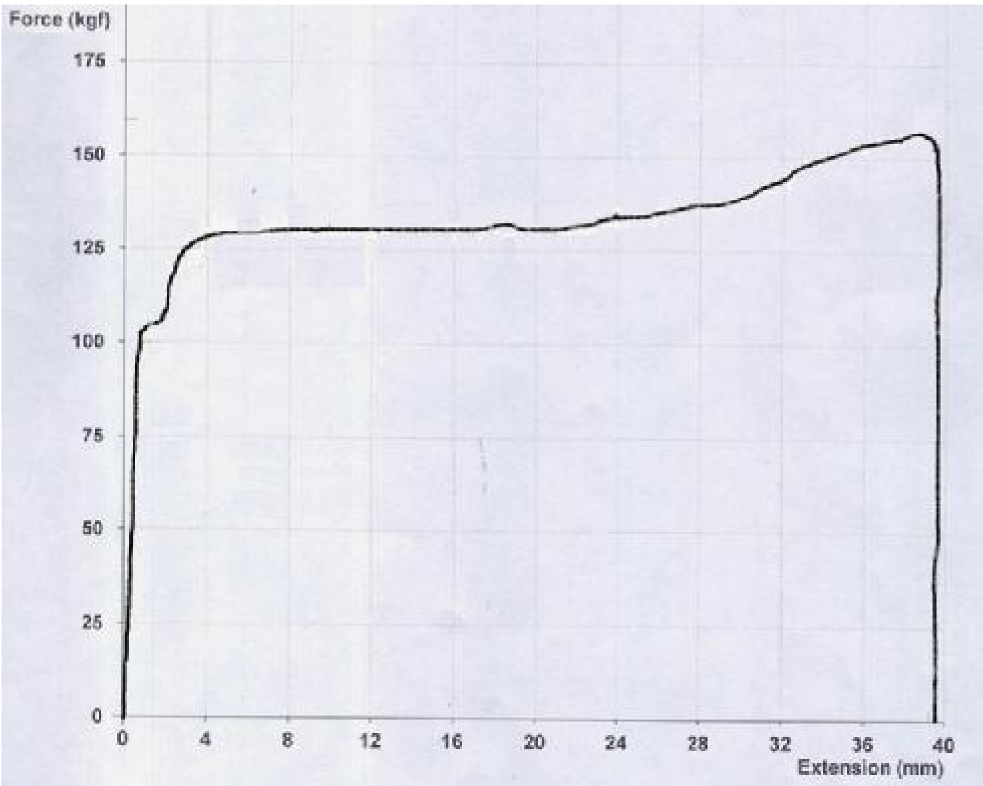
Fig(4) The general shape of tensile and flexural specimens

a)Specimen under tensile test b)Specimen under flexural test

Fig(5) Specimen under tensile and flexural test



Fig(6) Thickness ,weight and fiber volume fraction versa lamination No


Force (kgf)
175
150
125
100
75
50
25
0
0
4
8
12
16
20
24
28
32
36
40
Extension (mm)

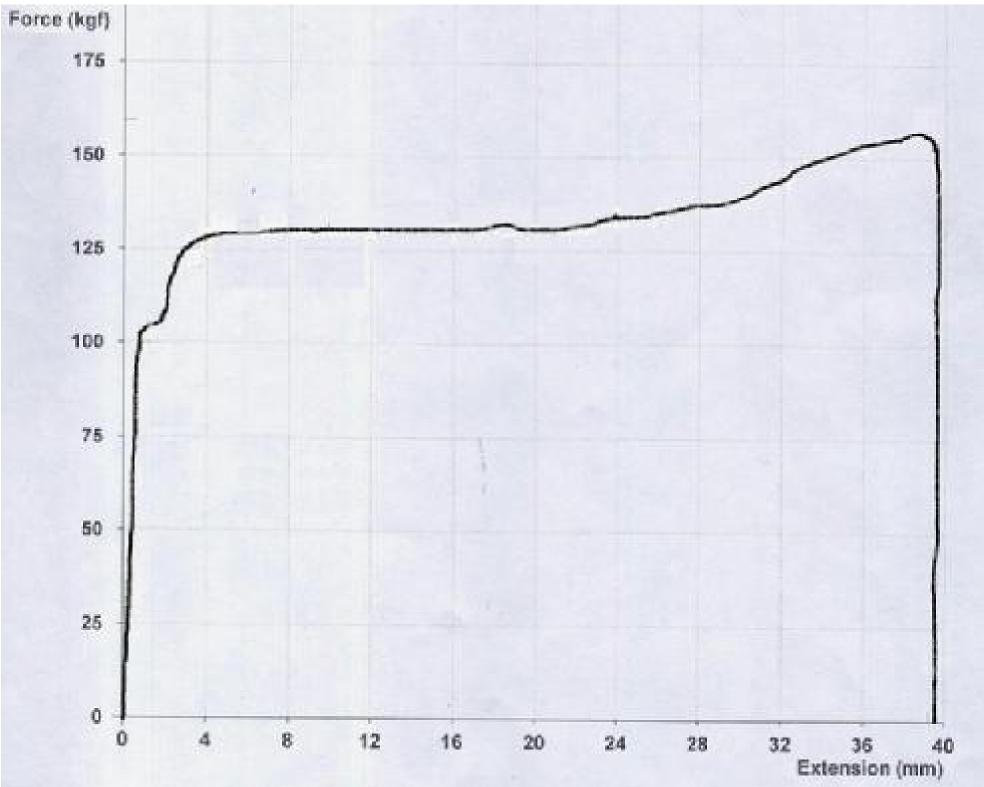
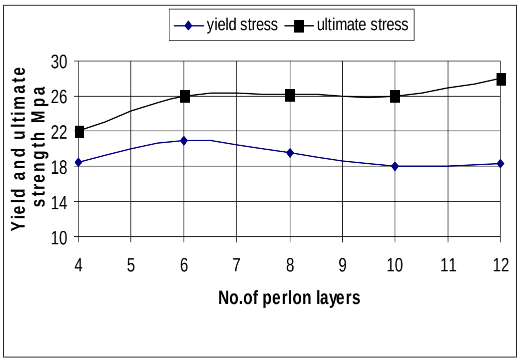
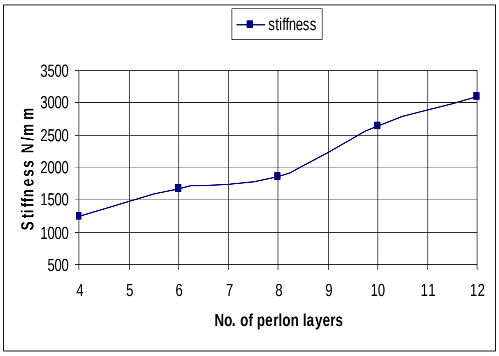


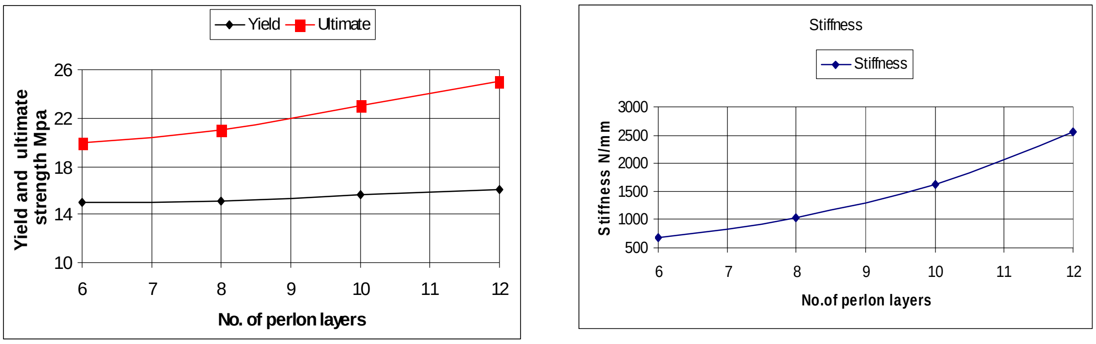
Fig (7) Load –extension curve for one sample of lamination 8





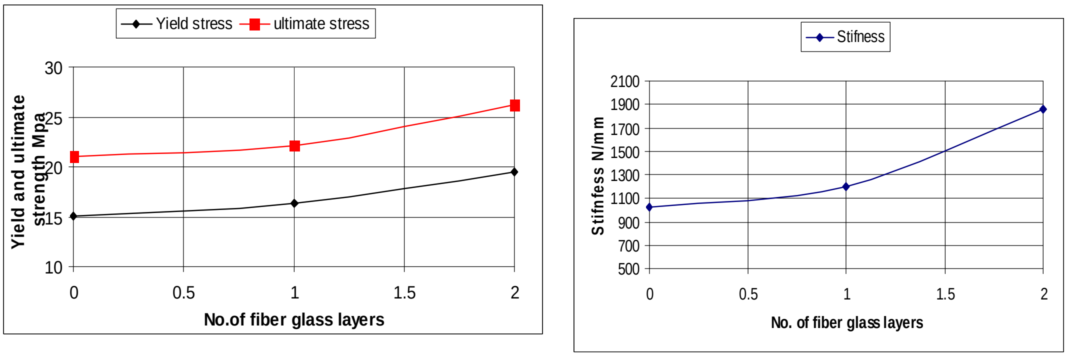
a)Yield and ultimate strength **b) Stiffness**

Fig (8) Yield ,ultimate strength and stiffness against No. of perlon layer during constant No. of fiber glass



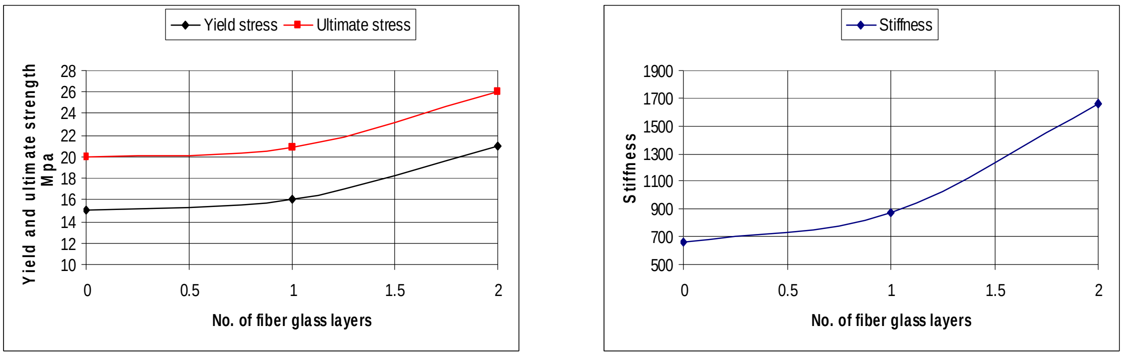
a)Yield and ultimate strength b) Stiffnes

Fig (9) Yield ,ultimate strength and stiffness against No. of perlon layer any layers of fiber glass



a)Yield and ultimate strength b) Stiffness

Fig(10) Yield ,ultimate strength and stiffness against No. of fiber glass layer with eight layers of perlon



a)Yield and ultimate strength b) Stiffness

Fig(11) Yield ,ultimate strength and stiffness against No. of fiber glass layer with six s of perlon