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Analysis of Prosthetic Running Blade of Limb Using Different Composite Materials

Saleel Hussein Abood *
M.Sc. student
University of Baghdad
College of engineering
Mech. Eng. Dept.
saleelhussein91@gmail.com

Dr. Majid Habeeb Faidh-Allah
Ass. Prof.
University of Baghdad
College of engineering
Mech. Eng. Dept.
drmajidhabeeb@gmail.com

ABSTRACT

Prostheses are used as an alternative to organs lost from the body. Flex-Foot Cheetah is considered one of the lower limb prostheses used in high-intensity activities such as running. This research focused on testing two samples of Flex-Foot Cheetah manufactured of two various materials (carbon, glass) with polyester and compare between them to find the foot with the best performance in running on the level of professional athlete. In the numerical analysis, the maximum principal stress, maximum principal elastic strain, strain energy; finally, the blade total deformation were calculated for both feet. In experimental work, the load-deflection test was done for foot to calculate the bending the results were very close to the numerical results and the curve of the carbon foot sample was lower than that for the glass foot sample that indicates the strength of carbon fiber.

Keywords: Prosthetic blade, Composite Materials, Load-Deflection Test.

تحليل شفرة الركض الاصطناعية لقدم باستخدام مواد مركبة مختلفة

*** سليل حسين عبود**
طالبة ماجستير
جامعة بغداد- كلية الهندسة
قسم الهندسة الميكانيكية

د. مجيد حبيب فيض الله
استاذ مساعد
جامعة بغداد- كلية الهندسة
قسم الهندسة الميكانيكية

الخلاصة

يتم استخدام الأطراف الاصطناعية كبديل للأعضاء المفقودة من الجسم. يعتبر الفهد - القدم الفهد أحد الأطراف الاصطناعية السفلى المستخدمة في الأنشطة ذات الصرامة العالية مثل الجري. ركز هذا البحث على اختبار عينتين من قدم_الفهد المصنعة

*Corresponding author
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من مادتين مختلفتين (الكربون والزجاج) مع البوليستر وقارن بينهما لإيجاد قدم مع أفضل أداء في التشغيل على مستوى الرياضي المحترف. في التحليل العددي ، الحد الأقصى للإجهاد الرئيسي، تم حساب التشوه الكلي للشفرة لكلا القدمين. في التجارب العملية،اختبار حساب الانحراف تم تطبيقه على كل عينة لحساب الانحناء حيث كانت النتائج العملية قريبة جدا من النتائج النظرية وكان منحني عينة القدم الكربونية أقل من ذلك لعينة الياف الزجاج التي تشير إلى قوة ألياف الكربون .
الكلمات الرئيسة: الشفرة الاصطناعية, المواد المركبة, اختبار حساب الانحراف.

1. INTRODUCTION

Artificial limbs design for sports is a comparatively new invention. War has a major role in the development of prosthesis and the ultimate specialization in the sport. The conception of the prosthesis was clear over the periods of 2700-2600 BC with regards to the toes amputation which was substituted by prosthesis made of wood and leather. In the 16th century, the amputation introduced by Andre Pare as a life-saving measure on the battleground and soon began to develop prostheses to help rehabilitate patients**, Gutfleisch, 2003, Cantos, 2005, Thurston, 2007**. Marquees Anglesey's leg was invented by James Potts at the ending of Waterloo's Combat in the 19th horn, **Thorston, 2007**. The artificial positioning of sport-specific limbs did not develop firmly until the 1980s.Foot introduction in Seattle in 1981 led to artificial feet for energy storage, **Hafner, et al., 2002**, which included an elastic beam inside the polyurethane crust (in the form of a foot). In the midmost-1980s, the main inventions of the design initially were used for entertainment purposes and were subsequently used for competition. The design of wound brace for arthropods was developed, which is famous as Terry Fox design, and used the design of a spiral coil spring, **Diangelo, et al.,1989**. Later, significant progress was made for amputation of the part above the knee and the part below the knee,when Van Phyllis conceived Flex feet in 1987, **Hafner, et al., 2002**. This is the basic design of current compensation technology for the return of energy in the running sprint. The Flex-foot design includes elastic carbon fiber leg and foot springs, a profile usually "c" or "j". **Jweeg, et al., 2007,** designed a new artificial foot, a foot testing tool for fatigue according to ISO 10328 and measured ground reaction force through the force plate and the properties of the gait. The result shows that the new prosthetic foot has good properties when compared to SACH foot, good dorsiflexion, stored energy, and life. **Nolan, 2008,** studied prosthetic feet made of carbon fiber and reviewed the effect of it on the transtibial truncated operation technique. He showed that the current efficiency of the artificial foot is not equal to the energy efficiency of normal natural foot. **Scholz, et al., 2011,** studied the effect of using composite materials in medical devices for orthopedic and prosthetic devices and stated that it is better to use composite reinforced carbon fiber because of its own strength and compatibility. **Mosfequr Rahman et al. 2014** focused on the high performance of prosthesis running foot manufactured from carbon fibers that have more advantages than their metal counterparts, they are lighter and have the ability to hold a significant amount of strain energy, finite element analysis technique was used to analyze the prosthetic running foot which known as the blade. **Mohsin N. Hamzah et al. 2017** manufactured two samples of APF (C-type, cheetah type) and compared between them. Glass fiber with unsaturated polyester the materials have been used in manufacturing. The foot subjected to (load deflection test). The result shows that cheetah blade best from C-type blade. In this paper, a practical and theoretical comparison was made between two feet manufactured from two different materials.

2. Design Consideration

The design shown in **Fig. 1. Leonard, 2013** is used with amputated athletes with a maximum weight of 50 kg. It is made of multi-layer materials with variable thickness of 4-8 cm.
The j blades are being in two different constructs:

1. One piece.
2. Multi-layer.

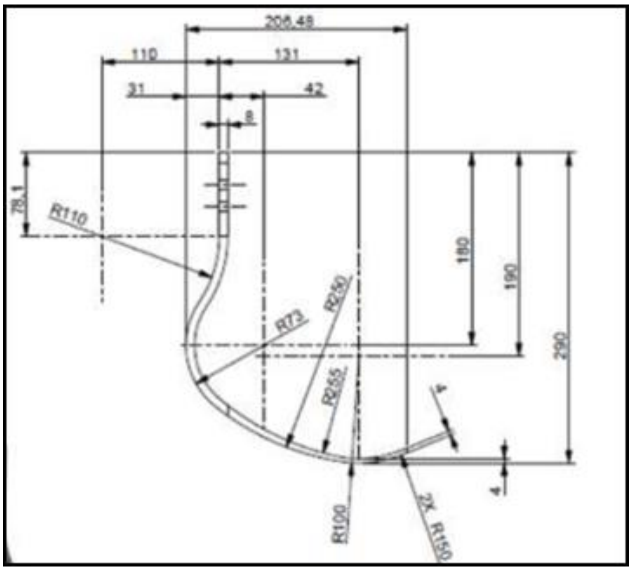

Figure 1. Design of prosthetic J blade **Leonard, 2013.**

3. NUMERICAL ANALYSIS

3.1 Finite Element Modeling

After drawing the dimensions using AutoCAD, it is converted to ANSYS WORKBENCH. The geometry is the first step of the modeling; the element type is set to be SHELL181, though using a proper material is important to get plausible results a realistic loading had to be applied to each blade. Once the distributed load 1500N was applied, each blade had also to be supported by making two holes at the top to mimic the connection to the body **Fig. 2.**

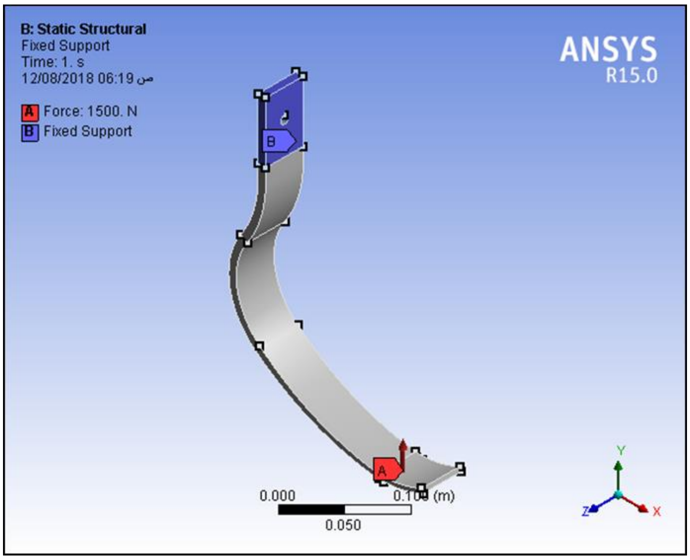

Figure 2. static structural show load and fixed support location.

3.2 Meshing and Convergence of FEM

The foot is divided into sub-elements by meshing as shown in **Fig. 3.** One first must be sure that the baseline design's mesh is fine enough to make accurate calculations.

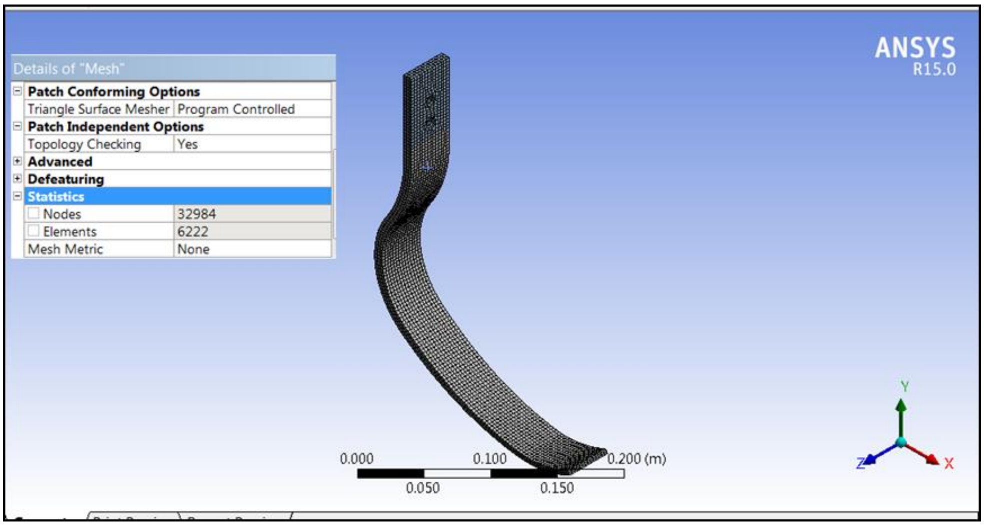

Figure 3. Mesh size.

A convergence study was performed to determine the appropriate finite element mesh to be used in static structural analysis of glass prosthetic foot model. Meshes were developed, with decreasing of element size and the total deformation for these models are shown in **Fig.4.** From this figure, it is clear that the total deformation stabiles at optimizing square element size equal to 3 mm and number of element equals to 6222.

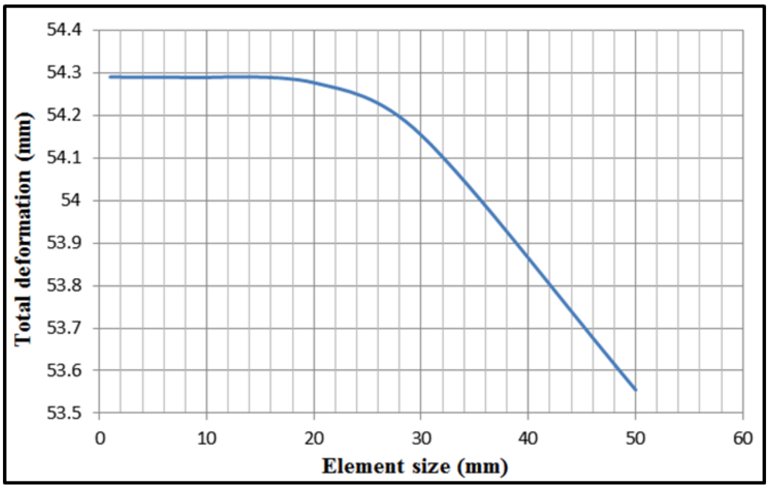

Figure 4. The convergence of FEM.

4. NUMERICAL RESULTS

For the blade, some tests were conducted to show how the blade interacted with the application of the loads for which the equivalent pressure value was collected. Max principal stress, Max principal elastic strain. Then show how the energy blades are stored the strain energy was calculated. The blade deformation showed that the blade design recompense for the load. Each of these values was calculated using ANSYS 15 FEA under the STATIC STRUCTURAL subcategory. The blade got a load from the ground and supported by growing holes. This ensures that the blade will not move when the load is applied and will simulate the blade that is worn correctly, **Fig. 5 to 10**.

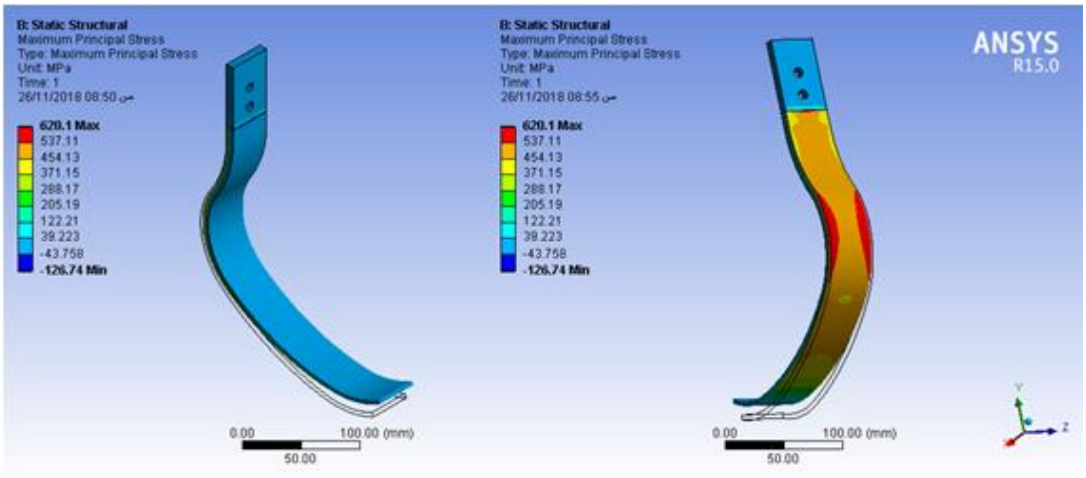

Figure 5. Max principal stress for glass fiber sample.

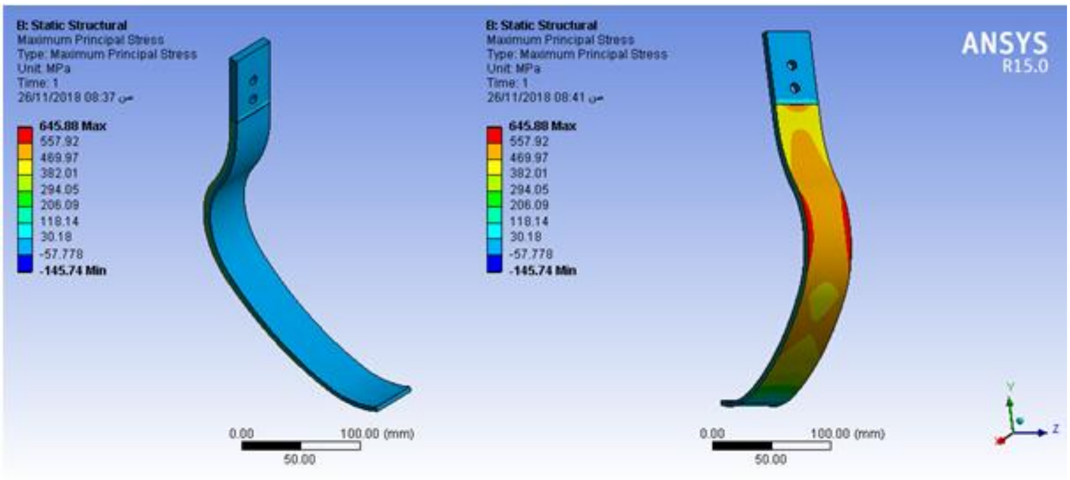

Figure 6. Max principal stress for carbon fiber sample.

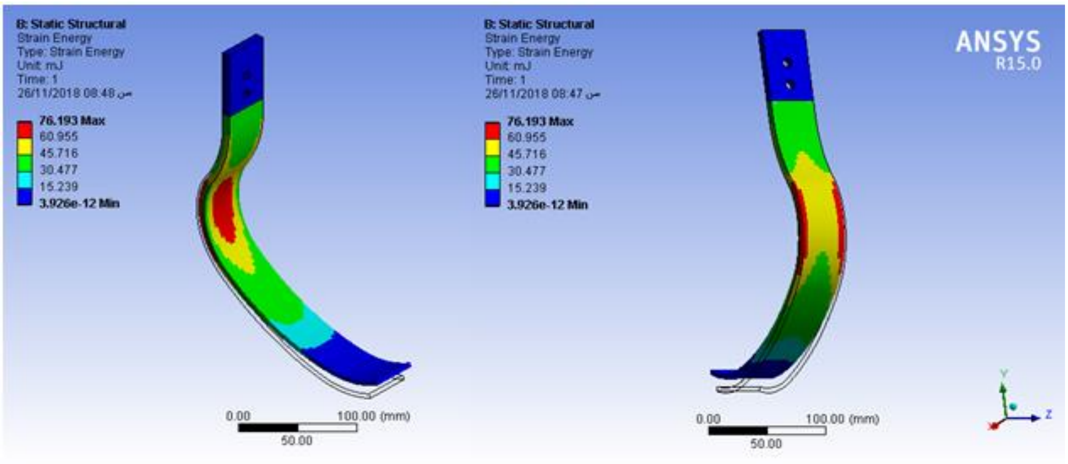

Figure 7. strain energy for glass fiber sample.

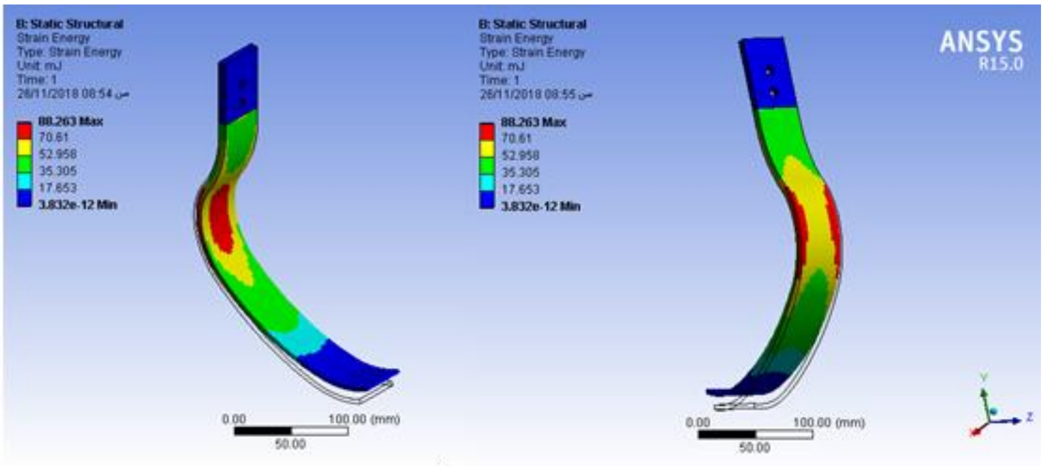

Figure 8. strain energy for carbon fiber sample.

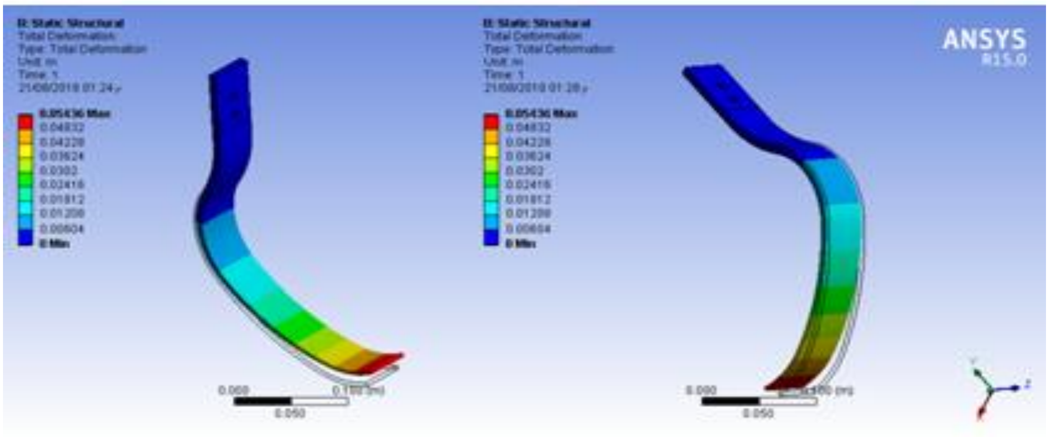

Figure 9. total deformation for glass fiber sample.

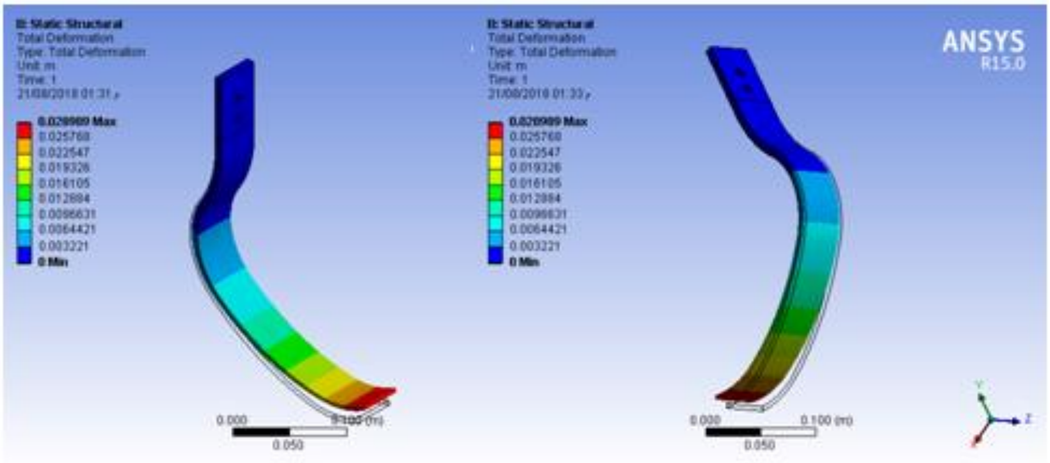

Figure 10. total deformation for carbon fiber sample.

5. EXPERIMENTAL PROCEDURE

5.1 Mold Manufacturing

The mold was manually manufactured from wood materials. The mold consists of two wooden pieces, the first representing the base and the second representing the cover. The width of the mold is 15 cm and the length is 60 cm. The two pieces were provided with fixing joints, **Fig. 11**.

Figure 11. Prosthetic foot mold shape.

5.2 Manufacturing of Prosthetic Feet Samples

Two samples of design prosthetic foot were manufactured by using (glass fibers and carbon fibers) with an unsaturated polymer. The layers of the fiber (25 layers) were arranged so that are different in length to obtain the variable thickness. The hardener is added to the polymer by 2 ml: 1 liter. This takes about two hours to start solidifying at 30°C. The manufacturing process begins on the bottom of the mold where the layers are arranged one after the other in sequence. A layer of fiber was put and the polymer was added on it by the brushes. Then the second layer was put. A serrated cylinder was passed to remove the bubbles and make sure that the polymer is distributed evenly **Fig. 12**. This process was repeated until all layers of fibers have been laid. After that, the top part of the mold was installed on the bottom and firmly fixed to get enough pressure helps exit the remaining bubbles.The mold was then left about 5 days at 30˚C to dry.

glass fibers carbon fibers

Figure 12. Laying up process.

6. LOAD-DEFLECTION TEST FOR SAMPLES

This test is completed to measure the deflection of the foot by applying a vertical load on the top of the foot, this load increased gradually from zero to 1500N maximum (equal to three times of runner weight) **Mosfequr Rahman et al. 2014**. Deflection test was made at the University of Technology Department of Materials Engineering by the compression device connected to the computer to record the deflection at force changing, then plot the load-deflection chart. **Fig. 13.**

Glass fiber Carbon fiber

Figure 13. The samples in the load-deflection test.

7. RESULTS AND DISCUSSION

7.1 Numerical Analysis

The values of max principal stresses are held constant between the two materials, this is because the stress is not dependent on the material properties; however it is dependent on the force and area of which the force is distributed over. The best thing to compare these blades is the amount of energy absorption where carbon blade absorbs nearly 88,263 MJ but glass blade absorbs only 76,193 MJ. The deformation of the prosthetic blade using carbon fiber has less value so it was the best design and material combination. When comparing the material test of each design it is shown that carbon fiber is a better material by holding all computed values lower and assisting the designs to perform more efficiently. With these calculations and results, due to the higher strength of carbon fiber, it is assumed that less material can be used in the design allowing for a reduction in weight.

7.2 Load-deflection Test Result

Fig. 14 and 15 demonstrate the theoretical line (which was drawn by ANSYS software program) and the experiment line for load-deflection test; the results are recorded in **Table 1** for both samples, where it is observed that a great approximation between the results. From the theoretical line, the stiffness can be calculated according to the equation:

$$K = \frac{F}{\Delta \ell} \tag{1}$$

The stiffness is proportional to the force and inverse with the deflection. **Table 2** demonstrates the stiffness of each sample to see if the stiffness of the foot is appropriate or not away from the excessive increase and decrease.

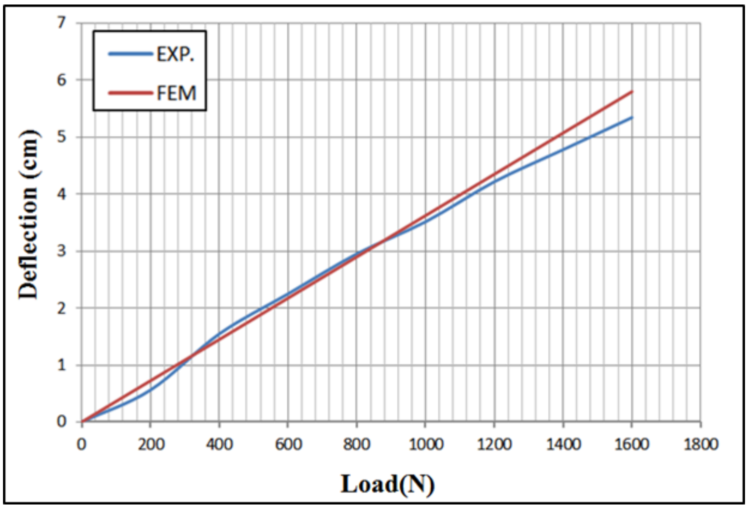

Figure 14. Load-deflection for glass fiber sample.

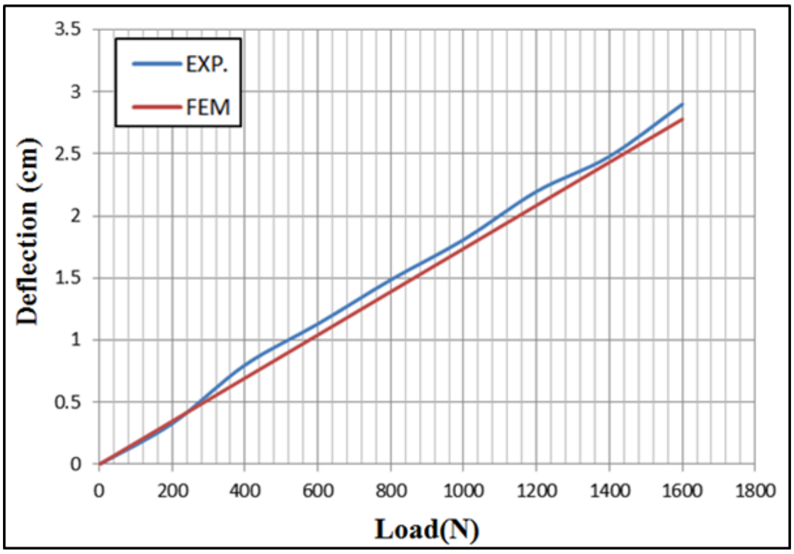

Figure 15. Load-deflection for carbon fiber sample.

Table 1 Numerical and experimental deflection results.

Foot	FEM	EXP
GF+ UNSA	5.4 cm	5.3cm
CF+UNSA	2.8cm	2.6cm

Table 2 Stiffness values for glass fiber and carbon fiber feet samples.

Feet	GF+UNSA	CF+UNSA
Stiffness K (N/m)	28×10^3	57×10^3

8. CONCLUSIONS

1- From the ANSYS program, the values of strain energy show that carbon fiber foot has higher ability to restore energy than glass fiber foot while running.

2- Carbon fiber foot has a lower deflection than glass fiber foot; this indicates that carbon fiber has higher strength.

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