Experimental Study for Materials Prosthetic above Knee Socket under Tensile or Fatigue Stress with Varying Temperatures Effect

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ABSTRACT

The residual limb within the prosthesis, is often subjected to tensile or fatigue stress with varying temperatures. The fatigue stress and temperatures difference which faced by amputee during his daily activities will produces an environmental media for growth of fungi and bacteria in addition to the damage that occurs in the prosthesis which minimizingthe life of the prosthetic limb and causing disconfirm feeling for the amputee.

In this paper, a mechanical and thermal properties of composite materials prosthetic socket made of different lamination for perlon/fiber glass/perlon, are calculated by using tesile test device under varying temperatures (from 20°C to 60°C), also in this paper a device for measuring rotational bending fatigue stress under varying temperatures was designed, manufactured, and calibrated (this device is not available in Iraq), to achieve S – N curves for different lamination of perlon/fiber glass/perlon composite materials of prosthetic above knee socket.

In this paper, the mechanical and thermal properties set (E, σ_y, σ_{ult}, K, and α) results of the above composite materials are decreased when the temperatures are increased.

The S–N curves results of rotational bending fatigue for these lamination of composite materials are decreased when the temperatures are increased,also the endurance limit stresses (σ_e) are decreased with the increasing of number of perlon, and increasing temperatures, generaly after about 10^7 cycles.

Key words: socket materials, tinsile test, fatigue stress, mechanical and thermal properties.

دراسة عملية لمواد وقب طرف سفلي صناعي أعلى الركبة تحت تأثير أجهاد الشد أو الكلال عند مختلف درجات الحرارة

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الخلاصة

يتعرض متبقي العضو المبتور الى اجهاد شد أو كلال متكرر مع اختلاف في درجات الحرارة بشكل دائم. ان تعرض الطرف المبتور الى اجهاد كلال متكرر ودرجات الحرارة المختلفة يسبب في كثير من الأحيان بيئة لنمو الفطريات والبكتريا ناهيك عن الضرر الذي يتعرض له متبقي الطرف المبتور بالأضافة الى الضرر الذي يحدث في الطرف الصناعي مما يسبب عدم راحة ذوي الأحتياجات الخاصة بالأضافة الى قصرعمر الطرف الصناعي.

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في هذا البحث تم أستخراج الخواص الميكانيكية والحرارية للمواد المركبة الداخلة في تصنيع وقب طرف سفلي صناعي أعلى الركبة مصنع من البرلون/ألياف الزجاج/البرلون ذو طبقات مختلفة وذلك بأستخدام جهاز أختبار شد معرض الى درجات حرارة مختلفة (من ٢٠ الى ٦٠ درجة مئوية). كذلك تم في هذا البحث تصميم وتصنيع ومعايرة جهاز أختبار كلال أنحناء دوراني حراري (الجهاز غير متوفر في العراق) وذلك لغرض استخراج منحنيات الأجهاد – عدد الدورات للوصول الى الفشل لطبقات مختلفة من المواد المركبة برلون / ألياف الزجاج / برلون المصنوع منها وقب الطرف الصناعي. أن نتائج الخواص الميكانيكية والحرارية التي أستخرجت في هذا البحث مثل (معامل المرونة وأجهاد الخضوع وأجهاد الشد الأعظم والمتانة ومعامل التمدد الحراري) للمواد المركبة التي ذكرت أعلاه تقل مع أرتفاع درجات الحرارة. كذلك وجد بأن نتائج منحنيات الأجهاد – عددالدورات للوصول الى الفشل من خلال أختبار أجهاد كلال الأنحناء الدوراني لصفائح المواد المركبة المذكورة تقل مع أرتفاع درجات الحرارة. كذلك وجد أن اجهادات حد التحميل تقل مع زيادة عدد طبقات البرلون وأرتفاع درجات الحرارة بعد حوالي عشرة ملايين دورة.

الكلمات الرئيسية: مواد الوقب، إختبار الشد، إجهاد الكلال، الخواص الميكانيكية والحرارية.

1. INTRODUCTION

A limb prosthesis can be prescribed an attempt to replace the lost functionality of an absent limb as a result of amputation or a birth defect. The lower limb prosthesis is generally used to aid much basic functions such as standing and walking **(Lafortune**, and **Henning, 1992)**.

In general, prosthesis for individuals with above knee amputation are comprised of four major components specifically: a socket interface to the residual limb, a knee joint, a shank, and foot assembly as illustrated in **Fig.1**, **(Lafortune,** and **Henning, 1992)**.

The study of tensile or fatigue failure under varying temperatures is very complex. The fatigue performance of a materials is determined by testing a number of similar test specimens at different levels of maximum stress and with either a complete reversal of stress of a lower stress of zero.

A more recent study evaluating the fatigue testing of energy storing prosthetic feet by **(Toh et al., 1993).**

Van et al. 1995, understood the mechanical properties of the prosthetic foot on different aspects of gait and briefly attempted to explain how a difference in stiffness and hysteresis of the prosthetic foot would alter the gait cycle.

Zhichao, 2007,carried out high temperature stress controlled tests for interaction behavior. Four fatigue – creep fracture character maps have been established. It was found that the fracture life will decrease rapidly and the fracture ductility will reach its minimum.

The manufacturing of above knee prosthesis by using different weighted materials such as perlon, nylon, carbon fiber, and fiber glass which was used in design and manufacturing the above knee prosthetic socket by a lamination consisting of a mixture of some of these materials embedded with an acrylic resin **(Dianyin,** and **Rongqia, 2009)** and **(Pierce, 2010).**

2.EXPERIMENTAL WORKS

The work steps of this work will be summarized as:

a) Materials part which describing the method of manufacturing socket made of perlon/fiber glass/perlon from different four laminations lay- up (3-2-3, 4-2-4, 5-2-5, and 6-2-6) respectivily.

b) Preparing dies to make about (20) different standard flat specimens from different four laminations of composide said in para.(a), for testing by static digital tensile device under varying temperatures (from 20^oC to 60^oC),to calculate a mechanical and thermal properties of these materials specimens.

c) Design and manufacturing a rotational bending fatigue stress under varying temperatures device for measuring (S – N) curves.

d) Making about (250) different standard hollow circular specimens from different four laminations of composite said in para. (a), for testing by a device validity of para. (c), to achieve S-N curves under varying temperatures (from 20^{o}C to 60^{o}C).

2.1Materials

In this work, the materials needed in the lamination of the above knee socket are as follows and shown in **Fig.2**.

a) Perlon stockinet white (Ottobock health care 623 T3).

b) Fiber glass stockinet (Ottobock health care 616 G3).

c) Lamination resin (80:20) polyurethane proterhand icap technology).

d) Hardening powder (Ottobock health care 99 B71).

e) Materials for Jepson mold.

2.2 Procedure of Laminations

All laminations were performed under vacuum with the following procedures:

a) Mount the positive mold at the laminating stand.

b)Put the perlon stockinet and fiber glass stockinet according to the laminating lay up given in **Table 1**.

c)Mix the lamination resin 80:20 polyurethane with the hardener.

d)Maintain constant vacuum until the composite materials becomes cold and then lift the resulting lamination as shown in **Fig. 3**.

2.3Tensile Test under Varying Temperatures

The tensile specimens were machined at the(Baghdad Center for Prosthetic and Orthotic Workshop). Twenty samples for each lamination were machined according to ASTM D638 **(Zhichao, 2007)**, with 80mm original length and 13mm the width, while thickness varied with the type of the lay-up, these samples as shown in **Fig. 4.**

All the specimens were tested by using the universal testing instrument for tensile under varying temperatures (from 20^{o}C to 60^{o}C), to find mechanical and thermal properties of different composite laminations said in **Table 1**. These specimens are tested in the Materials Laboratories of the Ministry of the Science and Technology. **Fig.5** shown specimen under tensile test with and without temperatures, and **Tables 2, and 3** give the mechanical and thermal results.

2.4Design and Calibration of Rotational Bending Fatigue Device

The main parts of the rotational bending fatigue under varying temperatures as shown in **Fig. 6** are:

a) Electric speed change motor.

b) Digital speed controller.

c) Rotational shaft with bearings.

d) Drill chuck.

e) Electronic stress meter.

f) Thermal chamber.

g) Thermometer control gauge.

h) Tachometer.

i) Change level frame.

j) Proximity sensor.

This device has been calibrated by the Central Organization for Standared Dization and Quality Control at room temperature (20^oC), with error rate about (7%).

2.5Rotational Bending Fatigue Test under Varying Temperatures

The rotational bending fatigue specimens were machined at the (Baghdad Center for Prosthetic and Orthotic Workshop) according to ASTM D1043-02.Two hundred fifty samples for each lamination were machined according to the ASTM D638, with 100mm original length while diameter varied with the type of the lay up, these samples as shown in **Fig.7.**

All the specimens were tested by using a rotational bending fatigue under varying temperatures (from 20^oC to 60^oC) device as design, manufacturing, and calibrating in this study (this device is not available in Iraq) as shown in **Fig. 6**. These specimens are tested at the Strength of Materials Laboratory of Baghdad University/College of Engineering /Mechanical Department, and the S – N curves results for different laminations with varying temperatures as shown in **Figs. from 8 to 12**

3.RESULTS ANALYSIS AND DISCUSSION

The mechanical and thermal properties results of each sample as shown in **Tables 2, and 3** can be calculated and by taking the average value of these properties (E, σ_y, σ_{ult}, K, and α) under varying temperatures (from 20^oC to 60^oC), these properties results for all laminations, with constant fiber glass layer in the lamination, the mechanical properties (E, and K) are increasing with the increasing perlon layers at constant temperature, especially for high number of perlon layers, also the mechanical and thermal properties (σ_y, σ_{ult}, and α) are decreasing with the increasing perlon layers, especially for high number of perlon layers at constant temperature. While in general for all laminations, the mechanical and thermal properties are said above are decreasing with the increasing temperatures.

The S – N curves results of each sample as shown in **Figs. from 8 to 12** can be calculated and by taking the average value of the failure stress with number of cycles under varying temperatures (from 20^oC to 60^oC), these S – N results for all laminations, with constant fiber glass layer in the lamination, the failure stress results are decreasing with the increasing perlon layers, while the number of cycles to reach the failure points are increasing with the increasing perlon layers at constant temperature. Also, from the S – N curves results as shown in **Figs. from 8 to 12**, for all laminations, the failure stresses are decreasing and the number of cycles to reached to the failure points are increasing with the increasing temperatures.Also, **Table 4** shows the results of endurance stress limit for laminations under varying temperatures, from these results the endurance limit stresses (σ_e) are decreased with the increasing of number of perlon, and increasing temperatures.

4.CONCLUSIONS

In this paper, the following mean summarized conclusions:

1)When the temperatures are increased, the mechanical and thermal properties are improved with the decreasing of number of perlon with two fixing layers of fiber glass.

2)When the number of perlon layers are increased, the mechanical properties (E, and K) are clearly improved with two fixing layers of fiber glass, at constant and changed in temperatures.

3)The mechanical and thermal properties (σ_y, σ_{ult}, and α) are decreased when the temperatures are increased for all laminations.

4)The failure stresses are decreased and the number of cycles to reach the failure points are increased when the temperatures are increased for all laminations.

5)The endurance limit stresses (σ_e) are decreased with the increasing of number of perlon, and increasing temperatures.

6)The maximum error difference in results at room temperature (20^{o}C) between a rotational bending fatigue is designed in this paper with the same standard device are about 7%.

7)A good conformability between the mechanical properties results of this work with these of the Reference [9] results at room temperature (20^{o}C), with maximum differences about 5%.

8)A good agreement between the S-N curves results at room temperature (20^{o}C) of a device in this work with that in the Central Organization for Standared Dization and Quality Control, with error rate about (7%).

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Figure1.The prosthesis components (**Lafortune,** and **Henning).**

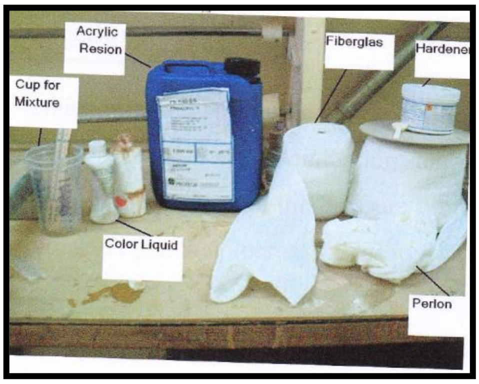

Figure2. Materials for above knee socket.

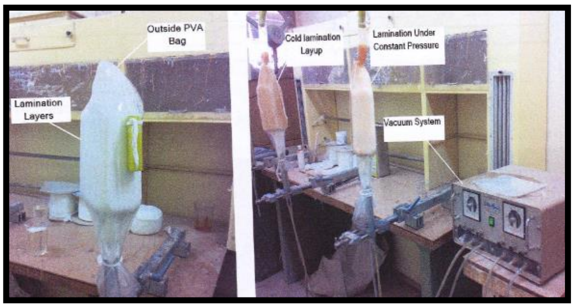

Figure3. Positive mold before and after lamination lay-up.

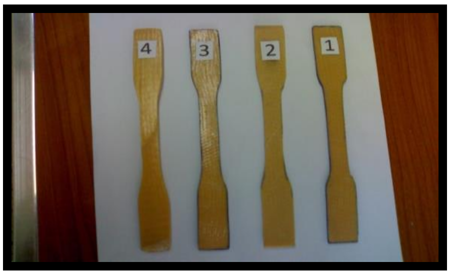

Figure4. Tensile test specimens.

a) without temp. **b)** with temp.

Figure5.Tensile test device without and with temperatures.

motor. shaft with bearings. frame.

thermal chamber, and themal control gauge.

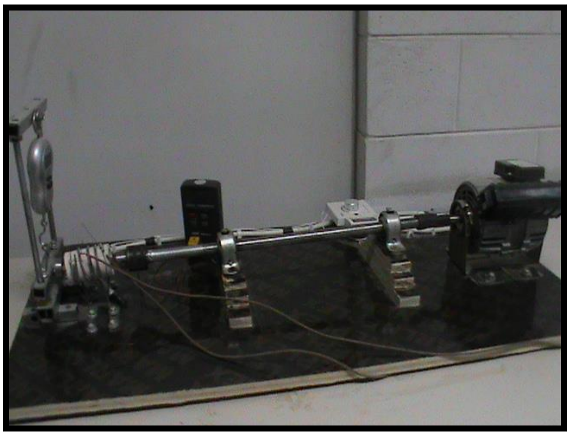

Figure6. Parts and device of rotational bending fatigue under varying temperatures.

Figure7. Rotational fatigue test specimens.

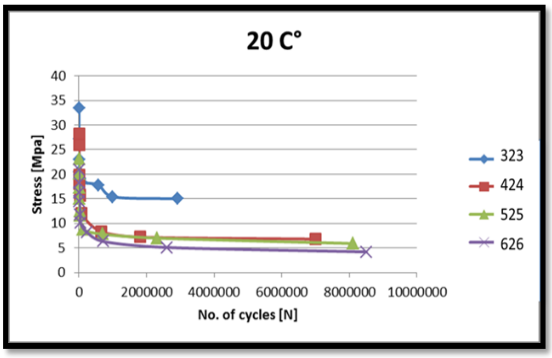

Figure8. S-N curves for laminations at 20^{o}C.

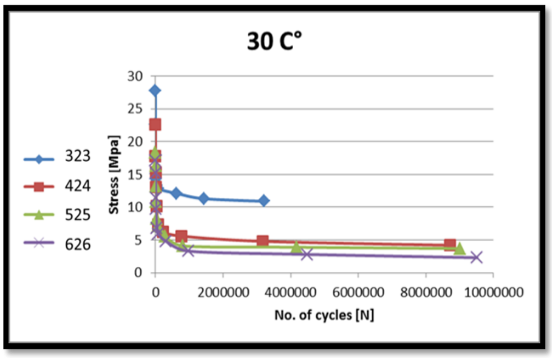

Figure9. S-N curves for laminations at 30^{o}C.

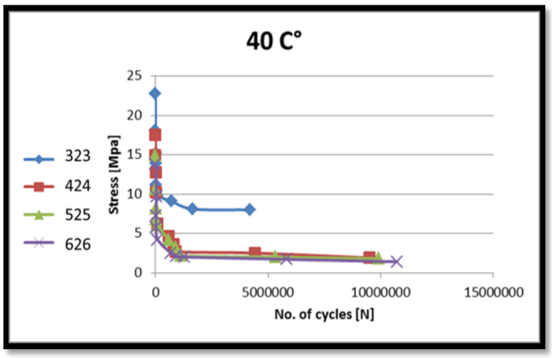

Figure10. S-N curves for laminations at 40^{o}C.

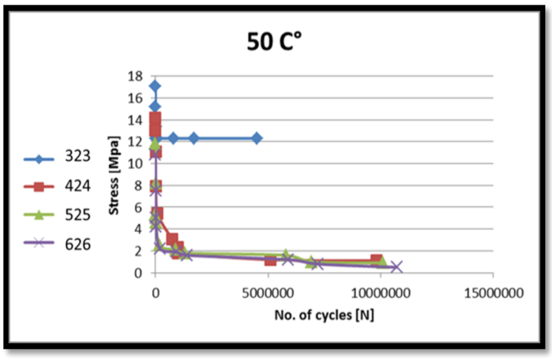

Figure11.S-N curves for laminations at 50^{o}C.

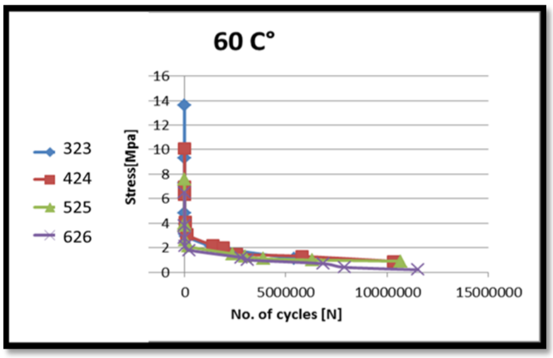

Figure12. S-N curves for laminations at 60^{o}C.

Table 1. Laminations lay-up.

No. of lamination	Lay up	No. of layers	Thickness (mm)	Description layers
1	3-2-3	8	2.41	(3Perlon+2fiber glass+3perlon)
2	4-2-4	10	2.92	(4Perlon+2fiber glass+4perlon)
3	5-2-5	12	2.96	(5Perlon+2fiber glass+5perlon)
4	6-2-6	14	3.37	(6Perlon+2fiber glass+6perlon)

Table 2. Mechanical properties results for all laminations.

T (C^o)	No. of lamination	Lay-up	σyield (Mpa)	σultimate (Mpa)	Modulus of elasticity E(Mpa)	Stiffness K(N/mm)	Poisson's ratio(υ)
20	1	3-2-3	58.2	73.1	0.857	1317.3	0.390
	2	4-2-4	41.2	50.3	0.924	1602.8	0.371
	3	5-2-5	37.4	45.5	0.979	1841.7	0.362
	4	6-2-6	33.9	44.8	1.027	2121.3	0.353
30	1	3-2-3	57.2	72.2	0.843	1309.2	0.383
	2	4-2-4	40.1	48.3	0.911	1600.2	0.368
	3	5-2-5	36.9	44.1	0.965	1840.3	0.356
	4	6-2-6	32.2	42.7	1.011	2119.1	0.348
40	1	3-2-3	56.6	71.6	0.821	1301.3	0.381
	2	4-2-4	39.4	46.5	0.903	1593.7	0.367
	3	5-2-5	35.8	42.5	0.933	1821.5	0.354
	4	6-2-6	31.4	41.4	1.007	2101.8	0.347
50	1	3-2-3	54.2	69.3	0.803	1295.8	0.380
	2	4-2-4	36.5	44.2	0.888	1585.0	0.366
	3	5-2-5	31.9	41.1	0.912	1812.7	0.353
	4	6-2-6	29.8	40.2	0.882	2088.1	0.345
60	1	3-2-3	51. 8	65.4	0.794	1278.3	0.374
	2	4-2-4	34.2	42,8	0.834	1501.4	0.364
	3	5-2-5	30.4	40.2	0.905	1773.0	0.352
	4	6-2-6	27.5	38.4	0.977	1997.2	0.343

Table3. Coefficients of thermal expansions results (α) for laminations with different temperatures (ΔT).

No. of laminations	α (1/ C°) *10^{-8}	ΔT (C°)
3-2-3	3.24	from 20 to 30
4-2-4	2.81	
5-2-5	2.66	
6-2-6	2.45	
3-2-3	3.11	from 20 to 40
4-2-4	2.78	
5-2-5	2.63	
6-2-6	2.43	
3-2-3	3.08	from 20 to 50
4-2-4	2.76	
5-2-5	2.62	
6-2-6	2.39	
3-2-3	3.02	from 20 to 60
4-2-4	2.74	
5-2-5	2.60	
6-2-6	2.37	

Table4. Endurance stress limit results (σ_e) with varying temperatures (T).

No. of laminations	Endurance stress limit σ_e (Mpa)	Temperatures (C°)
3-2-3	15.0	20
4-2-4	7.20	
5-2-5	6.20	
6-2-6	4.10	
3-2-3	12.6	30
4-2-4	4.30	
5-2-5	3.20	
6-2-6	2.50	
3-2-3	7.80	40
4-2-4	2.90	
5-2-5	2.10	
6-2-6	1.80	
3-2-3	2.0	50
4-2-4	1.60	
5-2-5	1.20	
6-2-6	0.60	
3-2-3	1.60	60
4-2-4	1.40	
5-2-5	0.80	
6-2-6	0.40	