Experimental and Numerical Measurement of the Impact Strength of Poly-lactic Acid through a Low-velocity Impact

Ali Jasim Mohammed Al-Behadili and Bashar Owaid Bedaiwi

Department of Mechanical Engineering, College of Engineering, Al-Mustansiriyah University, Baghdad, Iraq

E-mail: ali_jassim@uomisan.edu.iq

Abstract. This paper presents the results obtained through experimental work and numerical simulation of the kinetic energy dissipation of lactic acid after application of the impact load. The experimental tests were performed according to ASTM standards using the motion drop arrow test. It has been designed according to the standard ASTMD7136. The specimens were plates completely constrained with two edges by the clamping fixture. Two energy absorption parameters (namely saturation impact energy and damage degree), and two relevant characteristic values of the impact force history (namely the first damage force and the maximum force) were included. The impact energy of 2.4 J was measured by the difference in the thickness mode. The finite element method was used by FE symbol (Abaqus / Explicit Dynamic) implemented by a User Defined Sub routine (VUMAT). The results showed areas of shock injury and sample tolerance, and there was a match between the experimental and numerical results. Diagrams are presented to show the history of relevant kinematical, dynamic and energetic quantities, both to synthesize the dependency of the energy parameters and force threshold values on the impact velocity. This study will help to measure the absorbed and kinetic energy of polymers, thus, it will help define the properties of polymers used in critical applications such as medicine.

Key word. Impact, Poly-lactic Acid, Low velocity impact.

1. Introduction
The poly-lactic acid (PLA) is an attractive candidate for replacing petrochemical polymers because it is biodegradable and produced from annually renewable resources. Characterized by high tensile strength and excellent optical properties, PLA has been developed and made commercially available in recent years [1]. PLA has good mechanical properties, thermal plasticity, biocompatibility, and is readily fabricated, thus being a promising polymer for various end-use applications. Properties such as high tensile strength, high gloss and clarity, good heat seal-ability, and low coefficient of friction make PLA a suitable candidate for a wide variety of applications [2]. Economic challenges and environmental safety have prompted scientists and producers to find an alternative to petrochemical-based polymers to environmentally friendly polymers [3]. Static mechanical analysis and dynamic mechanical analysis were a test to examine the polymerase properties. The static mechanical analysis limits performance, precision, ability of the tool to detect real problems and slowness [4]. Compound covers were widely used to produce insubstantial mechanisms in automotive, microchip technology and airplane constructions. Though, the use of composites for making outside parts is still incomplete because these parts may be exposed to an amount of severe impacts arising from working events, e.g.,
collision, flying wreckage, tool drop or bird strike. On one hand, since composites exhibit limited plastic deformation, the impact injury can be beneficial as it develops the main energy debauchery mechanism [5]. In this study, composite materials from CFRP carbon fiber-reinforced plastic were used, and experimental and numerical approaches were used to investigate the strength of shock and energy, where the number of fiber layers was used differently [6]. In the current study, post-effect mechanical behavior was investigated. It was used in the experiment of carbon nanotubes (MWCNTs) as enhanced flax / carbon fiber nanomaterials (FLXC) and flax / fiberglass (FLXG) hybrid composites. Impact energies ranging from 5J to 20J, with different types of surfaces were exposed to Collider to compare their response under load. Post-collision pressure (CAI) A test was performed to evaluate the post-effect properties of the hybrid compounds [7]. In this work the researchers investigated the effects of hybridization of tenaf and fiberglass to develop hybrid compounds with different weight ratios on the low velocity effect response and post-effect properties of the compounds obtained in this work. Four main processes were performed in this study, namely vehicle fabrication and low speed impact testing. Four collision energy levels 10 J, 20 J, 30 J and 40 J were practiced to study the publishing of the impact of the polymer with optimal configuration [8]. This study presents a three-dimensional failure model to predict the response of dynamic materials to chips composite under shock loading, reducing stiffness during the collision damage process. The materials model was implemented in an explicit finite element LS-DYNA The code is within solid elements and has proven its ability to reproduce experimental results with good accuracy in terms of constant /dynamic replies, absorbed energy, and damage extent [9]. This study dealt with composite materials, the damages resulting from the effect of composite films on the form of cracks within and between the plates. The study included experimental and numerical tests, damage stress modeling and fracture technique, and finite element (FE) method to simulate the pattern. The numerical results gave good overall agreement when compared to the experimentally obtained curves from impact force and absorbed energy versus time. Various damage mechanisms were introduced meanwhile. In this paper, the researchers dealt with the difference in thickness between samples, as well as the difference in velocity, in order to determine the damage caused by shock, and to identify the strength. A user defined 3D damage model (VUMAT) with solid objects was developed and implemented in the Abaqus / Explicit finite element code to predict the type and extent of damage through the thickness of the plates.

2. Material and methods

2.1. Specimen preparation

Samples were processed using a Tevo Tornado 3D printer. Polycystic acid (PLA) was used according to ASTMD7136 stacks, [10-18]. Dimensions were 150 * 100 and different thicknesses. The model was drawn in a 3-max program and the file was converted in stl format, and transferred to the repetier program, which is a program to cut the pattern and control the sample density as well as the print speed of sample time. Figure 1. shows the sample design.
2.2. Material properties

In order to determine the mechanical properties of the PLA panels, it was therefore necessary to measure the mechanical properties of the base materials, [19-32]. Samples were printed according to the standards A STMD638 [33]. The test samples printed in the tensile testing machine at the Technological University in the Department of Materials were examined. The device had a load cell of 10 KN and the properties of the materials were evaluated by the elastic modulus and the Poisson ratio of the printed samples, Figure 2. Table 1 shows the mechanical properties of PLA.

| Mechanical properties of 3D printed PLA samples. |
|-----------------------------------------------|
| Young's modulus (MPa) | Ultimate strength (MPa) | Ultimate strain (u) | Plastic Poisson’s ratio (υp) |
|---------------------|------------------------|-------------------|---------------------------|
| 1000                | 46                     | 0.021             | 0.38                      |

2.3. Low-velocity impact tests

Low velocity influence tests and their job on various 3D printed polymer sheets as illustrated in Table 2 with a low heaviness machine based on the instructions in ASTM D7136 [34]. Collider block was 1 kg in diameter, 16. mm with a semi-spherical tip. Throughout the impact examination, the specimen was tied on both sides and 12.5 mm apart (see Figure 3). Adequate clamping compression was applied.
to prevent the sample from sliding during the experimentations. The two parameters measured in the experiment were the shock load during the shock test time. The impact force was measured by (FSR, Penetration Force Sensor, 10.5 kN). The change in the total energy of the impactor was also calculated by the impactor’s speed, mass and load according to the next equation; \( E(t) = m \left( V_i^2 - V_f^2 \right) + m \cdot g \cdot z(t) \), where \( E(t) \) is the energy of the impactor which was expected to be equivalent to the energy of the 3D printed board at time (associated with the prompt where the impactor touches the top expression of the panel).

Figure 3. 3D printed polylactic acid impact test.

2.4. Numerical
The Abaqus/Explicit code was used to track the numerical FE model where the proposed failure starts and fracture criteria were implemented composed with the shear trace material model described in the earlier sections [35-46]. Suitable geometrical models were structured and kinematic and loading boundary conditions were defined to represent the investigational set up.

2.5. Geometrical modeling and boundary conditions
The model was created in the program according to the standard. The dimensions of the sample were 150 * 100 with a thickness of 4, and all the dimensions are in mm. A part was selected and the rectangle was chosen to place the mentioned dimensions. After that, the mechanical properties were placed through an icon in the program characteristics. All the modulus of elasticity, yield stress, mass density and Poisson ratio, as well as conditional limits such as Two-sided fixing method were fixed tightly in all directions. The weight of the influencing ball, was positioned setting the ball velocity and restricting the displacement (U1, U2, UR1, UR2, UR3) only towards the movement in the direction of Z. (Consider rewriting)

2.6. Finite element
All calculations were performed with the ABAQUS / Explicit 16.9.1 commercial program using the User Materials (VUMAT) subroutine. The model consists of two parts, as shown in Fig.4; impact material and polymer, and collider diameter of 16 mm. The polymer plate consisted of eight three-dimensional solid nodes, reduced integration elements (Abaqus element type: C3D8R), a hexagonal
grid used, and the number of elements was 8300, calculated by using mesh generation technique [47-61]. The contact state between the first part (collider) and the second part (polymer) was determined during the time period of 0.005 seconds. The stress-strain curve of the PLA elastic-perfectly plastic specimen was assumed for FEM investigation [62-75]. Geometric nonlinearity was also measured for the examination to reflect the big distortion that occurred during the speed influence test of 3D printed plate.

Figure 4. Finite element sample of PLA under influence loading.

3. Results and discussions

3.1. Impact force
Two important jobs in low speed analysis are contact force and absorbed energy. In this section, we will present and explain the history of communication power and energy absorbed through practical and numerical experiences. The date and time (f-t) curves consist of an ascending section from loading to peak strength, and a descending section from discharging. In the f-t curve, the oscillations show the possibility of material failures because of the low material rigidity, and any sudden drop in strength does not indicate that the material has higher resistance under the influence of lower velocity. The peak strength on the f-t curve was an important indicator for assessing the carrying capacity of the polymer after impact. Before the peak force value is reached, the smooth trend on the f-t curve represents the polymer's elastic response, and the first sudden drop in strength reveals a crack development. The damaged polymer gap (PLA) and the occurrence of discharging indicates the maximum strength value which indicates a sudden decrease in the force value to the occurrence of cracks on the side of the damaged part in the panels.

Figure (5a) shows the oscillations obtained starting from the period 0 ms to 10 ms, where the maximum frequency shows the value of the maximum force. The forces obtained experimentally 230N were close to the forces obtained through 240N numerical simulation and the ratio between them was 4%. In the figure, we notice an increase in the value of the acting forces, which is due to the resistance of the material to the force and its cohesion, Figure (5b). As for the shape, we notice the effect of the force from 0 ms to 4 ms, and the maximum force of the experimental work was 137 N. There is a force obtained through simulation 142 N with a ratio between them as 3%. This is due to the lack of influence because of the thickness of the influencing sample. As for figure (5C), it shows the beginning of the period 0 mm to 10 mm. The forces 95 N were obtained experimentally, as for two numbers 105 N, the ratio was 38%. This was less effective, which makes the collider easy to penetrate the sample due to the lack of thickness. Through the test observation of the samples, there is dissolution of the material particles and failure that occurs in the sample, leading to breaking the sample with the lowest thickness during different periods. As samples were printed at 100% density, this different behavior of oscillations is due to the type of printing and the accuracy of the printer in operation. Likewise, the smaller the sample thickness, the less the force effect, so it is easier to penetrate the pattern. A thickness of 4.5 mm and an increase in strength resistance were observed. The materials used are similar to the brittle material. Observation of tensile tests and impact tests indicate there is no elongation or bending in the material.
Figure 5. The contrast plots of force – time from exploratory and numerical results for the case of 2.2 J of influence energy.
Table 2. Shows the impactor energy of 3D printed poly-lactic acid.

| Energy Impactor (J) | Velocity Impactor (m/s) | Thickness (mm) | Demeter Impactor (mm) | Density % |
|---------------------|-------------------------|----------------|-----------------------|-----------|
| 2.49                | 2.2                     | 3.5            | 16                    | 100       |
|                     |                         | 4              |                       |           |
|                     |                         | 4.5            |                       |           |

3.2. Effects of damage

Figure 6. shows the type of influence that affects the sample. Although the collider energy was the same across all samples, we observe a difference in this type of impact depending on the thickness of the sample. With a thickness of 4.5 mm, the damage was less than the thickness of 4.35 mm and the highest damage was as shown in Fig 6. With a thickness of 3.5 mm, due to insufficient resistance, the hardness of the material was reduced and also the thinnest sample which had the greatest impact resistance to the impact force. A crack occurred in all samples. The crack was in the form of a straight line sometimes extending to the edges of the sample, and the impact point was 60. The effect that occurs with the samples is small and continues to increase the impact of the collider. The effect of materials was due to the behavior and properties of the material.

Figure 6. Shows the type of effect through numerical and experimental methods for different thickness of samples. A. 4.5 mm, B. 4 mm and C. 3.5 mm.
4. Conclusions
In this paper, the impact response and the damaging effect of the type of poly-lactic sheet were investigated. An experimental and numerical study was performed under three different power levels. An effect-based failure criterion was used. During the damage spread in the model, results and observations were compared regarding peak strength, displacement and energy. The numerical simulations were accurately captured. The physical behavior was less accurate, and the model predicted was of less expected energy absorbed by the permanent deformation strike during the impact of 2.4 joules. This decrease is likely due to the variation in the material properties and the quality of the printed sample.

5. References
[1] Tokiwa, Yutaka and B P Calabia 2006 Biodegradability and Biodegradation of Poly (Lactide) (Applied microbiology and biotechnology) vol 72 no 2 pp 244–251
[2] Nam, J Young, M Okamoto, H Okamoto, M Nakano, A Usuki and M Matsuda, 2006 Morphology and Crystallization Kinetics in a Mixture of Low-Molecular Weight Aliphatic Amide and Polylactide (Polymer) vol 47 no 4 pp 1340–1347
[3] Jamshidian, Majid, E A Tehrany, M Imran, M Jacquot and S Desobry 2010 Poly-Lactic Acid: Production, Applications, Nanocomposites, and Release Studies (Comprehensive reviews in food science and food safety) vol 9 no 5 pp 552–571
[4] Anderson and Paul 2008 The use and Limitations of Static-Analysis Tools to Improve Software Quality (CrossTalk: The Journal of Defense Software Engineering) vol 21 no 6 pp 18–21
[5] Yudhanto, Arief, et al 2019 Revealing the Effects of Matrix Behavior on Low-Velocity Impact Response of Continuous Fiber-Reinforced Thermoplastic Laminates (Composite Structures) vol 210 pp 239–249
[6] Hou, Yuliang, et al 2019 Low-Velocity Impact Behaviors of Repaired CFRP Laminates: Effect of Impact Location and External Patch Configurations (Composites Part B: Engineering) 163 pp 669–680
[7] Ismail, K I, et al 2019 Low Velocity Impact and Compression After Impact Properties of Hybrid Bio–Composites Modified with Multi–Walled Carbon Nanotubes (Composites Part B: Engineering) vol 163 pp 455–463
[8] Ismail, Muhammad F, et al 2019 Low Velocity Impact Behavior and Post–Impact Characteristics of Kenaf/Glass Hybrid Composites with Various Weight Ratios (Journal of Materials Research and Technology) vol 8.3 pp 2662–2673
[9] Donadon, M V, et al 2008 A Progressive Failure Model for Composite Laminates Subjected to Low Velocity Impact Damage (Computers & Structures) vol 86 no 11–12 pp 1232–1252
[10] 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
[11] Kadhim K Resan, Abbas A Alasadi, Muhammad 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
[12] Ayad M Takhakh, Saif M Abbas and Aaseel 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
[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] Muhsin J Jweeg, Kadhim K Resan, Esraa AABBod and Muhammad Al-Waily 2018 Dissimilar Aluminium Alloys Welding by Friction Stir Processing and Reverse Rotation Friction Stir Processing (IOP Conference Series: Materials Science and Engineering, vol 454, International Conference on Materials Engineering and Science, Istanbul, Turkey, 8 August, 2018)
[15] 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

[16] Fahad M Kadhim, Jumaa S Chiad and Maryam Abdul Salam Enad 2020 Evaluation and Analysis of Different Types of Prosthetic Knee Joint Used by above Knee Amputee (Defect and Diffusion Forum Journal) vol 398 pp 34–40

[17] Dania 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

[18] 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

[19] Muhsin J Jweeg 1983 Application Of Finite Element Analysis To Rotating Fan Impellers (Doctoral Thesis, Aston University)

[20] Mohannad Al-Waily and Zaman Abud Almalik Abud Ali 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 04

[21] 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

[22] Mahmud Rasheed Ismail, Muhammad 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

[23] Fahad M Kadhim, Jumaa S Chiad and Ayad M Takhakh 2018 Design And Manufacturing Knee Joint for Smart Transfemoral Prosthetic (IJOP Conference Series: Materials Science and Engineering, International Conference on Materials Engineering and Science) vol 454

[24] Ragad Aziz Neama, Maher A R Sadiq Al-Baghdadi and Muhammad 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

[25] Ayad M Takhakh, 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

[26] 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

[27] 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 (IJOP Conference Series: Materials Science and Engineering, ICMSM) vol 561

[28] 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 Aluminum Alloys (Journal of Mechanical Engineering Research and Developments) vol 43 no 01 pp 48–66

[29] Sadiq emad Sadiq, Muhsin Jaber Jweeg and Sadeq Hussein Bakhy 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

[30] S E Sadiq, S H Bakhy and M J Jweeg 2020 Crashworthiness Behavior Of Aircraft Sandwich Structure with Honeycomb Core Under Bending Load (IJOP Conference Series: Materials Science and Engineering)
[31] 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

[32] 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

[33] Laureto, John J and Joshua M Pearce 2018 *Anisotropic Mechanical Property Variance Between ASTM D638-14 Type I and Type Iv Fused Filament Fabricated Specimens* (Polymer Testing) vol 68 pp 294–301

[34] Caputo, G Lamanna, A De Luca, R Borrelli and S Franchitti, 2013 *SDHM Structural Durability and Health Monitoring* vol 9 no 3 pp 253–267

[35] Najdat A Mahmood, Muhsin J Jweeg and Mumtaz Y Rajab 1989 *Investigation Of Partially Pressurized Thick Cylindrical Shells* (Modelling, simulation & control B AMSE Press) vol 25 no 03 pp 47–64

[36] Jumaa S Chiad 2014 *Study the Impact Behavior of the Prosthetic Lower Limb Lamination Materials due to Low Velocity Impactor* (ASME 2014 12th Biennial Conference on Engineering Systems Design and Analysis, ESDA, 2014, July 25–27)

[37] 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

[38] Rasha Hayder Al-Khayat, Maher A R Sadiq Al-Baghdadi, Ragad Aziz Neama and Muhammad 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

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

[40] 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

[41] Bashar Awaid Bedaiwi and Heider Abd Ali Abdalkadum 2018 *The Effect of Temperature on Stress Relaxation Behaviours in Bovine Cortical Bones* (2nd International Conference on Engineering Sciences, IOP Conference Series: Materials Science and Engineering) vol 433

[42] 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)

[43] Marwah Mohammed Abdulridha, Nasreen Dakel Fahad, Muhammad 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

[44] 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

[45] Mohsin Abdullah Al-Shammari, Qasim H Bader, Muhammad Al-Waily and A M Hasson 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] Bashar A Bedaiwi and Jumaa S Chiad 2012 Vibration analysis and measurement in the below knee prosthetic limb part I: Experimental work (ASME 2012 International Mechanical Engineering Congress and Exposition, Proceedings (IMECE))

[48] Bashar A Bedaiwi 2013 Analyzing of Impact, Vibration Response and Stability of Artificial Upper Limb (American Society of Mechanical Engineering, ASME 2013 International Mechanical Engineering Congress and Exposition, Biomedical and Biotechnology Engineering) vol 3B

[49] Muhannad Al-Waily, Maher A R Sadiq Al-Baghdadi, 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 pp 19–27

[50] Bashar O Bedaiwi 2017 Vibration Transimmiton of Human Femuer Bone Due to Massage Device (International Journal of Applied Engineering Research) vol 12 no 24 pp 15101–15106

[51] Noor Dhia Yaseen, Jumaa S Chiad and Firas Mohammed Abdul Ghani 2018 The Study and Analysis of Stress Distribution Subjected on the Replacement Knee Joint Components using Photo-Elasticity and Numerical Methods (International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)) vol 08 no 06 pp 449–464

[52] Saif M Abbas, Ayad M Takhakh, Mohsin Abdullah Al-Shammari and Muhannad 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

[53] 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

[54] Mahmoud Rasheed Ismail, Zaman Abud Almalik Abud Ali and Muhannad 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

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

[56] H J Abbas, M J Jweeg, Muhannad 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

[57] Muhannad Al-Waily, Mohsins 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

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

[59] Ali Jasim Mohammed Al-Behadili and Bashar Owaid Bedaiwi 2020 Measurement of Absorbed Energy of the Polylactic Acid (PLA) via Numerical Simulation (Journal of Mechanical Engineering Research and Developments) vol 43 no 5 pp 428–435

[60] Hasan Dawood Salman, Sadeq Hussein Bakhy and Mohsins 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

[61] 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

[62] Mohammed H Mahmou Alhamdo, Bashar A Bdaawi and Ali H Hasan 2014 Transient Response of Different Highly Conductive PCM Composites (Springer Proceedings in Physics)
[63] Ameer A Kadhim, Muhammad Al-Waily, Zaman Abud Almalik Abud Ali, Muhsin J Jweeg and 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 IJME-IJENS) vol 18 no 02

[64] Jawad K Olewif and Ahmed Namah Hadi 2018 Experimental and Numerical Investigation of Lower Limb Prosthetic Foot Made From Composite Polymer Blends (International Journal of Mechanical and Production Engineering Research and Development) vol 08 no 02 pp 1319–1330

[65] Yusra Alyas Shafeeq, Jumaa S Chiad and Yassr Y Kahtan 2018 Study, Analysis, the Vibration and Stability for the Artificial Hand During its Daily Working (International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS) vol 18 no 02

[66] 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

[67] Muhsein Abdallah 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

[68] Muhsein 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, 2nd International Conference on Engineering Sciences, Kerbala, Iraq, 26–27 March) vol 433

[69] Heider Abd Ali Abdalkadum, Bashar Awaied Bedaiwi 2018 Temperature Effects on Creep Behaviour of Bovine Cortical Bones’ International Conference on Materials Engineering and Science (IOP Conference Series: Materials Science and Engineering) vol 454

[70] 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

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

[72] S K Mahmood, S H Bakhy and M A Tawfik 2020 Novel Wall-Climbing Robot Capable of Transitioning and Perching (IOP Conference Series: Materials Science and Engineering)

[73] Esraa A Abbod, Muhammad Al-Waily, Ziaoon 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

[74] Fahad M Kadhim, Ayad M Takhakh and Jumaa S Chiad 2020 Modeling and Evaluation of Smart Economic Transfemral Prosthetic (Defect and Diffusion Forum Journal) vol 398 pp 48–53

[75] Muhammad 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