Study the Impact Behavior of the Prosthetic Lower Limb Lamination Materials Due to Low Velocity Impactor

Dr. Jumaa Salman Chiad
Assistant Professor
Engineering College -Al-Mustansiriya University
E-mail: jumaachiad@yahoo.com

ABSTRACT

This work involves three parts , first part is manufacturing different types of laminated below knee prosthetic socket materials with different classical laminated materials used in Baghdad center for prosthetic and orthotic (4perlon layers+2carbon fiber layer+4 perlon layers) , two suggested laminated materials(3perlon layers+2carbon fiber layer+3 perlon layers) and (3perlon layers+1carbon fiber layer+3 perlon layers)) in order to choose perfect laminated socket . The second part tests (Impact test) the laminated materials specimens used in socket manufacturing in order to get the impact properties for each socket materials groups using an experimental rig designed especially for this purpose. The interface pressure between the residual leg and prosthetic socket is also measured to cover all the surface area of the B-K prosthetic socket by using piezoelectric sensor in order to estimate the resulting stress according to loading conditions . A male with age, length, mass, and stump length of 42 years, 164 cm, 67 Kg and 13 cm respectively with a right transtibial amputation is chosen to achieve the above mentioned test procedures. The last part suggests a theoretical and analytical models for each group of specimen to find out the absorbed energy behavior and subjected maximum stress for each laminated B-K prosthetic socket materials .

Keywords :prosthetic, transtibial, impact, composite material

دراسه سلوك الصدم الواطئ السرعه للمواد المركبه المستخدمة في صناعه وقب الطرف الصناعي لبتر تحت الركبه

د. جمعه سلمان جياد
استاذ مساعد
كليه الهندسة/الجامعه المستنصرية

الخلاصة

يتضمن هذا العمل ثلاثة اجزاء رئيسية الاول شمل تصنيع وقب طرف صناعي وفق طريقة الخلط وعدد الطبقات المستخدمة كلاسيكيا في مركز بغداد للاطراف الصناعية وهي (4طبقة برلون+2طبقة كاربون فايبر +4 طبقة برلون) وايضا تم اقتراح نموذجين اخريين هما (3طبقة برلون+2طبقة كاربون فايبر +3 طبقة برلون) و(3طبقة برلون+1طبقة كاربون فايبر +3 طبقة برلون) .اما الجزء الثاني فكان تصنيع وفحص العينات لمختلف الفحوصات الميكانيكية كفحص الشد بالاضافة الى فحص الصدم من خلال استخدام منظومة فحص صممت وصنعت لغرض اجراء فحص الصدم الواطئ السرعة للمواد المركبة المستخدمة في تصنيع وقب طرف صناعي لبتر تحت الركبة.كما تم قياس ضغط التلامس بين وقب الطرف الصناعي ومتبقي الطرف لحالة بحثية تعرضت لبتر تحت الركبة بعمر 42سنة وطول 164 سم ووزن 67 كيلوغرام وطول بتر 13 سم من خلال استخدام منظومة قياس ضغط التلامس صممت وصنعت لهذا الغرض بهدف حساب الاجهادات التي يتعرض لها الطرف الصناعي اثناء تعرضة لظروف العمل المختلفة.الجزء الثالث والاخير تضمن اقتراح حل نظري ونموذج عددي للحالة البحثية

لكل مجموعة من العينات لكل مادة مقترحة لتصنيع وقب الطرف الصناعي لايجاد سلوك الطاقة المخزونة وايجاد الاجهاد الاعظم الذي يتعرض له وقب الطرف الصناعي اثناء الخدمة وظروف التحميل المختلفة .

1. INTRODUCTION

There are several levels of lower limb amputation, including partial foot, ankle disarticulation, transtibial (below the knee), knee disarticulation, transfemoral (above the knee), and hip disarticulation. The lower Limb Prosthesis is an artificial external device that replaces all or part of the lower extremity. Prosthesis is used for granting an individual who has an amputated limb the opportunity to perform functional tasks, particularly ambulation (walking), which may be impossible to do without the limb .Ideally, a prosthesis must be comfortable to wear, easy to put on and to be remove, light weight, durable, and cosmetically pleasing. Furthermore, a prosthesis must function mechanically in a good way and requires reasonable maintenance only. The frequently used prosthetic largely depends on the motivation of the individual as none of the above characteristics matters if the patient does not wear the prosthesis. The basic components of the B-K lower limb prostheses are the foot-ankle assembly, shank, socket, and the adapter . The below-knee sockets are laminated by using composite materials (perlon,carbon fiber and acrylic resion) with different layers under the vacuum condition .

The gait cycle consists of the stance phase which takes about 62% of total gait cycle time and the swing phase which comprises about 38% of the total gait cycle time ,**Goldberg,et al.,2008.**The ground gait cycle of a person is normally comprised of the following steps : (Initial contact (heel strike) ,loading response (fully flat foot) in the stance phase, midstance, the terminal stance (heel off),Toe-off (pre swing in swing phase),initial swing, mid swing, and terminal swing) , **Jason, 2005,Goujon,2006, Kumar, 2005,Christopher, et al., 1999 .**

The impact occurs when two or more bodies collide. Among important characteristics of the impact is the generation of relatively large forces at points of contact for relatively short periods of time. Such forces are sometimes referred to as the impulse-type forces. Three general classes of impact which are considered in this work including : (1) the impact between spheres or other rigid bodies, where the body is considered to be rigid if its dimensions are large in comparison to the wavelengths of the elastic stress waves in the body; (2) the impact of the rigid body against a beam or plate that remains substantially elastic during the impact; and (3)the impact involving yielding of structures ,**Hoppmann**, 1961. As a result, when impacted, a metal structure typically deforms but does not actually fracture. In contrast, composites are relatively brittle.

The brittleness of the composite is reflected in its poor ability to tolerate stress concentrations. The characteristically brittle composite material has poor ability to resist the impact damage without extensive internal matrix fracturing,**Tuttle, 2004.**The deformation remains elastic if the impact V_O velocity does not exceed $V_E=\sqrt{(EI/\rho)}$ where KE is the elastic-limit curvature . When $V_O > V_E$ and the hardening is linear, different deformation patterns develop for $V_E < V_O < 2.087 V_E$ and for $V_O > 2.087 V_E$, **Jacob ,2008**.

Roger ,et al.1989. Concluded that at the lowest impact energy level, the composite is able to absorb the majority of the energy imparted to it. At increasing impact energy levels, the damage is seen to occur, i.e. the energy was absorbed elastically by the material is less than the energy imparted to the material. The energy that was absorbed elastically by the material is the difference of the maximum energy vs. time curve minus the energy at the end of the test.

L.S. Chocron,et al.,1997. Developed a new failure criterion that was based on the energy that crosses each yarn, to build a simple analytical model of impact in textiles. This rnodel had been checked with Dyneema armours and predicted accurately the residual velocity of the Fragment Simulating Projectiles. The model has been completed with a delamination equation taken from Beaumont in order to include the composite characteristics of delamination.

Serge,2007. Showed that composite structures are sometimes subjected to impacts in partial penetration or the complete perforation. Tests are conducted to determine the velocity required to achieve complete penetration for a given projectile, and a model is required for data reduction purposes in order to understand the effect of the various parameters and to extrapolate for other test conditions. Here, a systematic approach for developing engineering models for composite structures is presented and the models obtained are used to analyze the experimental results.

Mohd,2008. suggested a computational model to analyze the behavior of the composite material that was subjected to the impact load tensile load. A general purposed commercial finite element code was employed to develop the computational model. Fiber glass that reinforced composite, one of the commonly used structural composites, was chosen to be used as the test material. The computational model was constructed 2-D axissymmetric finite elements.

Alastair ,2008. described the recent progress on the materials modeling and numerical simulation of the impact and crash response of fiber reinforced composite structures. The work is based on the application of explicit finite element (FE) analysis codes to composite aircraft structures under both low velocity crash and high velocity impact conditions. The detailed results are presented for the crash response of the helicopter subfloor box structures using a strain based damage and failure criterion for fabric reinforced composites.

Thibaut,et al. ,2010. concluded that the dynamic fracture in shock-loaded materials is governed by the propagation, reflection ,and interactions of the stress waves. The post-shock analyses of the residual damage observed in samples recovered from laser shock experiments, less destructive than the more conventional techniques, can provide valuable insight into the key aspects of wave propagation prior to fracture, such as the effects of the structural anisotropy, the role of lateral waves associated to edge effects, or the influence of polymorphic phase transformations on the response to the shock loading.

The impact literatures and papers are concerned with the impact of the general composite materials .This mean that this paper deals with the impact problem in B-K prosthetic socket is very limited , therefore , this work is devoted to enrich this field of work and also stands as a benchmark for other investigators in the future .

2.EXPERIMENTAL WORK

2.1Material and Laminations

The materials of the B-K prosthetic socket chosen are randomly laminated. This means that the material is Isotropic . In this work, the material needed for socket are laminated using vacuum technique as it is shown in **Fig. 1 .** Perlon stockinet white, Carbon fiber sheet ,Lamination resin 80:20 polyurethane ,Hardening powder, and Polyvinyalcohol PVA bag are used in the B-K prosthetic socket lamination. All the lamination materials are tested using tensile and bending instruments by manufacturing tensile and bending specimens for each lamination according to ASTM D638 for tensile specimens and ASTM D790 for bending specimens. Three type of lamination materials are used in this work, namely (3Perlon+1 carbon fiber+3Perlon), (3Perlon+ 2 carbon fiber+3Perlon) and (4Perlon+2 carbon fiber+4Perlon) as shown in **Table1**.

2.2 Impact Testing

In this work all below- knee prosthetic socket lamination are tested using low velocity impact instrument ,**Nasser, 2011. Fig. 2** shows all parts of this instrument. All impact specimens are with dimension of (50*200)mm*mm and different thickness according to laminations layers to be suitable for the impact instrument requirements . All specimens are tested by a drop-weight low velocity impact tester with different high and different impact energy as it is shown in **Table 2.**

2.3The Interface Pressure Measurement

The interface pressure between the residual leg and prosthetic socket is measured by using piezoelectric sensor shown in **Fig. 3** The pole of the sensor is connected with multi-meter devise to obtain the magnitude of the voltage that resulted from the response of the sensor through the stance phase. The multi-meter and piezoelectric are interface with the computer and recording data as shown in **Fig. 4 .**The pressure is measured in the region between residual limb and B-K prosthetic socket in four lines (Interior, Lateral ,Posterior and medial).Each line is divided into three parts longitudinally as it is shown in **Fig. 5**. A male with age of 42 years, height of 164 cm, mass of 67 Kg, and stump length of 13 cm with a right transtibial amputation is chosen to achieve the above mentioned testing procedures. **Fig. 6** shows the amputee during IP test.

The program of multi-meter giving maximum and minimum value of voltage with time .This reading can be calibrated to the interface pressure against gait cycle time .

3 Theoretical Consideration

Process shown in **Fig. 2** in order to calculate the deflection, force, impact energy , and absorbed energy. The simulated model can be treated as a beam fixed to a supporting plate which in turn fixed to the base during which the impact ball hits the specimens at the midpoint. It is clear that deflection will result from bending and shear deformation but the beam is impacted by the impact ball with different impact energy .This means that the Castigliano’s theorem must be used to estimate the total and dynamics deflection formula for all types of B-K prosthetic socket laminations materials. **Table 3**. lists the total and dynamics deflections formula for all types of laminations.

The total absorbed energy can be derived according to normal and shear by using the following general formula with the element length of d x.

Defor..energy=$\frac{1}{2}\left[\int_0^d \sigma_{xx\varepsilon_{xx}dV} + 2\int_0^d (\mathcal{T}_{xz}\gamma_{xz} + \mathcal{T}_{xy}\gamma_{xy})dv\right]$ (1)

Finally the absorbed energy also resulted due to momentum conversation using the general formula.

$$(mV_2 \ \ -mV_1 \ \ ) = \int_{t1}^{t2} pdt \tag{2}$$

$$E_{ab}A = \frac{1}{2}(mV_2^2 - mV_o^2) \tag{3}$$

4. NUMERICAL ANALYSIS

The general analysis by using ANSYS has three distinct steps that:

- Building the geometry as a model.
- Applying the boundary conditions load and obtaining the solution.

- Reviewing the results.

In this work (below –knee)prosthetic sockets model was drawn by using CAD system (Auto CAD) which was processed according to an default pattern in three dimensions .The dimension was taken from the same B-K socket that done on it measurement of experimental part. The aim of drawing models by AUTOCAD is to use in ANSYS workbench program for modeling, meshing and defining boundary condition such as applied load. The models is illustrated in **Fig. 7**,this figure shows the FEM meshing model and loading boundary condition in a and b respectively .

5. RESULTS AND DISCUSSION

5.1 Mechanical Properties

The mechanical properties for each sample can be calculated by taking the average value of the mechanical properties ($\sigma_y, \sigma_{ult}, E$ and G)according to the tensile and flexural test . The mechanical properties for all laminations are listed in **Table.4**.

5.2 Impact Results

The experimental impact test result can be divided into two groups. The first one is the force behavior of the specimen that includes oscillatory phenomena visible in the force–time trace .The second group is the deflection behavior according to the impact energy shown in **Table 2**. **Fig. 8** shows the force behavior for the first lamination(L1) which consists of three layers of perlon plus one layer of carbon fiber plus three layers of perlon . It is clear that the general behavior is near to the sinusoidal waves . **Fig. 8** shows the force behavior of the lamination materials according to three levels of impact energy, which are (8.82,18.12,and 36.12)) J for the impact load of (1)Kg with different impact height of (0.25,0,5 and 1)respectively .The figure shows that the maximum force is recorded at the mass 1 kg with height 1m In the same manner , it can be concluded that the maximum deflection recorded with the specimen subjected to 1kg with 1m height as it is shown in **Fig. 9.** The impact results for all lamination specimens are listed in **Table 5.**

The above table shows that the best behavior of absorbed energy is recorded for the below knee prosthetic socket which consists of three outer perlon layers plus one central carbon fiber layer plus three inner perlon layers .The ranges of the absorbed energy recorded for this lamination were between (74.8-89.40%) for all levels of the impact mass and height. While the second lamination which consists of(3perlon layer+2carbon fiber layers+3perlon layers)has the range of absorbed energy of(67.9-80)%. The third lamination which consists of(4perlon layer+2carbon fiber layers+4perlon layers)recorded the range of absorbed energy of(60.9-68.3)%.

5.3 Interface Pressure Results

The interface pressures results shows that the maximum value is recorded at socket interior region exactly at patella tendon with 202.6Kpa as it is shown in **Fig. 10** which shows the general IP behavior against gait cycle time during which two peaks are recorded at loading response , and toe off of gait cycle and small reduced will be noticeable at midstance of gait cycle. This behavior is the same for all measuring regions during which other maximum values IP are recorded at (popliteal depression, lateral tibia, medial gastrocnemius , and distal gastrocnemius) with values of (186.6,92.71,65.87, and 54.32) respectively as shown in **Table 6** .

5.4 Analytical Results

According to the loading boundary condition for the below – knee prosthetic socket of the testing amputee the Von –Mises stresses are shown in **Fig. 11** which shows that the stress distribution is a mirror of interface pressure distribution shown in **Fig. 7** and **Table 6 .** The Von- Mises stresses results shows that the maximum value is recorded at socket 5 interior region exactly at patella tendon with 0.8155 Mpa,while the values of stresses are recorded at (popliteal depression, lateral tibia, medial gastrocnemius and distal gastrocnemius) with values of (0.7212,0.5445,0.3954, and 0.2943) Mpa respectively .
Fig. 12 shows the stress distribution according to the interface pressure boundary condition and impact with impactor of 1 Kg of mass from 1 m height at the mid distance of socket interior length .It is clear that the values of stresses jump to the maximum value of 16.2 Mpa at impact contact point at center of anterior wall of prosthetic socket .**Table 7** shows all cases of the numerical solution for both inteterface pressure boundary condition and impact with different impact mass and impact height for all type of lamination .

6. CONCLUSION

1-The Maximum absorbed energy percent is recorded with B-K prosthetic socket lamination which consist of (3perlon +1 carbon fiber+3perlon) layers with 89.4%.
2- The maximum value of the interface pressure is recorded at socket interior region exactly at patella tendon with 202.6Kpa
3- The maximum value of the Von- Mises stress due to interface pressure boundary condition is recorded at B-K prosthetic socket at the interior region exactly at patella tendon with 0.8155 Mpa.
4- The maximum value of the Von- Mises stress due to interface pressure and impact boundary condition is recorded at B-K prosthetic socket lamination which consists of (3perlon +1 carbon fiber+3perlon) layers at the region of the impact contact in the center of anterior socket wall with 16.2 Mpa a0.8155 Mpa.
5- All types of B-K prosthetic socket lamination are safety used .
6- The suggested lamination which consists of (3perlon +1 carbon fiber+3perlon) is the best to be used due to its safety and because it reduces the cost and weight of the prosthetic socket.

7-References

Goldberg,J. E., Philip, S.R. and Eileen,G. F. ,2008, "***The Effects of Direct Measurement Versus Cadaver Estimates of Anthropometry in the Calculation of Joint Moments during Above –Knee Prosthetic Gait in Pediatrics***", Journal of Biomechanics ,Vol.41,No.3. pp. 695-700

Jason,W.J., 2005,***"Preliminary Design Approach for Prosthetic Anke Joints using Compliant Mechanisms "***, Msc. Thesis ,mechanical engineering department ,Brigham young University

H. Goujon,2006 "***Analyse De La Marche del'Amputee Femoral***", PhD. Thesis,biomechanical engineering department , Unversity of Ensam ..

Kumar, R.,T.,2005, ***"Task Oriented Stable Gait Synthesis in Biped Locomotion "***, Msc. thesis submitted to Indian institute of information technology .

Christopher, L.,V., Briant D.,S., and Jeremy C., C., 1999,***"Dynamics of Human Gait"***, Second edition , Kibiho publisher Cape town, South Africa.

Hoppmann, W.,H., 1961,*"**Shock and Vibration Handbook**"*,. McGraw-Hill Book Co., New York.

Tuttle, M.,E., 2004,***" Structural Analysis of Polymeric Composite Materials"***, Marcel Dekker Book, Inc

Jacob L.,R.,2008,***" Plasticity Theory"***, Dover Publications, University of California at Berkeley

Roger M., C., and Thomas ,D., J., January 1989 ***" Instrumented Impact Testing of Composite Materials"***, Approved for public release; distribution unlimited, Bethesda, Maryland,Ship Materials Engineering Department .

Chocron, L,.S., Benloulo,R.,T., and etl, 1 997**,*" A Simple Analytical Model for Ballistic Impact in Composites"***, Journal Dephysiqueiv, France .

Serge, A.,T., 2007,***" Ballistic Impact on Composites "***, 16Th International conference on composite Materials, Kyoto, Japan .

Mohd, A., S., 2008, ***" The Study of Impact Response of Composite Materials "***, Report submitted to Faculty of Mechanical Engineering, University Malaysia Pahang.

Alastair ,F., J., 2008, " ***Impact and Crash Modeling of Composites Structure*** " , German Aerospace Center (DLR) ,Institute of Structures and Design, Stuttgart, Germany

Thibaut, D.,R., 2010 " ***Wave Propagation and Dynamic Fracture in Laser Shock-Loaded Solid Materials"***, Edited by Andrey Petrin, CNRS,ENSMA,ParisTech,France.

Resan, K.,K., 2007 ***"Analysis and Design Optimization of Prosthetic BK"***, Ph.D. thesis ,university of technology ,Baghdad,.

Jumaa ,S., C., 2009 ***" Design and Optimization of the Above Knee Prosthetic Socket"***, PhD Thesis ,University of Technology ,Baghdad.

Nasserو N. J.و 2011***"Study of the Effect of Impact on Curved Composite Plates "***,Msc. Thesis ,Mech.Eng. Departments, Al-Mustansiriya Unversity,

NOMENCLATURE

Perlon= is a polyamide fibers Use in orthopedic technology as stockinette
B.K = below Knee
Vth= theoretical impactor velocity (m/s)
Vexp= experimental impactor velocity (m/s)
H= impactor height (m)
Abs.En.= absorbed energy (J)
Imp.En.= impact energy (J)
IP= interface pressure (Kpa)
Lam1= 3perlon+1carbon fiber+3perlon
Lam1= 3perlon+2carbon fiber+3perlon
Lam1= 4perlon+2carbon fiber+4perlon
Ms= impactor mass (Kg)
σ_Y = yield stress (Mpa)
σ_{Von} = Von –Mises stress(Mpa)

σ_{Ult} = ultimate stress (Mpa)
E,G= modulus of elasticity and rigidity (Gpa)
δ_T,δ_D= total and dynamics deflections (mm)

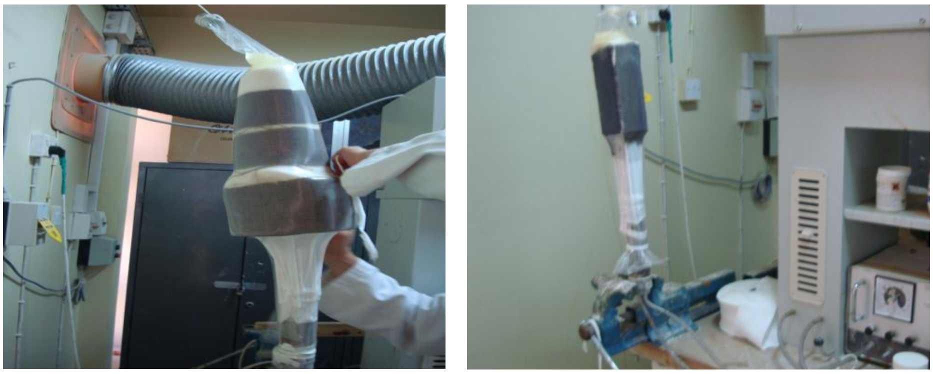


Figure 1. Vacuum technique for prosthetic socket lamination.

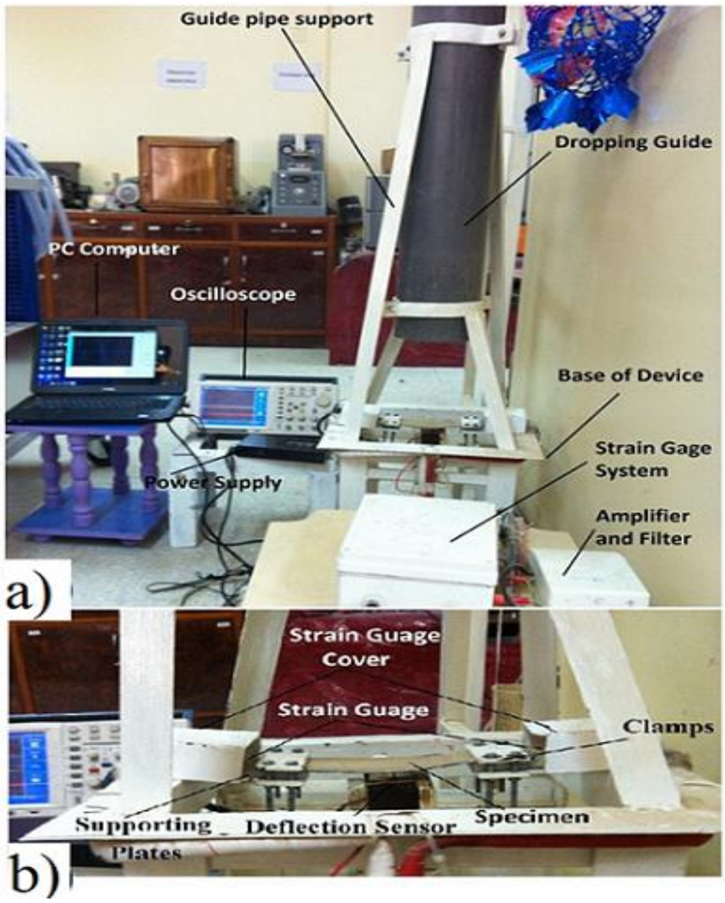


Figure 2. Impact instrument a)All parts b)Specimen region.

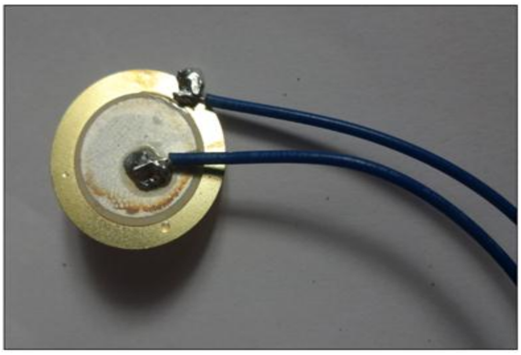


Figure 3. The piezoelectric sensor (Diameter = 15mm).

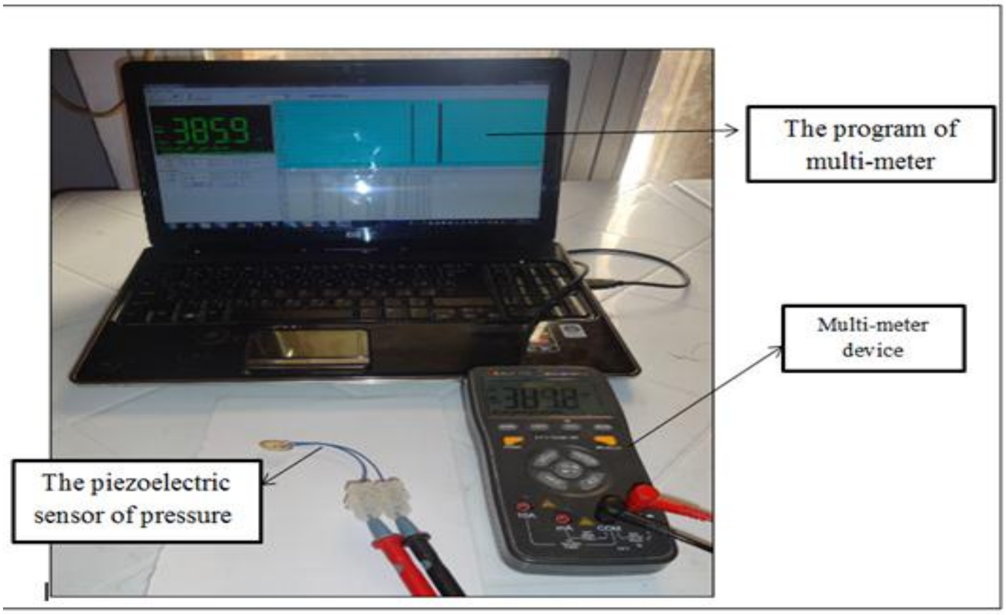
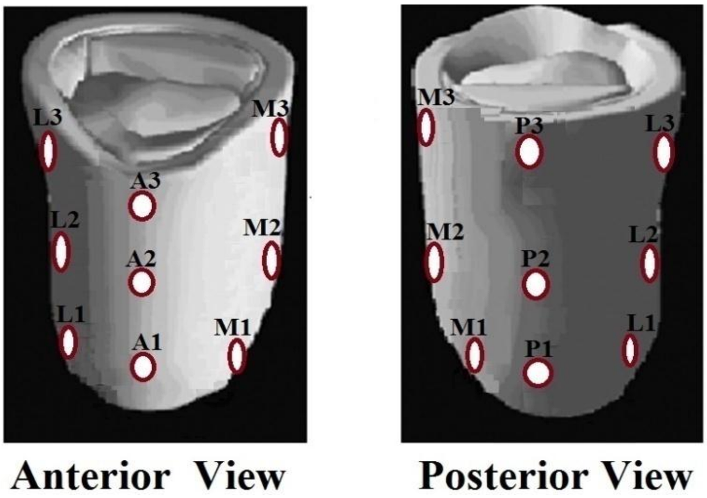


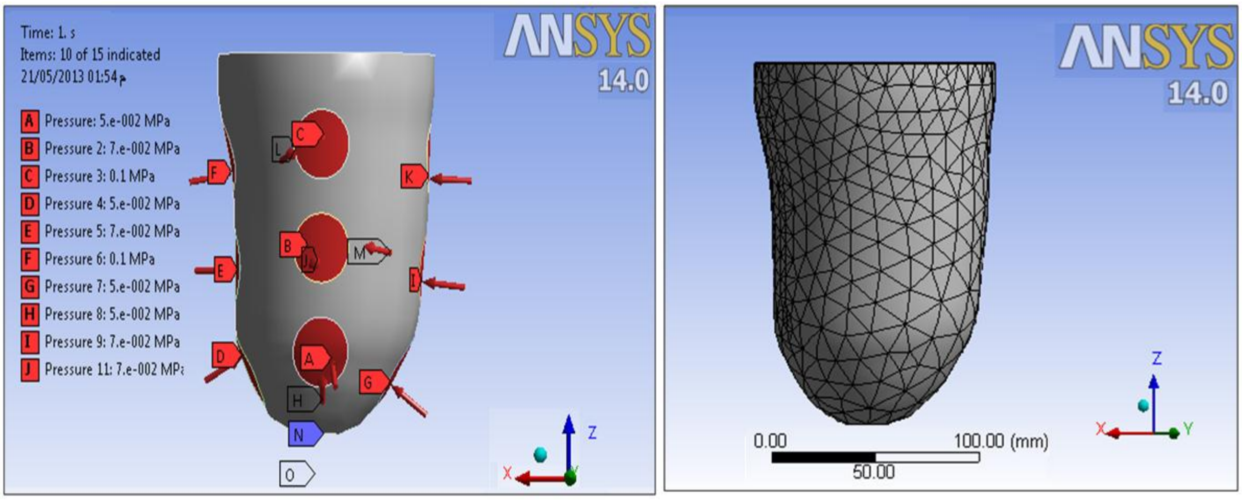
Figure 4. Multi-meter and sensor are interface with the computer.



Anterior View Posterior View

Figure 5. Piezoelectric sensor measuring position.

Figure 6. Transitibial amputee during IP test.

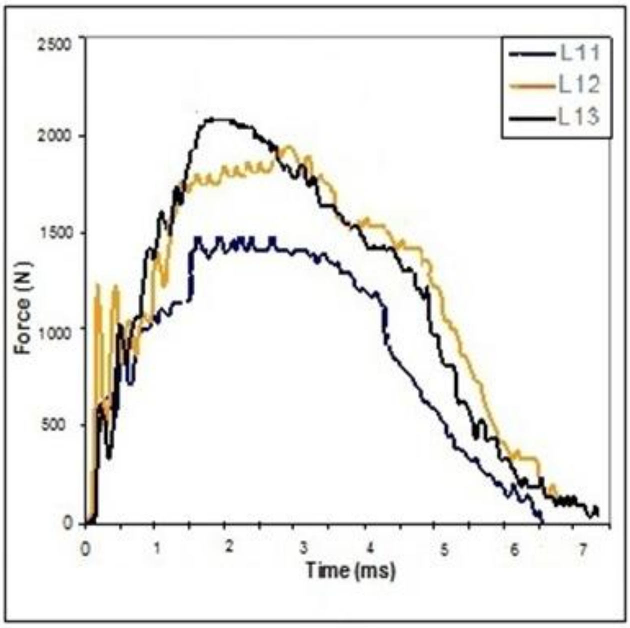

Time: 1. s
Items: 10 of 15 indicated
21/05/2013 01:54 م

A Pressure: 5.e-002 MPa
B Pressure 2: 7.e-002 MPa
C Pressure 3: 0.1 MPa
D Pressure 4: 5.e-002 MPa
E Pressure 5: 7.e-002 MPa
F Pressure 6: 0.1 MPa
G Pressure 7: 5.e-002 MPa
H Pressure 8: 5.e-002 MPa
I Pressure 9: 7.e-002 MPa
J Pressure 11: 7.e-002 MP

a)

b)

Figure 7. FEM mesh(a) and boundary loading condition (b) of the B-K socket model.



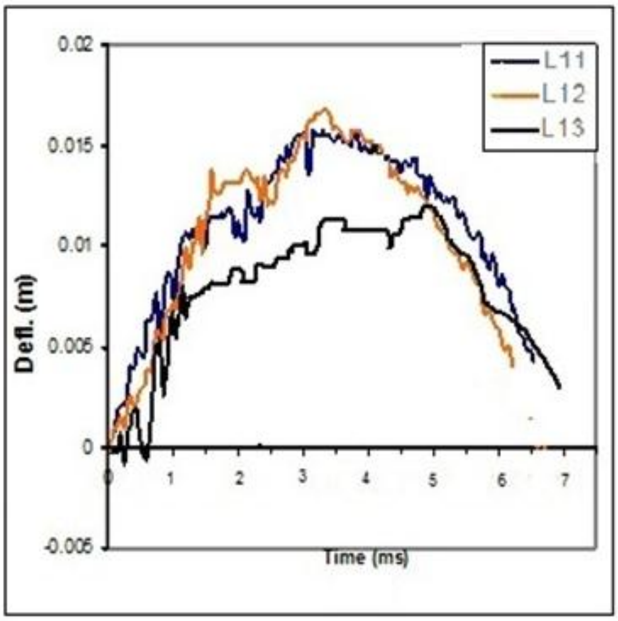


Figure 8. Force-Time curves for first lam.L1 **Figure 9.** Deflection-Time curves for first lam.L1.

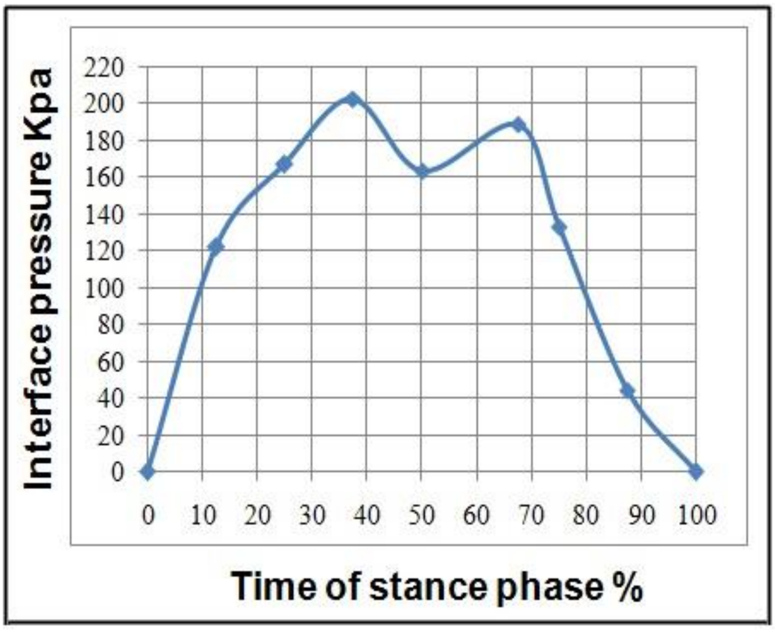


Figure 10. Interface pressure against gait cycle at Patella tendon.

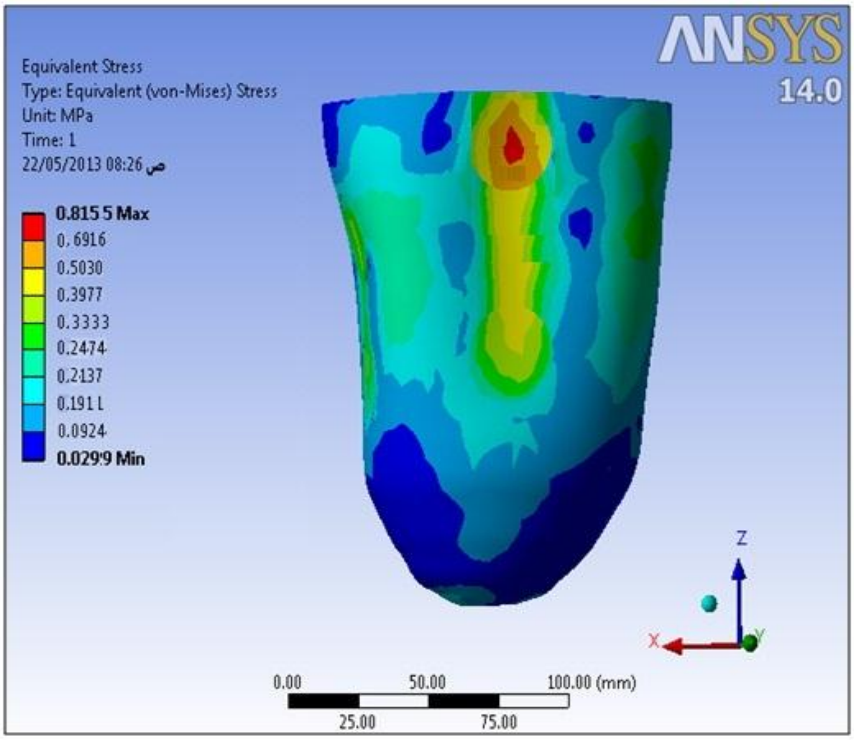


Figure 11. Von-Mises stress distribution according to the interface pressure boundary condition for B-K prosthetic socket lamination L1 (313).

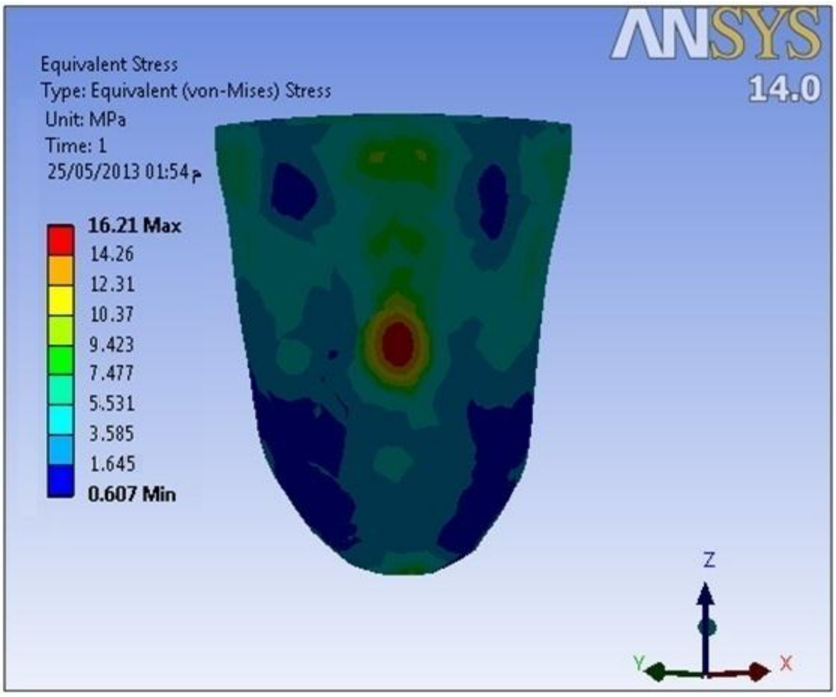


Figure12. Von-Mises stress distribution according to interface pressure boundary condition and impactor of 1 Kg with 1 m height at the center of the B-K prosthetic socket lamination L1 (313).

Table 1. All B-K prosthetic lamination material.

B-K Lam.	Total layers	Thick. mm	Lam. lay up procedures
Lam.1	7	2.8	3Perlon + 1 carbon fiber+3Perlon
Lam.2	8	2.9	3 Perlom + 2carbon fiber+ 3 Perlon
Lam.3	10	3.1	4 Perlon + 2carbon fiber+ 4 Perlon

Table 2. All impact specimens numbering with different impact energy.

Impact Mass Kg	Speci. Type	Speci. No.	Vth.	Vexp.	Imp. En. (J)	H (m)
0.25	L1	L11	2.2	2.1	0.55	0.25
		L12	3.1	3.01	1.13	0.5
		L13	4.4	4.25	2.25	1
	L2	L21	2.2	2.1	0.55	0.25
		L22	3.1	3.01	1.13	0.5
		L23	4.4	4.25	2.25	1
	L3	L31	2.2	2.1	0.55	0.25
		L32	3.1	3.01	1.13	0.5
		33	4.4	4.25	2.25	1
0.5	L1	L11	2.2	2.1	1.1	0.25
		L12	3.1	3.01	2.26	0.5
		L13	4.4	4.25	4.515	1
	L2	L21	2.2	2.1	1.1	0.25
		L22	3.1	3.01	2.26	0.5
		L23	4.4	4.25	4.515	1
	L3	L31	2.2	2.1	1.1	0.25

		L32	3.1	3.01	2.26	0.5
		33	4.4	4.25	4.515	1
1	L1	L11	2.2	2.1	2.205	0.25
		L12	3.1	3.01	4.53	0.5
		L13	4.4	4.25	9.031	1
	L2	L21	2.2	2.1	2.205	0.25
		L22	3.1	3.01	4.53	0.5
		L23	4.4	4.25	9.031	1
	L3	L31	2.2	2.1	2.205	0.25
		L32	3.1	3.01	4.53	0.5
		33	4.4	4.25	9.031	1

Table 3. Total and dynamics deflections formula for all type of below- knee prosthetic socket lamination material.

Lam. No.	δ_T	δ_D
L1	$\left(8.54 * 10^{-8} + \frac{98.39 * 10^{4}}{E}\right) P$	$\delta_T(1 + \frac{1 + 2h}{\delta_T})^2$
L2	$\left(8.54 * 10^{-8} + \frac{88.56 * 10^{4}}{E}\right) P$	$\delta_T(1 + \frac{1 + 2h}{\delta_T})^2$
L3	$\left(8.54 * 10^{-8} + \frac{80 * 10^{4}}{E}\right) P$	$\delta_T(1 + \frac{1 + 2h}{\delta_T})^2$

Table 4. Mech. properties of the tested specimens.

No. of Lam.	Lay up	σ_Y MPa	σ_{Ult} MPa	E GPa	G GPa
L 1	313	34.2	47	2.2	0.85
L 2	323	31	52.4	2	0.78
L3	424	32	54.7	1.9	0.73

Tabl1 5. Absorbed energy for all type of socket lamination materials with different of impact energy.

Impact Mass Kg	Spec. type	Spec. No.	Imp En. J	Abs. En. J	Percent of Abs. En.%
0.25	L1	L11	0.55	0.42	76.3
		L12	1.13	0.847	74.9
		L13	2.25	1.8	80
	L2	L21	0.55	0.38	69.1
		L22	1.13	0.768	67.9
		L23	2.25	1.63	72.4
	L3	L31	0.55	0.335	60.9
		L32	1.13	0.737	65.2
		33	2.25	1.456	64.57
0.5	L1	L11	1.1	0.898	81.6
		L12	2.26	1.919	84.9
		L13	4.515	3.652	80.9
	L2	L21	1.1	0.823	74.8
		L22	2.26	1.647	72.9
		L23	4.515	3.115	68.99
	L3	L31	1.1	0.725	65.9
		L32	2.26	1.46	64.6
		33	4.515	3.085	68.3
	L1	L11	2.205	1.942	88.1
		L12	4.53	4.047	89.4

1		L13	9.031	7.468	82.7
	L2	L21	2.205	1.552	70.4
		L22	4.53	3.474	76.7
		L23	9.031	7.225	80
	L3	L31	2.205	1.576	71.5
		L32	4.53	2.999	66.2
		33	9.031	5.735	63.5

Table 6. Maximum interface pressure recording at all measuring regions.

Socket Regions	Sensor Positions	Interface Pressure Kpa
Anterior	A1	45.76
	A2	77.87
	A3	202.6
Lateral	L1	50.4
	L2	86.7
	L3	52.5
Posterior	P1	54.32
	P2	62.7
	P3	186.6
Medial	M1	42.6
	M2	65.87
	M3	33.91

Table 7. Von-mises stress distribution according to IP and IP plus impact B.C. for all type of prosthetic socket lamination.

Impact Mass Kg	Spec. type	Spec. No.	Imp En. J	σ_{Von} Mpa, IP	σ_{Von}, Mpa IP+Impact
	L1	L11	0.55	0.8155	5.53
		L12	1.13		6.87

0.25		L13	2.25		8.96
	L2	L21	0.55	0.7152	4.95
		L22	1.13		5.65
		L23	2.25		7.76
	L3	L31	0.55	0.6189	3.99
		L32	1.13		4,92
		33	2.25		6.13
0.5	L1	L11	1.1	0.8155	7.45
		L12	2.26		9.87
		L13	4.515		11.87
	L2	L21	1.1	0.7152	6.23
		L22	2.26		8.87
		L23	4.515		10.12
	L3	L31	1.1	0.6189	6.14
		L32	2.26		7.98
		33	4.515		9,33
1	L1	L11	2.205	0.8155	8.44
		L12	4.53		12.4
		L13	9.031		16.21
	L2	L21	2.205	0.7152	8.14
		L22	4.53		10.77
		L23	9.031		14.54
	L3	L31	2.205	0.6189	7.77
		L32	4.53		9.54
		33	9.031		11.65