A Suggested New Material to Manufacture Above-Knee Prosthetic Socket Using the Lamination of Monofilament, Cotton and Perlon Fibers

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Abstract

At present use of glass fibers in lamination prosthetic socket, is due to its fiber strength and hardness, and low cost, but there are other more important things which must be considered than these specifications which are the health and safety. In this research fiberglass is replaced with monofilament fiber in order to be safe to on makers and users of this socket. In this paper two models of lamination manufacturing have been made and compared in terms of mechanical properties and fatigue life. The first is available and consists of: (4 perlon, 2 fiberglass and 4 perlon), The second is proposed lamination which consists of: (4 perlon, 1 cotton, 1 monofilament and 4 perlon). Simulations were conducted on the made socket made of two types of lamination by using ANSYS 14.5 to show the distribution of stresses, the amount of deformation and less safety factor for both cases. The results show an increase of 42% in the Young's modulus and a decrease in tensile stress and yield stress by 10.8% and 46% respectivel, As for the stress endurance it witnessed an increase of 140%.The simulation results show a decrease in the deformation by 40.7% and an increase in the minimum value of the safety factor of 0.323 to 1.05.

Keywords: Socket, monofilament fiber, cotton, fatigue stress, interface pressure.

Introduction

Transformal amputations, also known as above-knee-amputations or (AKA), represents 26% of the total leg amputations, in Iraq 55% of amputations are because of diseases or because of the negligence of medical care for the patient, and constitutes 36% of amputations because of accidents or attacks of terrorist bombings and 9% is because of congenital deformities from birth[1]. Successive the research and recommendations on the material that made them socket to arrive for optimam mechanical propertise and lower cost.

Previously sockets were manufactured from wood and aluminum and they posd a burden on the patient because they were uncomfortable and heavy, also on sockets maker because of taking effort and time [2].

Than they began to improve and develop where researchers at the US army began **In 1946** to use a new technique called suction socket which used a reinforcing fiber Stockinet with acrylic resin material as a matrix [3]

Saw the period of time from **1955-1960** [4] witnessed using technology of thermosetting resin for lamination in socket of lower limb prosthetics, Also the sockets made of plastic were used that was a great successes at that time and they are also used for the amputation below the knee and above the knee.

The summary of developments in the manufacture of material of socket involves the use of wood, aluminum and new plastics as it is used now in many ways such as polypropylene and polyethylene or lamination method using (carbon fiber, glass fiber, , nylon, perlon)[5]

Sockets made from polypropylene material will adapted by ICRC (International Committee of the Red Cross) disadvantage of these materials is loss of mechanical properties with time [6]

Sockets made from composite material (layers of glass fiber and perlon with epoxy acrylic resin) broadly have good mechanical and physical properties based on the study provided by J.S.Chiad et al in 2009 [7] a wide range of number these layers in terms of yield stress and tensile stress and elastic modulus and choose the best ones and also studied creep fatigue Interaction on this type of lamination by Muhsin Jweeg et al in 2012 [8] but at the same time contain some defects as a result of the presence of fiber glass which is causing the patient's sensitivity in the skin (skin itch) when it comes in direct contact with the skin[9], but for the person who makes the socket, it causes skin allergies, allergic bronchitis which may lead to lung cancer as a result of the volatility of material into the air during the cut and softing sockets[10]

1. Monofilament Fiber:

This material is a classified polymeric material made from several materials (polymers, Polyamide, Polyester, Copolyester, Polypropylene, Polyethylene, Polyphenylene sulfide, Polyvinylidene fluoride) The formation of the fibers monofilaments is by extrusion process [11].

2. Experimental Part

2.1. Manufacturing of Above Knee Socket Laminations

2.1.1. Materials of Prosthetic Socket

There are two material using in the manufacture of prosthetic socket

1. Available prosthetic socket material, The socket made from these materials:
   - Knit from perlon.
   - Woven from glass fiber.
   - Laminations resin 80:20 polyurethane.
   - Hardening powder.
2. Suggestion prosthetic socket material, The socket made from these materials:
   - Knit from perlon.
   - Woven from Monofilament and cotton.
   - Laminations resin 80:20 polyurethane.
   - Hardening powder.

2.1.2. Equipment to Manufacture Prosthetic Socket

Gypsum mold: Mold is made of gypsum material with an external shape of parallelogram with dimensions of 12 cm 12 cm 30 cm. This mold underwent operations sculpt and refine of the surface because the inner surface of the material to be manufactured will take the form of the outer surface of the mold see figure (1a)

Vacuum system: consisting of pipes, valves, vacuum pump is used this system for suction of the air completely out of the two spaces, the first is between the first bag and the gypsum mold, the second is space between the two bags .the purpose of vacuum in the first space is to take shape of gypsum mold perfectly and make sure there are no bubbles to change the external shape of the mold, the second is space for suction of air from the space in which the casting process is made and to ensure there are no bubbles in the cast see figure (1b).

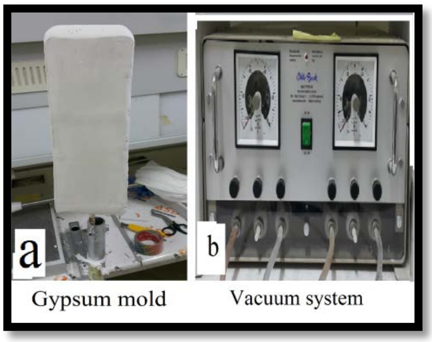


Figure (1): The equipment to made material prosthetic socket

2.1.3. Procedure Manufacturing Prosthetic Socket

- Make gypsum mold sculpted and refined as this dimensions 12cm 12cm 30cm as shown in figure (2a)
- Put the first piece from the PVA on the gypsum molds as shown in figure (2b) and suction the air between PVA and gypsum by the vacuum system.
- Putting the first Knit of perlon as shown in figure (2c) that density is 0.01331g / cm^2
- For available material Putting the mat from glass fiber the direction fiber 0˚,90˚ with density is 0.0269 g/cm^2. For suggestion material Putting the woven from Monofilament and cotton the direction fiber 90˚, 0˚ Respectively and rotate the second layer as direction fiber 0˚,90˚ Respectively as shown in figure (2d) with density is 0.0271 g/cm^2.
- Putting the second Knit of perlon as shown in figure (2e) that density is 0.01331 g / cm^2.
- Put the second piece from the PVA and suction the air between two bags by the vacuum system. Mix the laminations resin with hardening powder put this mixture on these layers as distributed equally as shown in figure (2f).

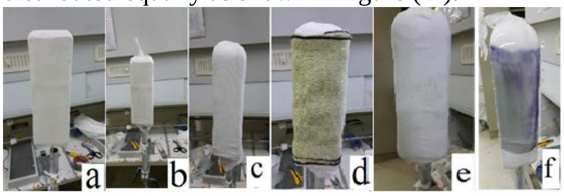


Figure (2): Procedure for made material of prosthetic socket

2.2. Tensile Test

This test was done at Al- Nahrain University in Mechanical Engineering Department by the tensile test machine (Testometric) as shown in figure (3). The tensile test is important to detect the mechanical properties of materials such as (yield stress, ultimate stress, modulus of elasticity, yield strain ….act). The specimens used in the tensile test are cut by CNC machine and according to ASTM D638 type 1 **[12]** as shown in figure (4) . All specimens were tested at strain rate equal to 2 mm/min.

Figure (3): The tensile test machine (Testometric)

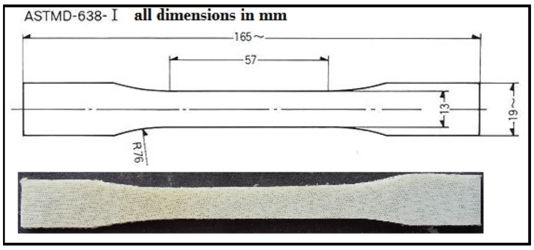


Figure (4): Tensile test specimens and the dimensions for available and suggested material.

2.3. Fatigue Test

Fatigue is a form of failure that occurs in material when socket subjected to dynamic and fluctuating stresses as a result of walking. The fatigue properties of the tested material can be described by scheme stress against a number of cycle curve (S-N curve), using fatigue machine (HSM20) as shown in figure (5). This machine applied the alternating bending stress at rotational speed 24 rps. The alternating bending fatigue specimens were manufacturing according to manual of the machine **[13]** as shown in figure (6). All calculation (length and deflection of testing) done according to the nomogram in manual of the machine.

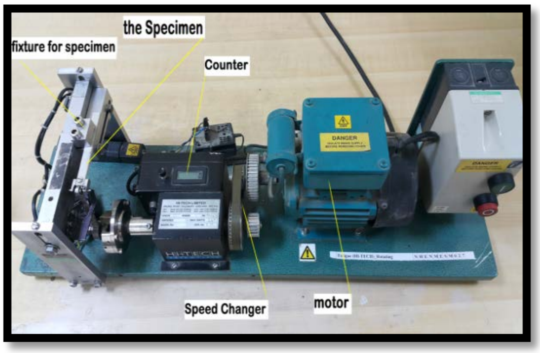


Figure (5): Fatigue test machine (HSM20)

Figure (6): Fatigue test specimens and the dimensions for available and suggested material.

2.4. Measure the Interface Pressure

The interface pressure between the residual limb and socket measured by using the F-Socket sensor as shown in figure (7). Connect the sensor with a computer program (F-Scan) to obtain the image showing the distribution and values of the pressure subjected on the sensor. Put the sensor on four regions in the residual limb (front, back, side internal and external). The data extracted from this program to be useful in the simulation program ANSYS. This test dons in Department of Engineering of Prosthesis and Orthotics at the Al-Nahrain University. Data of the case study listed in the table (1).

Table (1): Data of the patient was conducting examinations process

Gender	female
Age	24
Weight	49 kg
Length	155 cm
Type of imputation	AK
Side imputation	Lift leg

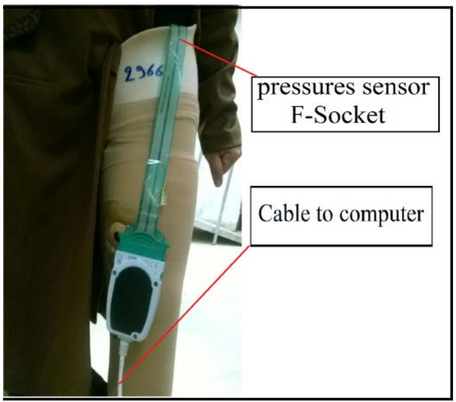


Figure (7): Position of sensor of pressure for patient with AK

3. Numerical Analysis for Above Knee Prosthetic Socket

The finite element method (FEM) is now extensively used in the multi purposes fields in engineeringand science, taking the advantage of the rapid development of digital computers with large memory capacity, as well as, fast computation.

The method is recognized as one of the most powerful numerical methods because of its capabilities which include complex geometrical boundaries and non-linear material properties. In this work, FEM with the aid of ANSYS workbench 14.5 software is used as a numerical tool to illustrate the effect of the fatigue performance in a structure element to determine the behavior of stress distributions contour, total deformations, and areas of safety factor **[14]**.

The general analysis by using ANSYS workbench version 14.5 has three distinct steps they are:

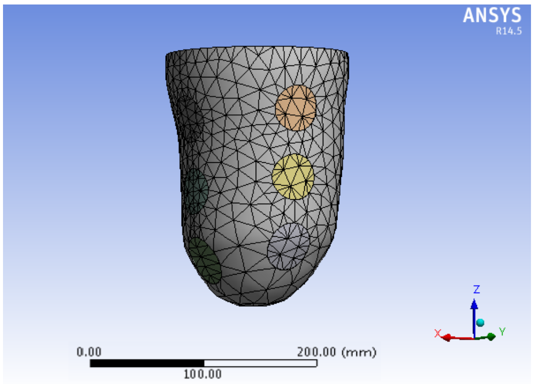
- Building the geometry as a model.
- Applying the conditions of boundaries load and get the solutions.
- Reviewing the results.

3.1 Graphing of the Above Knee Prosthetic Socket Geometry

In this paper selection available and suggested material sockets model drawn using Auto CAD program which processed according to an default pattern in three dimensions .the dimension was taken from the same sockets that done on it measurement of interface pressure. The aim of drawing models by this program so as for using in the simulation program ANSYS workbench 14.5, the socket models as shown in fig 8.

3.2. Mesh of the Model

The meshing process has been done by choosing the volume, and then the shape of element was selected as tetrahedron (Automatic meshing), for The prosthetic socket as shown in figure 8. This meshing contain on 8493 elements and (3621 nodes according to automatic ANSYS elements and nodes counter.



Figure(8): The model of above knee socket with meshing.

4. Result and Discussion

4.1. Experimental Results

4.1.1. Mechanical Properties

The mechanical properties as (σ_y, σ_{ult} and E) of each tested material represent the average value for three attempts are listed in **Table.2**. These properties will be used later in the fatigue test, as well as these properties are the key data in the program ANSYS 14.5 to simulate the prosthetic socket and analyze stress and deformation and safety factor.

Table (2): The mechanical properties of the material tested.

Material	suggested	available
Yield stress σ y (MPa)	12	22.41
Ultimate stress σ ult (MPa)	30	33.65
Modulus of elasticity (E) (MPa)	1342	941
Poisson's ratio(υ)	0.24	0.245

4. 1.2. Fatigue Properties Results

The relationship between the stress and the number of the cycle from fatigue testing gives an indication of the behaviour in terms of fatigue life is illustrated in figure 9. These results are come by using specimens for each stress level. The stress endurance of suggested material is higher than that of available material by 140%.

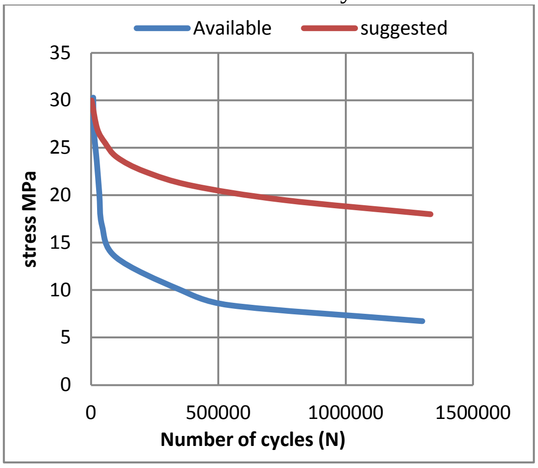


Figure (9): S-N fatigue tests curve for available and suggested material S1.

4.1.3. Interface Pressure Results

After conducting tests and extracting the results of interface pressure at four regions Anterior, Lateral, Posterior, and Medial, this region was divided to three parts upper, middle and bottom. The positions and values of the pressure on the inner sides of the socket are as detailed in Table (3). These values of interface pressure were used as a boundary condition for the prosthetic socket in simulation program ANSYS 14.5.

Table (3): Values of interface pressure on locations selected of the prosthetic socket.

Socket regions	Sensor positions	Interface pressure kPa
Anterior	A U	129
	A M	117
	A B	107
Lateral	L U	26
	L M	49.6
	L B	63.8
Posterior	P U	126
	P M	51.2
	P B	80
Medial	M U	93
	M M	54.4
	M B	78

4.2 The Numerical Results

There are two cases of prosthetic socket which were analyzed by simulation program (ANSYS), first case was the available prosthetic socket material (4 perlon 2 fiberglass 4 perlon) and second case was the suggested prosthetic socket material.

The equivalent Von-Mises Stresses analysis gave us knowledge on the amounts of stress and spread in the socket. The highest stress value reached was 20.7 MPa in the socket made from available material as shown in figure (10) and for the socket made from the suggested material was 18 MPa as shown in figure (11).

The deformation analysis gave us knowledge on the amounts of total deformation and the location in the socket that reached the highest deformation value of 13 mm in the socket made from available material as shown in figure (12) and for the socket made from the suggested material it was 7.7 mm as shown in figure (13).

The minimum equivalent stress-safety factor for the available prosthetic socket is equal to 0.32 as shown in figure (14) and for the suggested prosthetic socket was 1.05 as shown in figure (15).

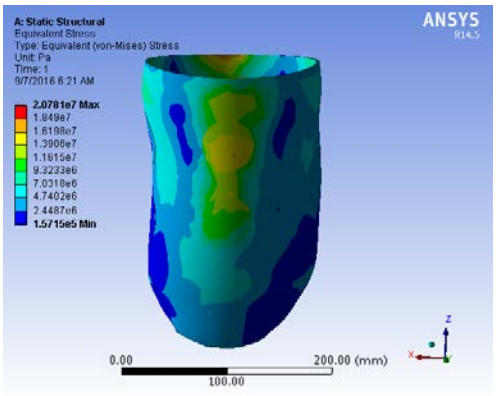


Figure (10): Von-Mises stress of available prosthetic socket material

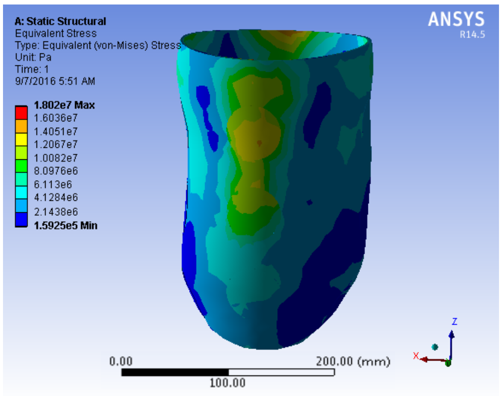


Figure (11): Von-Mises stress of suggested prosthetic socket material

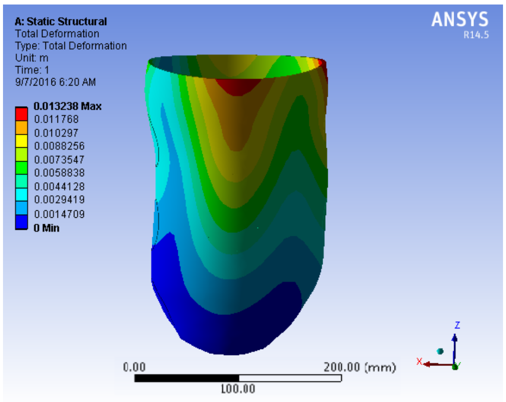


Figure (12): Total deformation for available prosthetic socket material

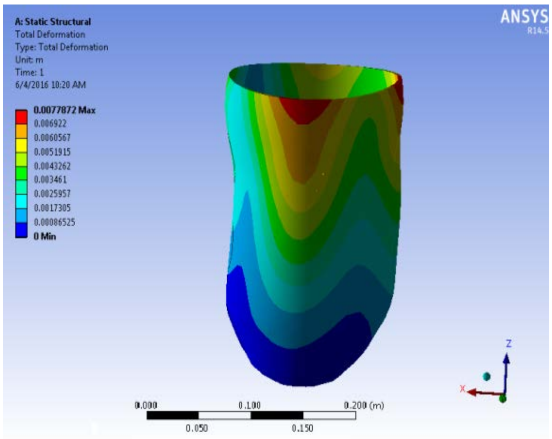


Figure (13): Total deformation for suggested prosthetic socket material

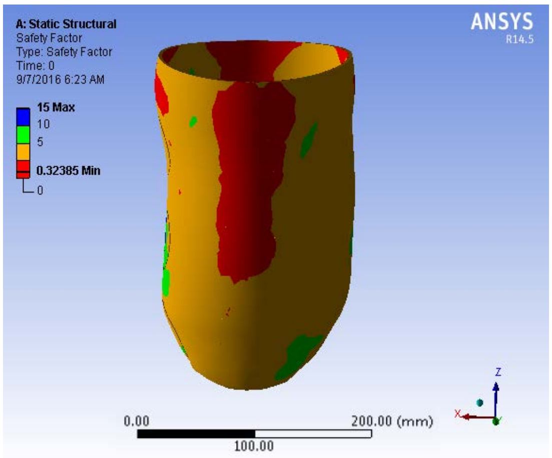


Figure (14): The equivalent stress-safety factor for available material

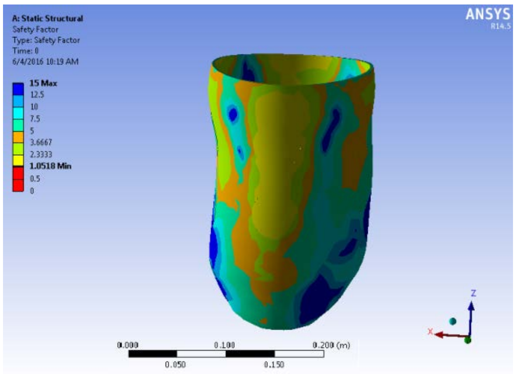


Figure (15): The equivalent stress-safety factor for suggested material

5. Conclusions

1. The suggested material has reduction in values of yield stress and ultimate stress by 45.4% and 10.6% respectively but in value of modulus of elasticity increase by 42.6% occurred comparing with available material.
2. The suggested material has increase in the stress endurance by 140% compared with available material.
3. The minimum safety factor in suggested material has increased compared with available material from 0.32 to 1.05.

References

1. Statistics in the hospital Ibn al-Quff center of Baghdad for prosthesis and orthosis

2. Sethi, P.K , " Technological Choices In Prosthetics and Orthotics for Developing Countries" , prosthetic and orthotics international ,13,pp.117-124,1989

3. C.w radcliffe "Above –Knee Prosthetic" the Knud Jansen lecture ,new-yourk,1977.

4. J. foort "Innovation in Prosthetic and Orthotic" the Knud Jansen lecture, copenhsgen, 1986.

5. R. Stewart "Socket Stress Distribution " Monash rehabilitation technology research ,Monash Australian international university ,1998.

6. Nguyen Hai Thanh " Polypropylene Prosthetic Component for Knee-Disarticulation Prosthesis" J. of Ortholetter .Viol .2 , No.12,July, 2003.

7. Muhsin Jweeg, Kadhim K. Resan and Mustafa Taraq “Study of Creep-Fatigue Interaction In A Prosthetic Socket Below Knee” ASME 2012 International Mechanical Engineering November 9-15, 2012, Houston, Texas, USA IMECE2012-85240.

8. J.S.Chiad , M.J.jweeg & S.S.Hasan “Effects of Lamination Layers on the Mechanical Properties for Above Knee Prosthetic Socket” Eng.&Tech.Journal,Vol.27,No.4,2009.

9. "13th Report on Carcinogens". National Toxicology Program. US Dept HHS. 2011. Retrieved 5 Feb 2013.

10. "Fibrous Glass Dust". OSHA. U.S. Department of Labor. 2002

11. John R. Wagner Jr., Eldridge M. Mount III, Harold F. Giles Jr “Extrusion the Definitive Processing Guide and Handbook” Second Edition (2014).

12. American Society for Testing and Materials International "Standard Test Method for Tensile Properties of Plastics" D 638, 2000.

13. Alternating Bending Fatigue Machine Instruction Manual HSM20.

14. Akeel Zeki Mahdi, " Design and Analysis of Knee Ankle Foot Orthosis " Thesis , University of Technology 2012

اقتراح مادة جديدة لتصنيع وقب طرف اصطناعي لبتر فوق الركبة باستخدام تصفيح الياف احادية افتيلة والقطن والبرلون

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الخلاصة

انتشر في الآونة الاخيرة استخدام الياف الزجاج في تصنيع صفائح الأوقاب الصناعية، لما تتميز به هذه الالياف من قوه وصلادة، وقلة التكلفة ولكن هنالك أمور يجب مراعاتها أهم من هذه المواصفات بكثير، وهي السلامة الصحية. ففي هذا البحث تم استبدال ألياف الزجاج بألياف احادية الفتيلة لكي تكون أكثر سلامة، على المصنع والمستخدم لذلك الوقب. وقد تم في هذا البحث تصنيع نموذجين من تصنيع الصفائح ومقارنتهما من حيث الخواص الميكانيكية وعمر الكلل. الاول وهو المتاح يتكون من: (4 برلون, 2 الياف الزجاج, 4 برلون) وأما التصفيح الثاني وهو المقترح واللذي يتكون من: (4 برلون, 1 قطن, 1 المونوفايلمنت, 4 برلون) وقد أجريت محاكات الوقب المصنع من تصنيع الصفائح الاولى والثانية عن طريق برنامج ANSYS 14.5 لمعرفة توزيع الاجهادات ومقدار التشوه و اقل معامل الأمان لكلا الحالتين. حيث بينت النتائج الميكانيكية زيادة بمقدار 42 % في معامل المرونة ونقصان في إجهاد الشد وإجهاد الخضوع بمقدار 10.8 % و 46% على التوالي. أما بالنسبة الى إجهاد التحمل فشهد زيادة بمقدار 140 %. أما نتائج المحاكات فشهدت نقصان في التشوه بمقدار 40.7% وزيادة في أدنى قيمة لمعامل الأمان من 0.323 إلى 1.05.