Characterization and Buckling Investigation of Composite Materials to be used in the Prosthetic Pylon Manufacturing

Hayder Zaher Abdalikhwa¹, Mohsin Abdullah Al-Shammari² and Emad Qasem Hussein¹

¹ University of Kerbala, Mechanical Engineering
² Universities of Baghdad, College of Engineering, Department of Mechanical Engineering, Iraq
E-mail: hyder.z@uokerbala.edu.iq

Abstract. A prosthetic pylon is a part of an artificial lower limb, which is a very interesting area of biomedical engineering today. The research aims to show the hung innovations and developments of new suggested composite material, to modify the prosthetic pylon (which is generally made of lightweight metal such as aluminum, titanium, stainless steel, or an alloy of these), extends its life and increase the comfort of its user. Vacuum bagging technique was used to manufacture the samples which consist of constant perlon layers and a different number of composite material (Carbon or Glass) fiber layers as reinforcement materials at (0º/90º) orientation relative to the applied load and polymethyl methacrylate (PMMA) as a resin. The work included two major parts; theoretical and experimental tests for the real case. The theoretical and experimental results showed that the modulus of elasticity, tensile strength, and critical buckling load increase with the increasing the number of composite fiber layers. The percentage of increase in modulus of elasticity, tensile strength and critical buckling load for the specimen with three carbon layers and perlon layers in PMMA matrix was compared with three glass layers and perlon layers in PMMA matrix specimen and it was (12.5%, 5% & 17%) respectively, at (0º/90º) fibers orientation relative to the applied force. Validation of the results is conducted by comparing with results in other literature, a good agreement between them was found.

Keyword. Pylon, Composite fibers, Buckling analysis, Tensile test, Vacuum bag technique.

1. Introduction
At the end of the last century and after the widespread use of composite materials in various industries such as aircraft, ships, cars, space, and biomedical applications, many of these polymer composites have been developed and reinforced with synthetic fibers in line with these uses. Composite materials consist of two main parts; fibers which are the elements that are usually strong and carry the load, and matrix, in which the fibers are combined, and where the loads are redistributed between adjacent fibers that will be obtained [1]. The efficiency of fiber-reinforced compounds depends on the manufacturing process that can transfer pressure from the matrix to the fiber in addition to the type of these fibers, the number of layers, and the arrangement of these layers. In the manufacture of artificial limbs, a prosthetic pylon which is manufactured from composite materials under a mechanical vacuum has good mechanical properties, and
low cost compared with metal prosthetic pylon. Therefore, it is used in biomedical applications, prosthetic limb for socket and foot [2]. Glenn K. Klute, et al. studied the mechanical properties of VSAP vertical shock absorbing pylons to standardized loading conditions to evaluate the effect of VSAP on amputee gait [3]. Priyadarsini et al. have conducted an experimental and numerical (FEM) study on buckling layered composite cylinders made of carbon fiber reinforced plastics (CFRP).

In this study, the effects of geometric properties, different types of loadings, lamina lay –up and amplitudes of imperfection on the strength of the cylinders under compression were studied [4]. Albert designed an adjustable prosthesis by using FEM where he specified shear stresses total deformation, the max, Von-Mises stresses and shear stresses.

He developed the lower limb (knee joint, adjustable pylon, ankle joint, and foot) and the lower part was made of beach wood and the upper part was made of aluminum. The results indicated that total deformation occurs at of the adjustable leg and hear stresses total deformation, the max, Von-Mises stresses and shear stresses occur at the edge of the upper part with support [5]. Mohsen conducted (tensile, impact, and fatigue) tests on pylon made of composite materials (a different number of layers of perlon with carbon fibers) as reinforcement materials and (acrylic) as a matrix.

It was shown that the number of layers of perlon increases, the mechanical properties increase and all pylons were inexpensive and lightweight [6]. SHASMIN studied pylon made from bamboo instead of metallic materials such as aluminum and titanium, and it was found through mechanical properties such as (compression, flexural, and tensile) that pylon made from bamboo (which is cost effective), is stronger than the other made from aluminum [7]. COLEMAN inspected two types of a pylon, a solid pylon made of aluminum and a flexible pylon made of nylon. The effect of elasticity on the strength of the reaction of the ground was observed [CRFs]. The results showed that the pylon made of nylon is more flexible and comfortable, which helps the amputee to walk more quickly [8].

Thurston suggested a leg below the knee using composite materials of resin and glass fiber. The leg was rigid and flexible to certain limits, allowing the use of energy storage properties while walking [9]. Lengvarsky, et al studied the buckling behavior of the rectangular composite plates with different orientations and layers (with four diverse layer directions and three, six, and twelve layers). They have proven that the critical buckling force increase with increasing thickness of the composite plate and increase of layers. Also, the orientation of layers affects the values of critical buckling load, for instance, the composite plate with three layers and the introduction of layers [90o / 0 ] is more sensitive to pressure work [10].

Therefore, the buckling behavior investigation was compared with other researchers to improve the critical buckling load by different techniques and reinforce with powder materials and Nano materials [11-16]. Also, the improvement for composite mechanical properties was investigated by many researchers. The improvement for mechanical properties lead to significant improvement of the mechanical behavior with. Thus, the mechanical properties are improved by reinforcement with different fiber types and powder materials, in addition to various types of nano material and amounts [17-35].

This paper aims to study the influence of volume fraction and number of carbon reinforcing fibers (one, two, and three) layers, in addition to the constant number of perlon fibers layers in PMMA resin on the tensile properties and critical buckling stress. The study also covers the effect of using glass fibers instead of carbon fibers in this composite on those properties.

2. Theoretical part

From the Euler equation [36], we can calculate the critical buckling load of the composite column:

$$P_{cr} = \frac{\pi^2 E_l}{I}$$

Where; C: The end condition number, when both ends are free for pivot use (C=1), L: Length of the column (m), A: Cross-section Area (m2), E: Modulus of elasticity (GPa), and I: Moment of inertia (m4).
3. Experimental part

There are two major experimental parts, the first is manufacturing composite specimens using the vacuum bagging technique and the second is determining the characteristics of the studied composite depending on the results of performing the buckling and tensile tests.

3.1. Materials used in the research

The materials used in the manufacturing of specimens in this research are as follows and shown in Fig. (1).

1. Polyvinylalcohol PVA bag (ottobock health care 99B71).
2. Perlon stockinet white or (polyamide 6) (ottobock health care 623T3).
3. Glass fiber
4. Carbon fiber (ottobock health care 616G15).
5. Poly methyl methacrylate (PMMA) resin.
6. Hardening powder (ottobock health care) is adding to the resin with the percentage (80:20). At room temperature to prepare the matrix.

The mechanical properties of these materials are shown in Table (1) and Figure (1).

| Fiber type   | Young's modulus (Gpa) | Tensile strength (MPa) | Elongation (%) | Poisson's Ratio | Density (gm/cm³) | State        |
|--------------|-----------------------|------------------------|----------------|-----------------|------------------|--------------|
| Carbon       | 230                   | 3800-4200              | 0.6-2          | 0.2             | 1.78             | Woven        |
| Glass        | 72                    | 3450                   | 4.3            | 0.21            | 2.58             | Woven        |
| PMMA         | 2.24-3.24             | 3625                   | 2.8            | 0.35            | 1.19             | Liquid (resin)|
| Perlon       | 2.6-3                 | 530-875                | 1-30           | 0.39            | 1.13             | Knit         |

3.2. The procedure of Samples’ Manufacturing

After manufacturing the mold from gypsum with dimensions (30 * 20 * 5) (cm)³, the inner Polyvinylalcohol (PVA) bag was applied and then the layers (Perlon, Glass fiber, or carbon fibers) were applied according to the sample as in the way stated in Table (2) and shown in Figure (1). The outer PVA was set, and the top end was left open for resin supply. A hole was made near the lower end to remove air bubbles by using a vacuum device Figure (2 a). PMMA resin mixture is prepared by adding a relative to a percentage (80:20). The specimens were prepared by using a vacuum bagging technique with pressure reach up to (5MPa) as shown in Figure (2 b).
Table 2. Type of samples.

| Group Name | Type of materials  | Fiber stockinet layers | Total No. of layers |
|------------|--------------------|-------------------------|---------------------|
| Group A    | PMMA+Glass layers at (0º/90º) + Perlon layers | (2 perlon+ 1 glass fiber + 2 perlon) | 5                   |
| Group B    | PMMA+Glass layers at (0º/90º) + Perlon layers | (2 perlon+ 2 glass fiber + 2 perlon) | 6                   |
| Group C    | PMMA+Glass layers at (0º/90º) + Perlon layers | (2 perlon+ 3 glass fiber + 2 perlon) | 7                   |
| Group D    | PMMA+Carbon layers at (0º/90º) + Perlon layers | (2 perlon+ 1 carbon fiber + 2 perlon) | 5                   |
| Group E    | PMMA+Carbon layers at (0º/90º) + Perlon layers | (2 perlon+ 2 carbon fiber + 2 perlon) | 6                   |
| Group F    | PMMA+Carbon layers at (0º/90º) + Perlon layers | (2 perlon+ 3 carbon fiber + 2 perlon) | 7                   |

3.3. Tensile test

To determine the mechanical properties of the samples produced, a tensile test must be performed. This test was done by using the material testing machine as shown in Figure (3). The tests aim to estimate the values of the modulus of elasticity, yield stress, and ultimate stress for each material used for the suggested prosthetic pylon. Using a computer numeric control machine (CNC) for each sample, the specimens were cut according to the dimension of the American Society for Testing and Materials (ASTM) D638 [38]. The specimens were machined as shown in figure (4). Thickness varied along with the type of the layup lamination (G1, G2, G3, G4, G5, and G6) as shown in Table (3). Next, at room temperature specimens were used in the tensile test carried out at the speed of 5 mm/min by tensile testing machine with capacity load of (5 KN) [39-47].
The tests were applied for the specimens for each sample in the laboratories of the Ministry of Higher Education and Scientific Research in Iraq - University of Technology. Figure (5) shows the specimens before and after testing.

**Figure 4.** Specimen for tensile test.

(a) Before test.  
(b) After tensile test.

**Table 3.** The mechanical properties of composite specimens for prosthetic pylon.

| Proper                      | 2 Perlon layers +Different Glass fiber layers +2 Perlon layers+PPMA | 2 Perlon layers +Different Carbon fiber layers +2 Perlon layers+PPMA |
|-----------------------------|---------------------------------------------------------------------|---------------------------------------------------------------------|
|                             | 1 layer (G1)  | 2 Layers (G2) | 3 Layers (G3) | 1 Layers (G4) | 2 Layers (G5) | 3 Layers (G6) |
| $E_1$ (GPa)                 | 1.63         | 2.35         | 3.696        | 1.71         | 2.468        | 4.426        |
| $E_2$ (GPa)                 | 1.63         | 2.35         | 3.696        | 1.71         | 2.468        | 4.426        |
| $E_3$ (GPa)                 | 1.5          | 1.5          | 1.5          | 1.5          | 1.5          | 1.5          |
| $v_{12}$                    | 0.338        | 0.326        | 0.318        | 0.345        | 0.330        | 0.336        |
| $v_{23}$                    | 0.35         | 0.35         | 0.35         | 0.35         | 0.35         | 0.35         |
| $v_{13}$                    | 0.35         | 0.35         | 0.35         | 0.35         | 0.35         | 0.35         |
| $G_{12}$ (GPa)              | 0.809        | 1.048        | 1.121        | 0.940        | 1.022        | 1.053        |
| $G_{23}$ (GPa)              | 0.829        | 0.829        | 0.829        | 0.829        | 0.829        | 0.829        |
| $G_{13}$ (GPa)              | 0.829        | 0.829        | 0.829        | 0.829        | 0.829        | 0.829        |
3.4. Buckling test
The second type of composite material specimens prepared in this work is the buckling test specimen (18). The specifications of specimens that were taken into consideration for this test are illustrated in Table (4). Fig. (6) shows the geometry of buckling test specimens, and Fig. 7 shown the buckling test machine.

Table 4. Specimens specifications prepared for buckling test.

| No. of sample | Angle of fiber (0º/90º) | Volume of fraction (%) | Width (mm) | Width (mm) | Thickness (mm) | Length (mm) | Aspect ratio L/T % | NO. of layers | Critical Load(N) |
|---------------|--------------------------|------------------------|------------|------------|----------------|-------------|-------------------|---------------|-----------------|
| G1            | (0º/90º)                 | 28%                    | 20         | 20         | 2              | 220         | 11                | 5             | 40.2            |
|               |                          |                        |            |            |                | 250         | 12.5              |               | 30.3            |
| G4            | (0º/90º)                 | 28%                    | 20         | 20         | 2              | 220         | 11                | 5             | 45.1            |
|               |                          |                        |            |            |                | 250         | 12.5              |               | 34.3            |
| G2            | (0º/90º)                 | 30%                    | 20         | 20         | 2.6            | 220         | 8.4               | 6             | 130             |
|               |                          |                        |            |            |                | 250         | 9.6               |               | 99.6            |
| G5            | (0º/90º)                 | 30%                    | 20         | 20         | 2.6            | 220         | 8.4               | 6             | 152.3           |
|               |                          |                        |            |            |                | 250         | 9.6               |               | 115.4           |
| G3            | (0º/90º)                 | 32%                    | 20         | 20         | 3              | 220         | 7.3               | 7             | 319.5           |
|               |                          |                        |            |            |                | 250         | 8.3               |               | 250.6           |
| G6            | (0º/90º)                 | 32%                    | 20         | 20         | 3              | 220         | 7.3               | 7             | 385             |
|               |                          |                        |            |            |                | 250         | 8.3               |               | 301.4           |

(a) Before test. (b) After test.

Figure 6. Specimens of buckling test: (a) before test, and (b) after test.
4. Results and discussion

4.1. Effect of aspect ratio and volume fraction on critical load

Figures (8-10) show the effect of aspect ratio and volume fraction of composite column (suggested samples for pylon) on critical load for glass and carbon fibers. These figures proved that when the fiber volume fraction increase, the critical load increased because the fibers have high values of stiffness and this leads to increase in the stiffness of composite specimens which improves buckling resistance. As anticipated, the fiber volume fraction is a significantly important factor for improving the buckling resistance. Also, the figures indicate that when the column length (aspect ratio) increases, the buckling resistance decreases for two reinforced layers.

Figure 8. The critical load and Aspect ratio for (G1 and G4) at volume fraction 28%

Figure 9. The critical load and Aspect ratio for (G2 and G5) at volume fraction 30%.
4.2. *The tensile strength and number of reinforcing layers*

The specimens with layers of reinforcing fibers of carbon have the highest modulus of elasticity and failure strength than specimens with layers of reinforcing fiber glass. In addition, the specimens with three layers of reinforcing fiber carbon have the highest modulus of elasticity and failure strength than specimens with one or two layers of reinforcing fiber carbon. Usually, the fibers are stiffer and stronger than matrix because they have higher strength and modulus of elasticity than the matrix. So, the increase of layers of fibers to resin means an increase of strength and modulus of elasticity for composite specimens, as shown in Figs. (11&12).

![Figure 10. The critical load and Aspect ratio for(G3 and G6) at volume fraction 32%](image)

4.3. *The Elongation percentage and number of fiber layers*

The specimens which have glass reinforcing layers have highest elongation percentage in comparison with specimens of carbon reinforcing layers. The highest elongation percentage value was found with specimens of one glass reinforcing layers which was (8%). On the other hand, the lowest value was in specimens consisting of three carbon reinforcing layers of about (4 %), as shown in Fig. (13). Increasing
the number of carbon reinforcing layers leads to a decrease in the elongation percentage for specimens because the carbon fibers are stiffer than the glass fiber and thus imposes a mechanical curb on the specimens. Also, the interphase between the fibers and PMMA resin plays an important role in elongation percentage, strong structure (higher interphase) that results in a decrease in the elongation for specimens.

![Figure 13](image1.png)

**Figure 13.** The elongation percentage and number of fiber layers.

### 4.4. Comparison between experimental and theoretical results

Therefore, the results of the current study required comparison with other results evaluated by another technique [48-60]. The bar charts of figures (14-17) highlight a very good agreement between experimental and theoretical results obtained in this work with a maximum discrepancy of 7%. Then, the experimental and theoretical techniques were in agreement, which can be used to calculate the load of composite with different parameter effects [61-77].

![Figure 14](image2.png)

**Figure 14.** Critical load & aspect ratio of glass fiber.

![Figure 15](image3.png)

**Figure 15.** Critical load & aspect ratio of carbon fiber.
5. Conclusions
The following points can are concluded from this work:

1. In mechanical properties (modulus of elasticity, tensile strength, and critical buckling load), the percentage of increase for a specimen have three (carbon) layers and perlon layers compared with a specimen with three (lagss) layers and perlon layers of (12.5%, 5% & 18%) respectively.
2. Modulus of elasticity and tensile strength increase with increasing the number of reinforcing fiber layers (carbon or glass) at direction (0º/90º) of fibers relative to tensile load. The higher values of these properties are found with specimens that have three carbon fibers layers, equal to (4.426GPa and 172MPa) respectively.
3. Modulus of elasticity and tensile strength are the mechanical properties that increase with increasing fiber volume fraction for two types (glass and carbon) fiber.
4. Elongation percentage is the mechanical properties in specimens that have three carbon layers and specimens of three glass layers of (4.8% and 8%) respectively.
5. The critical load of composite columns increases with increasing fiber volume fraction for two types of reinforcing layers (glass and carbon) fiber.
6. The theoretical and experimental results of critical load are reasonably good. The maximum difference between theoretical and numerical results was (7%).

6. References
[1] Pietropaoli E and Riccia A 2012 Finite Element Analysis of the Stability (Buckling and Post-Buckling) of Composite Laminated Structures:Well Established Procedures and Challenges (Journal of Appl Compos Mater) vol 19 pp 79–96
[2] Allan G A Coombes, Christopher D Greenwood and John J Shorter 1996 Human Biomaterials Applications (Springer Science + Business Media New York)
[3] Glenn K Klute, Carol F Kallfelz and Joseph M Czerniecki 2001 Mechanical Properties of Prosthetic Limbs : Adapting to the Patient ( J of Rehabilitation Research & Development) vol 38 no 3 pp 87–101
[4] Priyadarsini Kalyan and Srinivasan S M 2012 Numerical and Experimental Study of Buckling of Advanced Fiber Composite Cylinders under Axial Compression
[5] Albert E Yousif and Ahmed Ali Sadiq 2012 *The Design, Development and Construction of an Adjustable Lower Extremity* (Journal of Engineering) vol 2

[6] Muhsin J, Kadhim K and Muhand N 2010 *Design and Manufacturing of a New Prosthetic Low Cost Pylon for Amputee* (Journal of Engineering and Development) vol 14 no 4

[7] Shasmin H N, N A Abu Osman and L Abd Latif 2008 *Economical Tube Adapter Material in Below Knee Prosthesis* (Department of Biomedical Engineering, University of Malaysia) vol 21

[8] Coleman K L, Boone D A, Smith D G and Czerniecki J M 2001 *Effect of Trans-tibial Prosthesis Pylon Flexibility on Ground Reaction Forces During Gait* (Prosthetics and Orthotics International) vol 25 no 3

[9] Thurston A J, J Rastorfer, H Burian, and A W Beasley 1989 *The Flek-Shine: A Composite Material for use in Flexible Shank Below-Knee Prosthesis* (Prosthetics and Orthotics International) vol 13

[10] Lengvarsky P, Bocko J and Hagara M 2016 *Buckling Analysis of the Composite Plates with Different Orientations of Layers* (American Journal of Mechanical Engineering) vol 4 no 7 pp 413–417

[11] Muhammad Al-Waily and Zaman Abud Almalik Abud Ali 2015 *A Suggested Analytical Solution of Powder Reinforcement Effect on Buckling Load for Isotropic Mat and Short Hyper Composite Materials Plate* (International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS) vol 15 no 14

[12] Muhammad Al-Waily, Alaa Abdulzahra Deli, Aziz Darweesh Al-Mawash and Zaman Abud Almalik Abud Ali 2017 *Effect of Natural Sisal Fiber Reinforcement on the Composite Plate Buckling Behavior* (International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS) vol 17 no 01

[13] Mohsin Abdullah Al-Shammari and Muhammad Al-Waily 2018 *Analytical Investigation of Buckling Behavior of Honeycombs Sandwich Combined Plate Structure* (International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)) vol 08 no 04 pp 771–786

[14] Jumaa S Chiad, Muhammad Al-Waily and Mohsin Abdullah Al-Shammari 2018 *Buckling Investigation of Isotropic Composite Plate Reinforced by Different Types of Powders* (International Journal of Mechanical Engineering and Technology (IJMET)) vol 09 no 09 pp 305–317

[15] Mahmud Rasheed Ismail, Zaman Abud Almalik Abud Ali and Muhammad Al-Waily 2018 *Delamination Damage Effect on Buckling Behavior of Woven Reinforcement Composite Materials Plate* (International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS) vol 18 no 05 pp 83–93

[16] Muhammad Al-Waily, Mohsin Abdullah Al-Shammari and Muhsin J Jweeg 2020 *An Analytical Investigation of Thermal Buckling Behavior of Composite Plates Reinforced by Carbon Nano Particles* (Engineering Journal) vol 24 no 3

[17] Muhsin J Jweeg, Ali S Hammood and Muhammad Al-Waily 2012 *A Suggested Analytical Solution of Isotropic Composite Plate with Crack Effect* (International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS) vol 12 no 05

[18] Mohsin Abdullah Al-Shammari, Emad Q Hussein and Ameer Alaa Oleiwi 2017 *Material Characterization and Stress Analysis of a Through Knee Prosthesis Sockets* (International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS) vol 17 no 06

[19] Ameer A Kadhim, Muhammad Al-Waily, Zaman Abud Almalik Abud Ali and Muhsin J Jweeg, Kadhim K Resan 2018 *Improvement Fatigue Life and Strength of Isotropic Hyper Composite Materials by Reinforcement with Different Powder Materials* (International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS) vol 18 no 02

[20] Ahmed Khaleel Abdelameer and Mohsin Abdullah Al-Shammari 2018 *Fatigue Analysis of Syme’s
Prosthesis (International Review of Mechanical Engineering) vol 12 no 03

[21] Lara E Yousif, Kadhim K Resan and Raad M Fenjan 2018 Temperature Effect on Mechanical Characteristics of A New Design Prosthetic Foot (International Journal of Mechanical Engineering and Technology (IJMET)) vol 09 no 13 pp 1431–1447

[22] Muhsin J Jweeg, Zaid S Hammoudi and Bassam A Alwan 2018 Optimised Analysis, Design, and Fabrication of Trans-Tibial Prosthetic Sockets (IOP Conference Series: Materials Science and Engineering, 2nd International Conference on Engineering Sciences) vol 433

[23] Ayad M Takhakh and Saif M Abbas 2018 Manufacturing and Analysis of Carbon Fiber Knee Ankle Foot Orthosis (International Journal of Engineering &Technology) vol 07 no 04 pp 2236–2240

[24] Saif M Abbas, Ayad M Takhakh, Mohsin Abdullah Al-Shammari and Muhammad Al-Waily 2018 Manufacturing and Analysis of Ankle Disarticulation Prosthetic Socket (SYMES) (International Journal of Mechanical Engineering and Technology (IJMET)) vol 09 no 07 pp 560–569

[25] Mohsin Abdullah Al-Shammari 2018 Experimental and FEA of the Crack Effects in a Vibrated Sandwich Plate (Journal of Engineering and Applied Sciences) vol 13 no 17 pp 7395–7400

[26] Ayad M Takhakh, Saif M Abbas and Aseel K Ahmed 2018 A Study of the Mechanical Properties and Gait Cycle Parameter for a Below-Knee Prosthetic Socket (IOP Conference Series: Materials Science and Engineering, 2nd International Conference on Engineering Sciences) vol 433

[27] Mohsin Abdullah Al-Shammari and Sahar Emad Abdullah 2018 Stiffness to Weight Ratio of Various Mechanical and Thermal Loaded Hyper Composite Plate Structures (IOP Conference Series: Materials Science and Engineering, 2nd International Conference on Engineering Sciences) vol 433

[28] Saif M Abbas, Kadhim K Resan, Ahmed K Muhammad and Muhammad Al-Waily 2018 Mechanical and Fatigue Behaviors of Prosthetic for Partial Foot Amputation with Various Composite Materials Types Effect (International Journal of Mechanical Engineering and Technology (IJMET)) vol 09 no 09 pp 383–394

[29] Muhsin J Jweeg, Muhammad Al-Waily, Ahmed K Muhammad and Kadhim K Resan 2018 Effects of Temperature on the Characterisation of a New Design for a Non-Articulated Prosthetic Foot (IOP Conference Series: Materials Science and Engineering, vol 433, 2nd International Conference on Engineering Sciences, Kerbala, Iraq, 26–27 )

[30] Ehab N Abbas, Muhsin J Jweeg and Muhammad Al-Waily 2018 Analytical and Numerical Investigations for Dynamic Response of Composite Plates Under Various Dynamic Loading with the Influence of Carbon Multi-Wall Tube Nano Materials (International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS) vol 18 no 06 pp 1–10

[31] Muhsin J Jweeg, Abdulkareem Abdulrazzaq Ahumdany and Ali Faik Mohammed Jawad 2019 Dynamic Stresses and Deformations Investigation of the Below Knee Prosthesis using CT-Scan Modeling (International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS) vol 19 no 01

[32] Fahad M Kadhim, Ayad M Takhakh and Asmaa M Abdullah 2019 Mechanical Properties of Polymer with Different Reinforcement Material Composite That used for Fabricates Prosthetic Socket (Journal of Mechanical Engineering Research and Developments) vol 42 no 4 pp 118–123

[33] Ehab N Abbas, Muhsin J Jweeg and Muhammad Al-Waily 2020 Fatigue Characterization of Laminated Composites used in Prosthetic Sockets Manufacturing (Journal of Mechanical Engineering Research and Developments) vol 43 no 5 pp 384–399

[34] Ekhlas Edan Kader and Akram Mahdi Abed 2020 Mohsin Abdullah Al-Shammari ‘Al2O3 Reinforcement Effect on Structural Properties of Epoxy Polysulfide Copolymer (Journal of Mechanical Engineering Research and Developments) vol 43 no 4 pp 320–328

[35] S E Sadiq, S H Bakhy and M J Jweeg 2020 Crashworthiness Behavior of Aircraft Sandwich
Structure with Honeycomb Core Under Bending Load (IOP Conference Series: Materials Science and Engineering)

[36] Assakkaf and I A 2003 Mechanics of Materials (Mc–Graw-Hill, 3rd edition)

[37] William D. Callister and Jr 2001 Fundamentals of Materials Science and Engineering (5th edition, John Wiley & Sons Inc.)

[38] American Society for Testing and Materials International 2000 Standard Test Method for Tensile Properties of Plastics D 638

[39] Marwah Mohammed Abdulridha, Nasreen Dakel Fahad, Muhammed Al-Waily and Kadhim K Resan 2018 Rubber Creep Behavior Investigation with Multi Wall Tube Carbon Nano Particle Material Effect (International Journal of Mechanical Engineering and Technology (IJMET)) vol 09 no 12 pp 729–746

[40] Abeer R Abbas, Kadhim A Hebeatir and Kadhim K Resan 2018 Effect of Laser Energy on the Structure of Ni46–Ti50–Cu4 Shape-Memory Alloy (International Journal of Nanoelectronics and Materials) vol 11 no 04 pp 481–498

[41] Worood Hussein and Mohsin Abdullah Al-Shammari 2018 Fatigue and Fracture Behaviours of FSW and FSP Joints of AA5083-H111 Aluminium Alloy (IOP Conference Series: Materials Science and Engineering, International Conference on Materials Engineering and Science) vol 454

[42] Abeer R Abbas, Kadhim A Hebeatir and Kadhim K Resan 2018 Effect of CO2 Laser on Some Properties of Ni46Ti50Cu4 Shape Memory Alloy (International Journal of Mechanical and Production Engineering Research and Development) vol 08 no 02 pp 451–460

[43] Yousuf Jamal Mahboba and Mohsin Abdullah Al-Shammari 2019 Enhancing Wear Rate of High-Density Polyethylene (HDPE) by Adding Ceramic Particles to Propose an Option for Artificial Hip Joint Liner (IOP Conference Series: Materials Science and Engineering, ICMSMT) vol 561

[44] Suhair Ghazi Hussein, Mohsin Abdullah Al-Shammari, Ayad M Takhakh and Muhammad Al-Waily 2020 Effect of Heat Treatment on Mechanical and Vibration Properties for 6061 and 2024 Aluminium Alloys (Journal of Mechanical Engineering Research and Developments) vol 43 no 01 pp 48–66

[45] Mohsin Abdullah Al-Shammari, Qasim H Bader, Muhammad Al-Waily and A M Hassan 2020 Fatigue Behavior of Steel Beam Coated with Nanoparticles under High Temperature (Journal of Mechanical Engineering Research and Developments) vol 43 no 4 pp 287–298

[46] Muhammad Al-Waily, Iman Q Al Saffar, Suhair G Hussein and Mohsin Abdullah Al-Shammari 2020 Life Enhancement of Partial Removable Denture made by Biomaterials Reinforced by Graphene Nanoplates and Hydroxyapatite with the Aid of Artificial Neural Network (Journal of Mechanical Engineering Research and Developments) vol 43 no 6 pp 269–285

[47] Dana Fadhil Abbas, Kadhim Kamil Resan and Ayad M Takhakh 2020 Microstructure, Mechanical and Corrosion Properties of the 50%Ni-47%Ti-3%Cu Shape Memory Alloy (3rd International Conference on Engineering Sciences, IOP Conference Series: Materials Science and Engineering) vol 671

[48] Muhhsin J Jweeg 1983 Application of Finite Element Analysis to Rotating Fan Impellers (Doctoral Thesis, Aston University)

[49] Muhhsin J Jweeg and S Z Said 1995 Effect of Rotational and Geometric Stiffness Matrices on Dynamic Stresses and Deformations of Rotating Blades (Journal of the Institution of Engineers (India): Mechanical Engineering Division) vol 76 pp 29–38

[50] Ekhlas M Alfayyad, Sadeq H Bakhy and Yasir M Shkara 2014 A New Multi-Objective Evolutionary Algorithm for Optimizing the Aerodynamic Design of HAWT Rotor (ASME 2014 12th Biennial Conference on Engineering Systems Design and Analysis, ESDA)

[51] Muhammad Al-Waily, Maher A R Sadiq Al-Baghdadi and Rasha Hayder Al-Khayat 2017 Flow Velocity and Crack Angle Effect on Vibration and Flow Characterization for Pipe Induce
Vibration (International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS) vol 17 no 05 pp19–27

[52] Kadhim K Resan, Abbas A Alasadi, Muhandd Al-Waily and Muhsin J Jweeg 2018 Influence of Temperature on Fatigue Life for Friction Stir Welding of Aluminum Alloy Materials (International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS) vol 18 no 02

[53] Mohsin Abdullah Al-Shammari, Lutfi Y Zedan and Akram M Al-Shammari 2018 FE Simulation of Multi-Stage Cold Forging Process for Metal Shell of Spark Plug Manufacturing (1st International Scientific Conference of Engineering Sciences-3rd Scientific Conference of Engineering Science, ISCES 2018–Proceedings)

[54] Sadeq Bakhy, Enass Flaieh and Mortada Jabbar 2018 An Experimental Study for Grasping and Pinching Controls for An Underactuated Robotic Finger using a PID Controller (2nd International Conference on Engineering Sciences, IOP Conference Series: Materials Science and Engineering) vol 433

[55] H J Abbas, M J Jweeg, Muhandd Al-Waily and Abbas Ali Diwan 2019 Experimental Testing and Theoretical Prediction of Fiber Optical Cable for Fault Detection and Identification (Journal of Engineering and Applied Sciences) vol 14 no 02 pp 430–438

[56] Russul A Kadhim, Ekhlas M Fayyadh and Sadeq H Bakhy 2020 Stirrer Speed Control Of A Fluidized Bed Dryer For Biomass Particles Using Pwm Technique (Plant Archives) vol 20 pp 673–680

[57] Hussein I Mansoor, Mohsin Abdullah Al-shammari and Amjad Al-Hamood 2020 Experimental Analysis of Cracked Turbine Rotor Shaft using Vibration Measurements (Journal of Mechanical Engineering Research and Development) vol 43 no 2 pp 294–304

[58] Mortada A Jabbar, Sadeq H Bakhy and Enass H Flaieh 2020 A New Multi-Objective Algorithm for Underactuated Robotic Finger During Grasping and Pinching Assignments (3rd International Conference on Engineering Sciences, IOP Conference Series: Materials Science and Engineering) vol 671

[59] Esraa A Abbod, Muhandd Al-Waily, Ziadoon M R Al-Hadrayi, Kadhim K Resan and Saif M Abbas 2020 Numerical and Experimental Analysis to Predict Life of Removable Partial Denture (IOP Conference Series: Materials Science and Engineering, 1st International Conference on Engineering and Advanced Technology, Egypt) vol 870

[60] S K Mahmoud, S H Bakhy and M A Tawfik 2020 Novel Wall-Climbing Robot Capable of Transitioning and Perching (IOP Conference Series: Materials Science and Engineering) vol 43 no 03 pp 47–64

[61] Najdat A Mahmoud, Muhsin J Jweeg and Muntaz Y Rajab 1989 Investigation Of Partially Pressurized Thick Cylindrical Shells (Modelling, simulation & control. B. AMSE Press) vol 25 no 03 pp 192–201

[62] Ghairth G Hameed, Muhsin J Jweeg and Ali Hussein 2009 Springback and Side Wall Curl of Metal Sheet In Plain Strain Deep Drawing (Research Journal of Applied Sciences) vol 04 no 05 pp 192–201

[63] Mahmud Rasheed Ismail, Muhandd Al-Waily and Ameer A Kadhim 2018 Biomechanical Analysis and Gait Assessment for Normal and Braced Legs (International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS) vol 18 no 03

[64] Rasha Hayward Al-Khayat, Maher A R Sadiq Al-Baghdadi, Ragad Aziz Neama and Muhandd Al-Waily 2018 Optimization CFD Study of Erosion in 3D Elbow During Transportation of Crude Oil Contaminated with Sand Particles (International Journal of Engineering & Technology) vol 07 no 03 pp 1420–1428

[65] Ragad Aziz Neama, Maher A R Sadiq Al-Baghdadi and Muhandd Al-Waily 2018 Effect of Blank Holder Force and Punch Number on the Forming Behavior of Conventional Dies (International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS) vol 18 no 04

[66] Muhsin J Jweeg, Kadhim K Resan, Esraa A Abbod and Muhandd Al-Waily 2018 Dissimilar
Aluminium Alloys Welding by Friction Stir Processing and Reverse Rotation Friction Stir Processing (IOP Conference Series: Materials Science and Engineering), International Conference on Materials Engineering and Science, Istanbul, Turkey) vol 454

[67] Muhannad Al-Waily, Emad Q Hussein and Nibras A Aziz Al-Roubaiee 2019 Numerical Modeling for Mechanical Characteristics Study of Different Materials Artifical Hip Joint with Inclination and Gait Cycle Angle Effect (Journal of Mechanical Engineering Research & Developments (JMERD)) vol 42 no 04 pp 79–93

[68] Muhannad Al-Waily, Moneer H Tolephih and Muhsin J Jweeg 2020 Fatigue Characterization for Composite Materials used in Artificial Socket Prostheses with the Adding of Nanoparticles (IOP Conference Series: Materials Science and Engineering, 2nd International Scientific Conference of Al-Ayen University) vol 928

[69] Hussein I Mansoor, Mohsin Al-shammari and Amjad Al-Hamood 2020 Theoretical Analysis of the Vibrations in Gas Turbine Rotor (3rd International Conference on Engineering Sciences, IOP Conference Series: Materials Science and Engineering) vol 671

[70] Muhsin J Jweeg, Salah N Alnomani and Salah K Mohammad 2020 Dynamic Analysis of a Rotating Stepped Shaft with and Without Defects (3rd International Conference on Engineering Sciences, IOP Conference Series: Materials Science and Engineering) vol 671

[71] Sadiq emad Sadiq, Muhsin Jaber Jweeg and Sadeq Hussein Bakhy 2020 The Effects of Honeycomb Parameters on Transient Response of an Aircraft Sandwich Panel Structure (2nd International Scientific Conference of Al-Ayen University (ISCAU-2020), IOP Conference Series: Materials Science and Engineering) vol 928

[72] Marwah Ali Husain and Mohsin Abdullah Al-Shammari 2020 Analytical Solution of Free Vibration Characteristics of Partially Circumferential Cracked Cylindrical Shell (Journal of Mechanical Engineering Research and Developments) vol 43 no 3 pp 442–454

[73] Ehab N Abbas, Muhannad Al-Waily, Tariq M Hammza and Muhsin J Jweeg 2020 An Investigation to the Effects of Impact Strength on Laminated Notched Composites used in Prosthetic Sockets Manufacturing (IOP Conference Series: Materials Science and Engineering, 2nd International Scientific Conference of Al-Ayen University) vol 928

[74] Sadiq emad Sadiq, Sadeq Hussein Bakhy and Muhsin Jaber Jweeg 2020 Effects of Spot Welding Parameters on the Shear Characteristics of Aluminum Honeycomb Core Sandwich Panels in Aircraft Structure (Test Engineering and Management) vol 83 pp 7244–7255

[75] Hasan Dawood Salman, Sadeq Hussein Bakhy and Mohsin Noori Hamzah 2020 Design and Optimization of Coupled and Self-Adaptive of an Underactuated Robotic Hand Using Particle Swarm Optimization (2nd International Scientific Conference of Al-Ayen University (ISCAU-2020), IOP Conference Series: Materials Science and Engineering, vol 928)

[76] Akeel Z Mahdi, Samir A Amin and Sadeq H Bakhy 2020 Influence of Refill Friction Stir Spot Welding Technique on the Mechanical Properties and Microstructure of Aluminum AA5052 and AA6061-T3 (3rd International Conference on Engineering Sciences, IOP Conference Series: Materials Science and Engineering) vol 671

[77] S E Sadiq, S H Bakhy and M J Jweeg 2020 Crashworthiness Behavior of Aircraft Sandwich Structure with Honeycomb Core Under Bending Load (IOP Conference Series: Materials Science and Engineering)