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3D Model of Bone Scaffolds Based on the Mechanical Behaviour for a Hybrid Nano Bio-composites

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ABSTRACT

Ceramic/polymer Nano composites in the view of possessing design uniqueness and property combinations have gained a great attention and reported to be the materials of the 21st century that are not found in conventional composites. In the present work, an attempt has been made to study, develop and improve the bio-mechanic for a designed and fabricated Ceramic/polymer bio-composite for a human natural bone repair and replacement in the case of complex fracture and bone diseases by adding the Nano fillers ceramic particles to the Polymer Matrix Nano composites (PMNC) for fabricated a hybrid Titanium dioxide and yttria stabilized zirconia reinforced high density polyethylene (HDPE) matrix bio-composites properties. These bioactive composites have been investigated by using hot pressing technique at different compression pressures of (30, 60, and 90 MPa) at a compounding temperature of (180, 190, and 200 °C). The SOLIDWORKS 17.0 and the finite element ANSYS 15.7 software programs were used to the simulation, modelling and analysing of femur bone biomechanics that can withstand the highest stresses and strains. The response surface methodology (RSM) technique was used to improve and verify the results. For all the fabricated Nano bio-composites systems, the results showed that the obtained output parameters values were increased with increasing the process input parameters, also the vice versa for the strain energy and equivalent elastic strain values, also the Nano ceramic compositions represented the main factor influenced the results. The main investigates results of the current research deduced that for the increase of the Nano ceramic powder (TiO_2*) contain from 1% to 10%, the compression fracture strength and the micro-Vickers hardness values increased by 50% and by 8.45%, respectively, and when adding 2% of zirconia (*ZrO_2*), an additional increase in the compression fracture strength and micro hardness by 28.21% and 40.19% achieved, respectively. When using 10%* TiO_2 *+ 2%* ZrO_2*/HDPE bio-composite at highest compact*

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temperature of 200 °C and compounding pressure of 90 MPa, the strain energy and the equivalent elastic strain reduced by 82.69% and 14.53% when compared with using of 1% TiO_2 content. While when increasing the nano ceramic content from 1% to 10% without adding the ZrO_2 nano filler, they reduced by 142.25% and 67.81%, respectively. The maximum equivalent von Misses stress obtained is equal to 39.957MPa and when increasing the nano ceramic content from 1% to 10%, the stress safety factors and fatigue live values increased by 58.38% and by 46.28%, respectively and when adding 2% of zirconia (ZrO_2), the stress safety factor reached its maximum values, with an additional increase in its values by 21.42% and 69.40%, respectively. These results give great choices to use successful in vivo tests and for a better life performance with any age, patient status and degree of injury.

Keywords: *Nano ceramic Bio-composites; ANSYS Femur bone modelling; Fatigue life; Finite element analysis; Bone biomechanics;*

Introduction

Bone is a living material with a complex hierarchical structure [1]. Bone fracture is a multi-scale susceptibility problem related to musculoskeletal loading, tissue properties, bone metabolism and other factors, such as material properties variations, bone loss and microstructure changes etc. [2-3]. Bone, as a composite, has a complex micro structural feature which has been a major challenge in mimicking its load-bearing performance [4]. For the future of osseous defects therapies, the Scaffold-based bone tissue engineering holds great promise.

Bone tissue engineering applies scientific principles to regenerate, repair, and restore the functions of defected hard tissues [5]. Four classes scaffolds materials can be categorized: polymeric, ceramic, composite, and metallic scaffolds [6-7]. The development and use of polymeric nano composites advanced materials in recent years have been expanded exponentially. In order to design polymeric nano composites in an efficient and safe manner, a substantial amount of research has been done [8].

In the past few years, the finite element analysis (FEA) has been increasingly adopted to study the mechanical behaviour of biological structures and the comparisons between the experimental testing results and those obtained from FEA and reveal a close correlation [9]. A number of researchers are interested in using the 3D finite element analysis (FEA) to investigate the effect of loading conditions on the stress and strain distribution within the osteoporotic human femur bone tissue, i.e. the mechanical strength in human bone [10-15].

Polymer nano composites have attracted increasing attentions in recent years because of their significant improvement in mechanical performance, thermal stability and electrical properties. They are materials of a new class, incorporating an ultrafine dispersion of nano materials in a polymeric matrix [16]. Inorganic nano particles such as Zirconium dioxide (ZrO_2), titanium dioxide (TiO_2) and synthesized hydroxyapatite (HAP) have been used as Nano fillers in composites to improve the polymer properties [17-18].

In the latest past, TiO_2-filled polymers fabricated by melt compounding have been reported to improve the properties over a micron-sized particle-filled polymer composite. It was found that the addition of TiO_2 increased the impact and tensile strength of the polyethylene [8, 16]. High density polyethylene (HDPE) is a thermoplastic material, as a matrix component of bone implants, and has shown a great promise. Its structure consists of long chains of carbon and hydrogen atoms bonded with a variable branching, which determines its mechanical properties [8]. HDPE polymer has been proposed by Bonfield et. al, since the early 1980s as a matrix in HA/HDPE composite for bone repair application because of its optimum combination of mechanical, considerable bioactivity and biological performance which is closed to the bone structure [19-21]. It is used to obtain a high strength-to-density ratio. It is converted into ethylene from methane gas and then into polyethylene with the application of heat and pressure. It should be processed into porous scaffolds with high moldability and exhibits mechanical properties similar to those of the native bone and does not produce any toxins that hinder osteogenesis integration [22].

By adding small percentages of Yttrium oxide, also known as yttria (Y_2O_3), which is an air-stable and a very hard ceramic, the phase changes are eliminated, and the resulting material has superior thermal, mechanical, and electrical properties to produce yttria-stabilized zirconia (YSZ) or partially stabilized zirconia (PSZ). These oxides are commonly called "zirconia" (ZrO_2) and "yttria" (Y_2O_3), with a stable structure at the room temperature. YSZ has a number of applications for its hardness and chemical inertness, like tooth crowns, refractories, insulation, abrasives, electro-ceramics, jewellery, etc. [22].

The main aim of this work is to investigate the influence of adding titanium dioxide and partial stabilized zirconia (PSZ) nano ceramic fillers powders with different concentrations at different compression pressures and temperatures using the hot pressing fabricating technique on the mechanical properties for TiO_2/ HDPE and Y_2O_3- partial stabilized zirconia (Y-PSZ)/ TiO_2/ HDPE nano composites polymer matrices systems and to investigate the longest fabricated biomaterials fatigue lives and the highest stress factors of safety to withstand the loads of the daily human activities. The femur bone 3D geometry was created by using the SOLIDWORKS 17.0, analysed and modelled by using finite element ANSYS 15.0 software program. For improving and verifying the results, reaching and evaluating the optimal thermal and mechanical properties, the response surface methodology (RSM) technique and the Design Expert software program were used.

Materials and Methods

Nano composites Preparation method

Six nano composites systems; TiO_2/ HDPE and Y_2O_3- partial stabilized zirconia (Y-PSZ)/ TiO_2/ HDPE were prepared, fabricated and used in this study as bioactive material to be used as bone grafting bio-composite materials. The two types of ceramic filler were used; the titanium dioxide (TiO_2) of 99% purity with an average particle size of 40 nm and a particle density of 4.23 g/cm^3 supplied by M.K Nano (Canada, Toronto) and the partially-stabilized zirconia (ZrO_2-PSZ) which was doped with 3 mol. % of yttria (Y_2O_3). The Y-PSZ nano powder of 99.9% purity with an average particle size of 40 nm and density of 5.91 g/cm^3 was supplied by M.K. Nano (Canada, Toronto). The used biomaterial powder matrix was the high-density polyethylene (HDPE) with particle size of 5 μm and a density of 0.95 gm/cm^3, supplied by Right Fortune Industrial Limited (China, Shanghai).

In this work, three groups of experiments were prepared using concentration contents of titanium dioxide ceramic filler as 1, 5 and 10% TiO_2, without use of Y_2O_3- partial stabilized zirconia (Y-PSZ).Other three groups of experiments were also prepared using the same concentration contents of titanium dioxide ceramic filler as 1, 5 and 10% TiO_2, but with the use of 2 % PSZ.

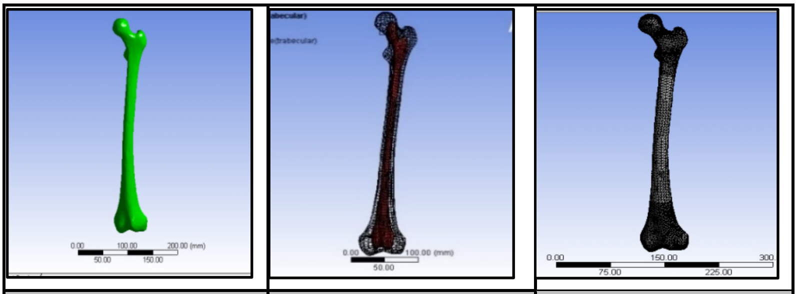
The prepared powders were first dry mixed with the each desired composition in a ball mill machine for 12 hr and then hot pressed at 180, 190, and 200 °C at a compounding pressure of 30, 60, and 90 MPa, respectively to obtain cylindrical shaped test samples with 10 mm diameter and a height varying between 3 and 5 mm. Figure 1 shows the fabricated hot-pressed system installed on the Instron testing machine, where the diametrical compression test was used to measure the fracture strength. This test is used for simple geometry and loading conditions like “dog bone” shaped specimens, which are too difficult to process or machine into the ASTM standard [23].

Figure 1: The fabricated hot pressed systems (1), installed on the Instron testing machine (2); thermostats (3) connected to the digital temperature control system (4)

Modelling and Analysis of Femur bone

It is difficult to assign the material properties along each direction of human bone model as it is solid, inflexible and highly heterogeneous and nonlinear in nature [10]. The human femur bone 3D geometry was modeled as a static problem by using the 3D Solid works 17.0 software and analyzed using the finite element module ANSYS WORKBENCH® 15.7 Multiphysics software, as shown in Figure 2a.

The bone material was assumed as homogeneous, isotropic and perfectly elastic [11]. The femur bone model was implemented by two components, namely the spongy cancellous (trabecular) covered by a thin layer of compact trabecular bone as illustrated in Figure 2b.



(a) (b) (c)

Figure 2: Modeling of femur bone; (a) human femur bone 3D geometry; (b) the natural inner trabecular and outer cortical bone parts; (c) the FEA meshing refinement of the natural bone

Boundary Conditions

The 3D Finite element method (FEM) was used to find the numerical solution and to simulate the stress distribution for a different loading conditions model of the implant femur bone [24-26]. Finite element modelling is an important tool for stress analysis of bones as a key to assessment of fracture risk, understand bone remodelling, and to the designing of fracture fixation [27-28].

The meshing process was imported in ANSYS with triangle surface, 3 degrees of freedom meshed elements as presented in Figure 2c. The number of nodes and elements for the model was about 39893 and 19419, respectively. The boundary conditions with the field equations govern the deformation and stress fields for the femur bone.

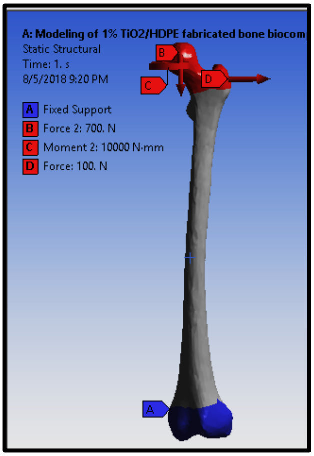
To simulate the stress and strain fields corresponding to the patient activities, two types of boundary conditions imposed. The elastic modulus of trabecular bone is 20–30% lower than the modulus of elasticity cortical bone [2, 11, 26]. The natural femur bone composed of two components of tissues: cortical (compact dense and hard tissue) and cancellous (trabecular) bone (cellular spongy tissue), which differ in their apparent density threshold and behavior [9, 15, 25-26, 30]. The femur bone material properties for an adult human are given in Table 1 [1, 10-12, 26, 30-33].

Table 1: The femur bone material properties for an adult human

It. no.	Material property	Value
1.	Density (gm/cm^3)	1.75
2.	Young's modulus (Gpa):	
	for cortical bone	17.0
	for trabecular bone	0.8
	for total femur bone	16.7
3.	Ultimate tensile strength (Mpa)	43.5
4.	Ultimate compressive strength (Mpa)	115.3
5.	Poisson's ratio for both bone layers	0.3

The concentrated and eccentric external loads (due to influence of eccentricity between the stem and femur head) were applied at the head of the bone to simulate the static and dynamic forces acting corresponding to periodic cycles of patient's activities with 70 kg body patient weight. The femur bone head-implant systems were loaded with 700 N axial, 100 N lateral loads and a torsional moment of 10.0 Nm. At the lower medial condyle and patellar surface, a fixed support is provided and the displacement is restricted in the all direction [11-13, 26].

During the walking and running conditions, the biomechanical characteristics of femur bone have an associated laterality movement and the horizontal load components had a significant effect on the lubrication film of the head bone joint [10-12]. The boundary conditions model for the femur bone in ANSYS 15.0 is shown in Figure 3.



A: Modeling of 1% TiO2/HDPE fabricated bone biocom
Static Structural
Time: 1. s
8/5/2018 9:20 PM

A Fixed Support
B Force 2: 700. N
C Moment 2: 10000 N·mm
D Force: 100. N

Figure 3: The boundary conditions model for the femur bone in ANSYS 15.0

Mathematical Modeling

The determination of the mechanical stresses in human bones that induce physiological activities is of great importance in both clinical and research practice [9]. Stress distribution is the important tool to indicate the crack or failure of the total femur bone arthroplasty which is affected by static and dynamic loads. Both the static load analysis applied due to the weight of the body and the dynamic load analysis applied due to walking cycle have been described in this study [32].

The effects of different biomechanical loading are investigated using a system of nonlinear differential equations [12]. The 3D mathematical model due to the loading caused by patient activities is constructed to analyze the stress field in the artificial bone component. From the continuum mechanics principles, the field equations governing the stress fields in the bone include the stress equilibrium equations, the geometric equation and constitutive equations [12, 33]. To solve the problem boundary value, the finite element analysis (FEA) is used.

High Cycle's Fatigue Analysis

Fracture and fatigue behavior is a time-related scenario may form and grow in the femur bone as a result of daily loading activities. The bone fatigue eventually reduces the load-carrying capability from the bone, leading to increase the stress redistribution within the bone structure [34]. To avoid and localized progressive damage caused by daily cyclic loading as a result of walking, the femoral implant bone prosthesis was designed against the high cycles infinite fatigue fracture using the Soderberg's criterion as fatigue failure theory [14]. By using finite element analysis (as a cost efficient and computing time saving method in the biomedical engineering), the mean and alternative stresses are obtained to determine the design fatigue safety factor (SF) and to estimate the fatigue life until the failure of the prosthesis, i.e. the useful life of the prosthesis [32].

During its lifetime, bone is able to adapt its internal microstructure and varying physiological and mechanical environments in bone remodeling process. To predict such remodeling process, a number of biomechanical theories and algorithms have been proposed. On its mixed mode, bones withstand the repeated loadings (tensile, compression and shear) in daily activities [33].

The human body bones, as a structure, gradually turn into engineering material fatigue. In the past decades, the researchers reported that the bone damage caused by bone fractures and related diseases. In the modern bone biomechanics, fatigue and fracture form and grow due to that the accumulation of the bone damage is superior to the bone repairing ability. As a result, the study of the bone damage and fatigue became an important branch in clinical medicine and biomechanics [33].

Results and Discussions

This study attempted to create a bone simulation model that can withstand the highest stresses and strains producing during daily activities for prepared and fabricated nano composites for bones repairs. The maximum equivalent von–Misses stress obtained from the experimental tests, which have been introduced in the engineering date of the ANSYS 15.7 and the application of FEA, is equal to 39.957, which represent the stresses resulting from the boundary conditions and the application of loads resulting from daily activities on the human femur bone.

The location of these maximum equivalent von –Misses stresses, as expected, is in the middle portion where the bone has the less cross-sectional area where the fractures are confirmed by most cases in various incidents. The distribution of these stresses was shown in Figure 4. The obtained maximum equivalent von–Misses stress value was higher than the withstand values of daily human activity loads in a previous study by 53.68% [15].

The experiments in the present work were designed by using the full factorial method (FFM) and the response surface methodology (RSM). The analysis of variance (ANOVA) technique was used to analyze the results.

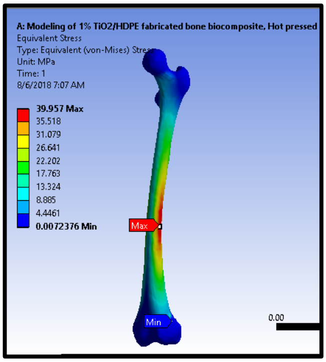


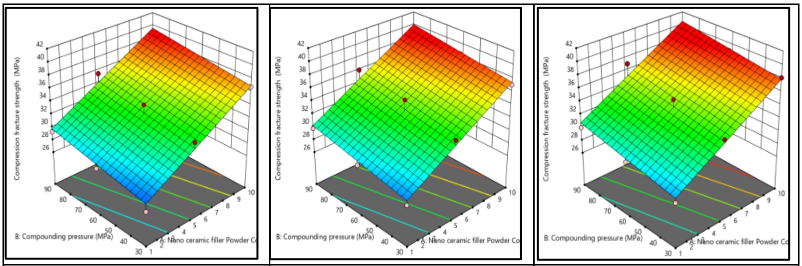
Figure 4: The Equivalent von–Misses Stress distribution

The three level factorial ANOVA analysis using the quadratic design model was implemented for analyzing the effect of input parameters on the compression fracture strength resulting for all the fabricated nano biocomposites systems. The model F-value of 143.38 and the P-values less than 0.0500 implies that the model is significant.

The 3D graphs of the effect of input parameters on the compression fracture strength obtained values for all the fabricated nanobiocomposites systems are shown in Figure 5. These graphs depict that the compression fracture strengths values increased with increasing the process parameters, i.e. the nano ceramic powder (TiO_2), the compounding pressure and the hot pressed temperature. The nano ceramic powder compositions represented the main factor influencing the results. With the increase of the TiO_2 content from 1% to 10%, the compression fracture strength value increased from 26 to 39 MPa, i.e. by 50%.

The maximum compression fracture strength reached 50 MPa when using 10% titanium oxide nano ceramic powder (TiO_2) with 2% partial stabilized zirconia (Y-PSZ), a compounding pressure of 90 MPa and a hot pressed temperature of 200 °C. This value is higher than the case of using the same content ratio of titanium oxide but without adding of zirconia (ZrO_2) by 28.21%. These results are higher than those in the previous studies using 5% TiO_2/HDPE nano composites for maximum ultimate strength by 90.11% [8] and by 51.52% for other previous study used 1% Mn filler/ TiO_2 dispersion in PE matrix [16].

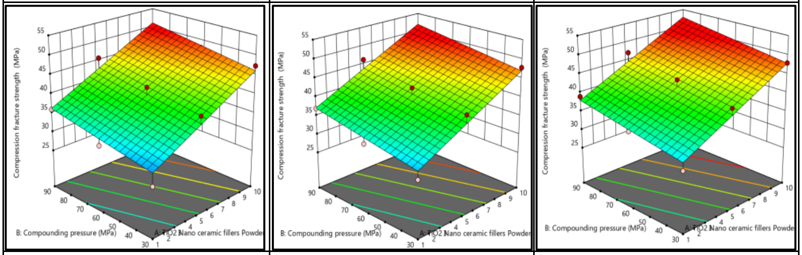
The most important reasons for this increase in the compression fracture strength values of the produced nano composites are the high values of the ceramic nano filler materials added, and the most important properties that are density, elastic and shear modulus, tensile and compression strengths, hardness and fracture toughness.



(a) TiO_2/HDPE at pressed temperature = 180 °C

(b) TiO_2/HDPE at pressed temperature = 190 °C

(c) TiO_2/HDPE at pressed temperature = 200 °C



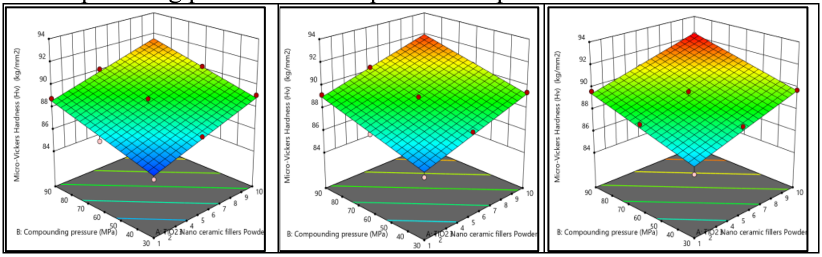
(d) TiO_2/2% ZrO_2/HDPE at pressed temperature = 180 °C

(e) TiO_2/2% ZrO_2/HDPE at pressed temperature = 190 °C

(f) TiO_2/2% ZrO_2/HDPE at pressedtemperature = 200 °C

Figure 5: The 3D graphs for the effect of input parameters on the compression fracture strength for the fabricated nano bio-composites systems

The reasons of the enhancement in strength could be attributed to the excellent bonding between the nano ceramic particles with HDPE polymer matrix interface. The effect of input parameters on the micro-Vickers hardness (H_v) for all the fabricated nano biocomposites systems are shown in the 3D graphs in Figure 6. These graphs manifest that the micro-Vickers hardness values were increased with increasing the ceramic powders contents as well as the compounding pressure and hot pressed temperature.



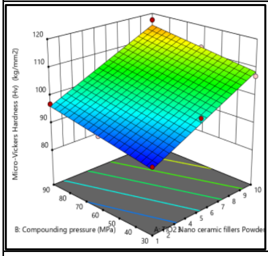
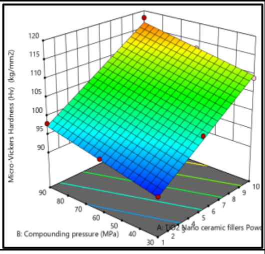
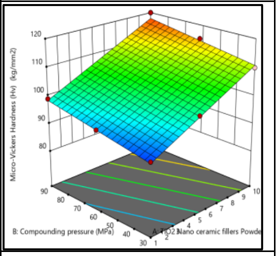
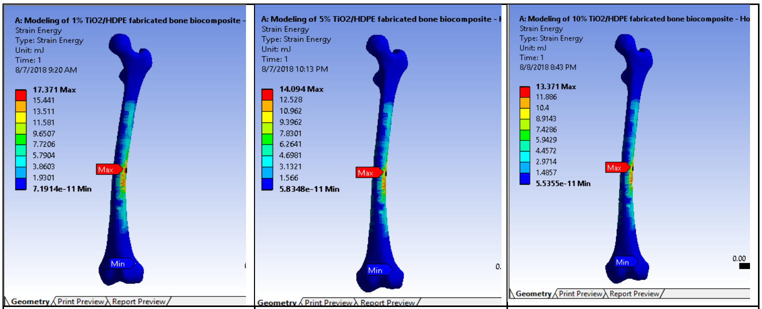
(a) TiO_2/HDPE at pressed temperature = 180°C	(b) TiO_2/HDPE at pressed temperature = 190°C	(c) TiO_2/HDPE at pressed temperature = 200°C
		
(d) TiO_2/2% ZrO_2/HDPE at pressed temperature = 180°C	(e) TiO_2/2% ZrO_2/HDPE at pressed temperature = 190°C	(f) TiO_2/2% ZrO_2/HDPE at pressedtemperature = 200°C

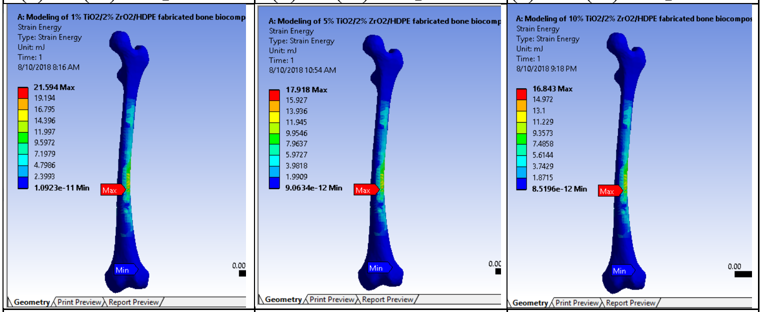
Figure 6: The 3D graphs for the effect of input parameters on micro Vickers hardness (H_v) for all the fabricated nano bio-composites systems

When increasing the nano ceramic content from 1% to 10%, the micro-Vickers hardness increased by 8.45% and when adding 2% of zirconia (ZrO_2), the micro-Vickers hardness reached its maximum values, i.e. an additional increase in microhardness by 40.19% was achieved. These hardness values are higher than the values obtained in a prior study using LDPE + 20% Al_2O_3 + 10% TiO_2 nano composites by 118.18% [35]. The increase in the micro hardness values of the fabricated nano compsites hard tissues is attributing to the high physical and mechanical properties of the added ceramic nano filler materials and their high molecules cohesion with the HDPE matrix.

The daily human activities movements, i.e. the external mechanical work done, cause a femur bone structure elastic deformation that is transformed into internal strain energy. Figure 7 elucidates the effect of the input parameters for all the six fabricated nano composites systems on the strain energy, for different TiO_2 nano ceramic fillers powders compositions and best experimental results (90 MPa compounding pressure and 200°C hot pressed temperature) from each fabricated system, while the 3D graph in Figure 8 evinces the effect of these parameters on the strain energy values for all the fabricated nano composites systems.



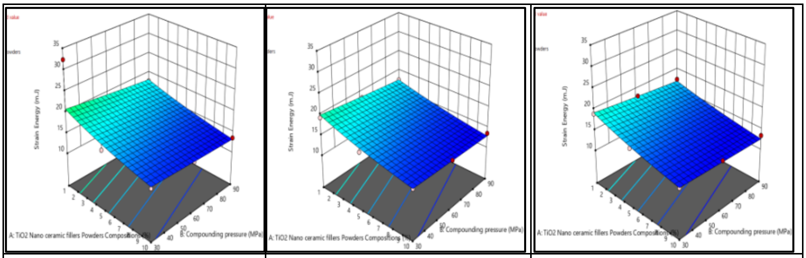
(a) 1 (%) TiO_2/HDPE | (b) 5 (%) TiO_2/HDPE | (c) 10 (%) TiO_2/HDPE



(d) 1 (%) TiO_2+2 (%) ZrO_2/HDPE | (e) 5 (%) TiO_2+2 (%) ZrO_2/HDPE | (f) 10 (%) TiO_2+2 (%) ZrO_2/HDPE

Figure 7: The effect of the input parameters on the strain energy values at 90 MPa compounding pressure and 200 °C hot pressed temperature

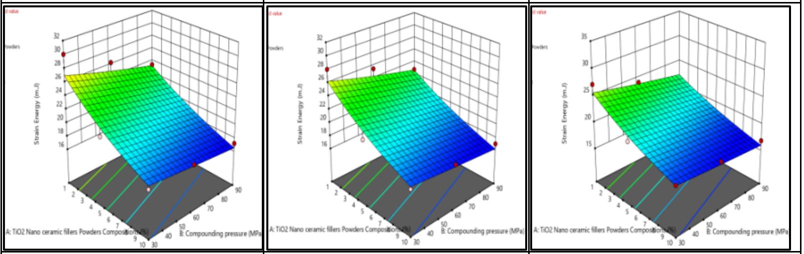
Figure 8 illustrates the 3D graphs for the effect of the input parameters on the strain energy values. It shows that the lower strain energy values obtained for these complex states of stress systems due to external loadings for the modeled femur bone with the best fabricated parameters using 10% TiO_2 + 2% ZrO_2/HDPE bio composite at highest compact temperature of 200 °C and compounding pressure of 90 MPa is equal to 16.843 m.J., i.e., the strain energy reduced by 82.69% when compared with the use of 1% TiO_2 + 2 % ZrO_2/HDPE bio composite. While when increasing the nano ceramic content from 1% to 10% without adding the ZrO_2 nano filler, it reduced by 142.25%.



(a) TiO_2/HDPE at pressed temperature = 180 °C

(b)TiO_2/HDPE at pressed temperature = 190 °C

(c) TiO_2/HDPE at pressed temperature = 200 °C



(d) TiO_2/2% ZrO_2/HDPE at pressed temperature = 180 °C

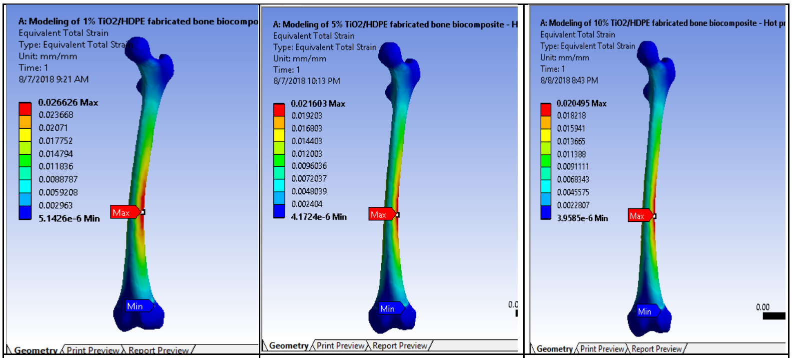
(e) TiO_2/2% ZrO_2/HDPE at pressed temperature = 190 °C

(f) TiO_2/2% ZrO_2/HDPE at pressedtemperature = 200 °C

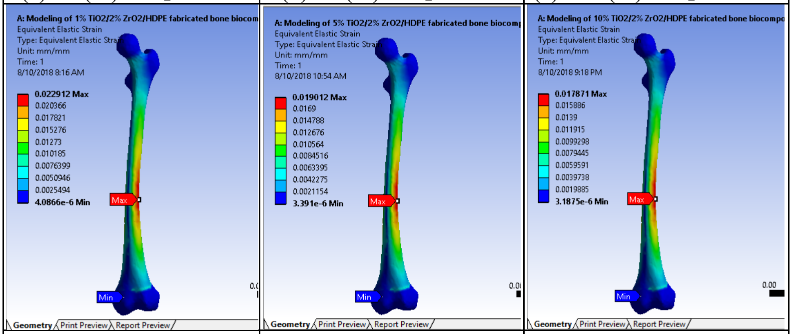
Figure 8: The 3D graphs for the effect of the input parameters on the strain energy values

In a previous study, the strain energy was found for the natural human femur bone equal to 15,61 m.J and for a fabricated bio composite material (20% vol. TiO2/5% vol. Al2O3/PEEK) as 13,01 m. J. [36]. The results obtained for the all fabricated nano composites systems allow the designers to choose the appropriate biomaterial according to the clinical situation, age of the patient and the resulting static and dynamic loads dynamic when designing the material to repair the fractured bones due to the different types of accidents.

The effect of input parameters on the equivalent elastic strain values for all the fabricated nanobiocomposites systems are show in the Figure 9 and Figure 10. These graphs exhibit that the lowest equivalent elastic strain value was obtained with increasing the ceramic powders content as well as the compounding pressure and hot pressed temperature. When increasing the nano TiO_2 ceramic content to 10%, this value reached 0.0205 mm/mm, which is lower than when use the TiO_2 ceramic content of 1% by 67.81%.

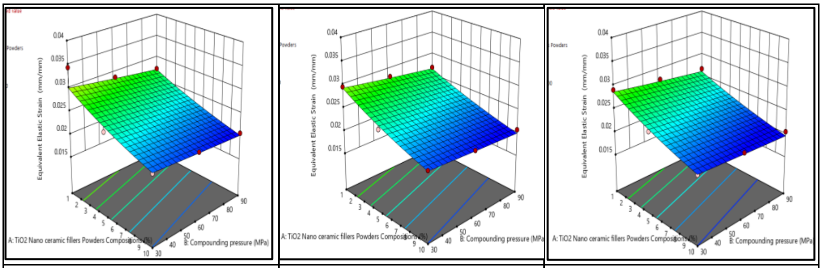


(a) 1 (%) TiO_2/HDPE (b) 5 (%) TiO_2/HDPE (c) 10 (%) TiO_2/HDPE

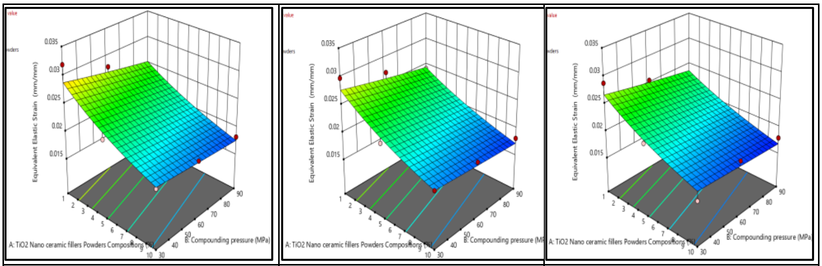


(d) 1 (%) TiO_2+2 (%) ZrO_2/HDPE (e) 5 (%) TiO_2+2 (%) ZrO_2/HDPE (f) 10 (%) TiO_2+2 (%) ZrO_2/HDPE

Figure 9: The effect of the input parameters on the equivalent elastic strain values for different TiO_2 nano ceramic fillers compositions at 90 MPa compounding pressure and 200 °C hot pressed temperature



(a) TiO_2/HDPE at pressed temperature = 180 °C (b)TiO_2/HDPE at pressed temperature = 190 °C (c) TiO_2/HDPE at pressed temperature = 200 °C



(d) TiO_2/2% ZrO_2/HDPE at pressed temperature = 180 °C

(e) TiO_2/2% ZrO_2/HDPE at pressed temperature = 190 °C

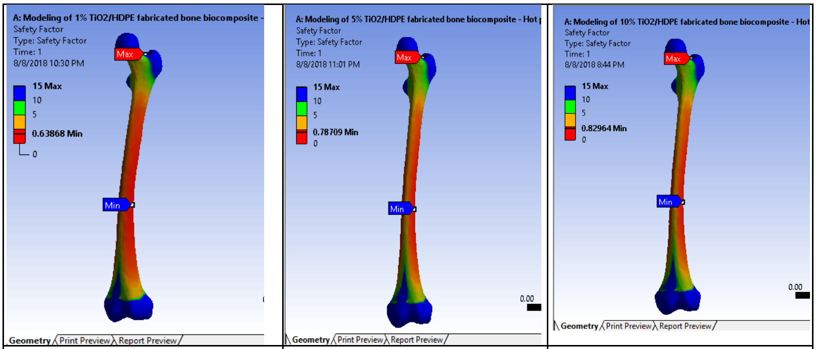
(f) TiO_2/2% ZrO_2/HDPE at pressedtemperature = 200 °C

Figure 10: The 3D graphs for the effect of the input parameters on the equivalent elastic strain values

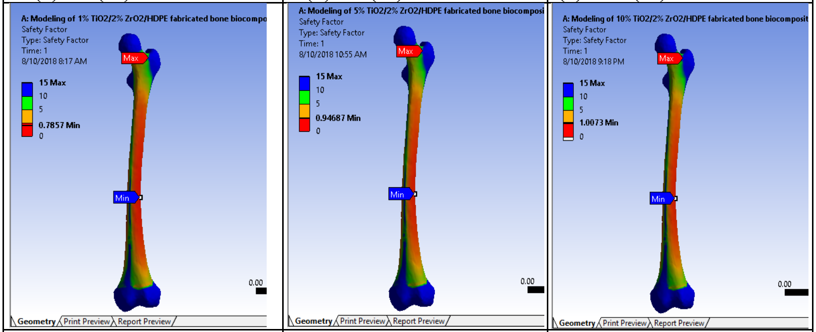
The equivalent elastic strain value reached reduced further in its value by 14.53% when adding 2% of zirconia (ZrO_2), the micro-Vickers hardness reached its maximum values, i.e. an additional increase in microhardness by 40.19% was achieved. These results are lower than those in the previous studies using 5% TiO_2/HDPE nano composites for equivalent elastic strain by 169.22% [8] and by more than 300% for another previous study [37].

This means that the nano particles fabricated in this study are the closest to the natural bone properties and therefore they exclued the new fractures because of the variation in the elongation rates due to different dynamic and static loads and this is one of the most important characteristics required in the replacement or bone grafting designs. The reduction in the equivalent elastic strain values of the fabricated nanocompsites is ascribed to the hard and brittle ceramic nano filler materials. That means these fabricated nano composites have the properties of lowest elongation and as those of the natural bones, and this achieves the objectives of using them in the clinical repair of bones operations. These low equivalent elastic strain values are of great importance in helping the patient to withstand higher external loads.

The 3D graphs in Figure 11 and Figure 12 display the effect of fabrication process input parameters on the stress safety factors for all the produced nano biocomposites systems. As demonstrated in these figures, the stress safety factors values were increased by increasing the ceramic filler content as well as the hot pressed temperature and the compounding pressure. Experimental results revealed that when increasing the nano ceramic content from 1% to 10%, the stress safety factors increased by 58.38% and when adding 2% of zirconia (ZrO_2), the stress safety factors reached its maximum value, with an additional increase in its value by 21.42%. The increase in the stress safety factor values can be returned to the addition of the high mechanical properties of the ceramic nano filler materials.

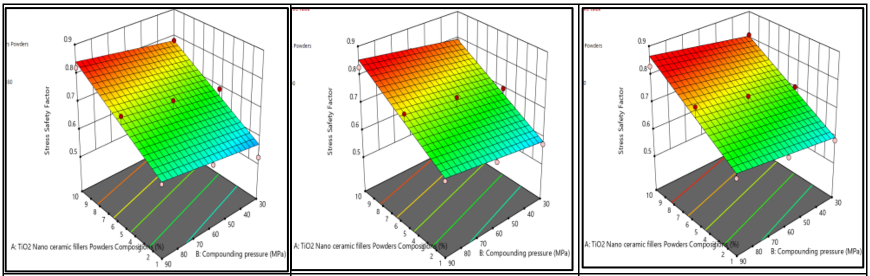


(a) 1 (%) TiO_2/HDPE (b) 5 (%) TiO_2/HDPE (c) 10 (%) TiO_2/HDPE



(d) 1 (%) TiO_2+2 (%) ZrO_2/HDPE (e) 5 (%) TiO_2+2 (%) ZrO_2/HDPE (f) 10 (%) TiO_2+2 (%) ZrO_2/HDPE

Figure 11: The effect of input parameters on the stress safety factors values at 90 MPa compounding pressure and 200 °C hot pressed temperature



(a) TiO_2/HDPE at pressed temperature = 180 °C (b)TiO_2/HDPE at pressed temperature = 190 °C (c) TiO_2/HDPE at pressed temperature = 200 °C

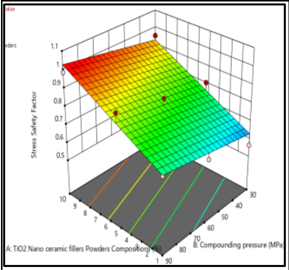
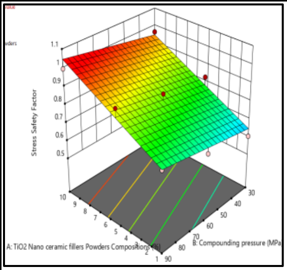
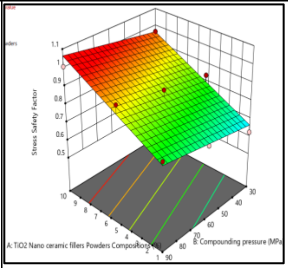
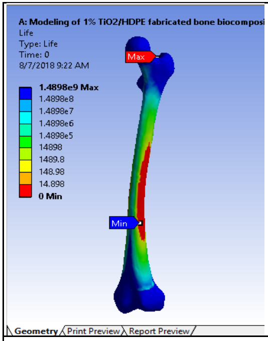
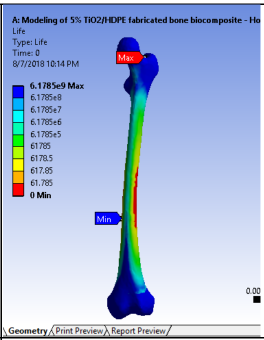
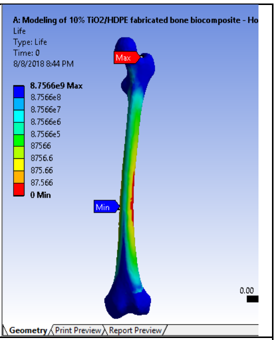
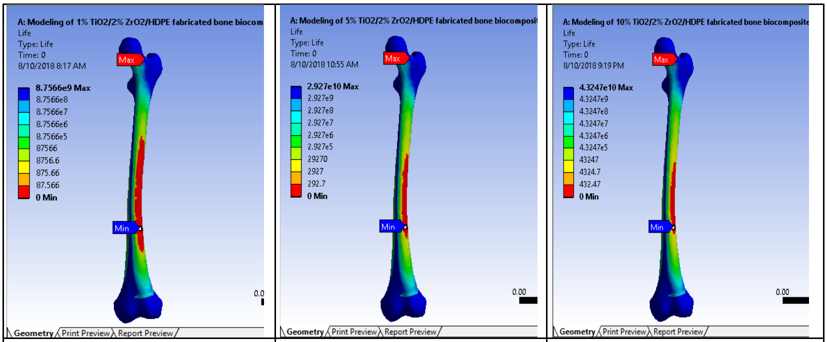
		
(d) TiO_2/2% ZrO_2/HDPE at pressed temperature = 180 °C	(e) TiO_2/2% ZrO_2/HDPE at pressed temperature = 190 °C	(f) TiO_2/2% ZrO_2/HDPE at pressed temperature = 200 °C

Figure 12: The 3D graphs for the effect of the input parameters on the stress safety factors values

The ANSYS analyses of the fatigue life values for the fabricated bio materials are given in Figure 13 and Figure 14, where the fatigue life values increased with increasing the compact temperature, the pressure and the nano filler content. The maximum fatigue livevalueof the modeled femur bone reached 4.3247x10^{10} cycles which is equivalent to actual service of the activity during normal movement of the patient after the operation for more than 28 years.

This value is the case of using 10% TiO_2/2% ZrO_2/HDPE nano composite and it is more than when using 1% TiO_2/2% ZrO_2/HDPE nano composite by 46.28% and more than if not using 2% ZrO_2 nano filler by 69.40. These results give a great freedom of choice to use the successful biocomposite substances in vivo tests with a good flexibility and a better life performance in line with the age, the patient status and the degree of injury.

		
(a) 1 (%) TiO_2/ HDPE	(b) 5 (%) TiO_2/ HDPE	(c) 10 (%) TiO_2/ HDPE

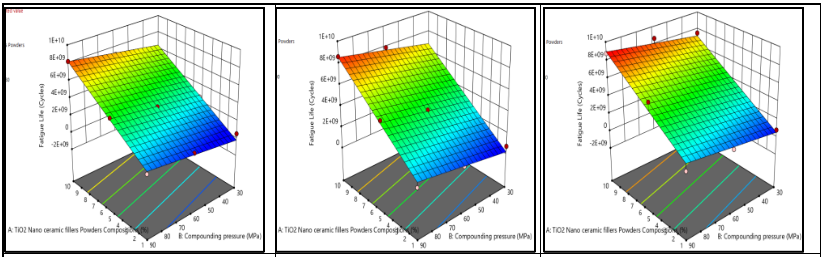


(d) 1 (%) TiO_2+2 (%) ZrO_2/ HDPE

(e) 5 (%) TiO_2+2 (%) ZrO_2/ HDPE

(f) 10 (%) TiO_2+2 (%) ZrO_2/ HDPE

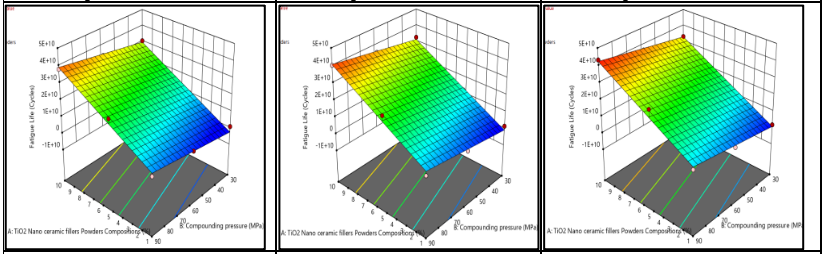
Figure 13: The effect of the input parameters on the fatigue life values at 90 MPa compounding pressure and 200 °C hot pressed temperature



(a) TiO_2/HDPE at pressed temperature=180 °C

(b)TiO_2/HDPE at pressed temperature =190 °C

(c) TiO_2/HDPE at pressed temperature =200 °C



(d) TiO_2/2% ZrO_2/HDPE at pressed temperature=180 °C

(e) TiO_2/2% ZrO_2/HDPE at pressed temperature =190 °C

(f) TiO_2/2% ZrO_2/HDPE at pressedtemperature =200 °C

Figure 14: The 3D graphs for the effect of the input parameters on the fatigue life values

Conclusions

This study attempted to create a bone simulation model that can withstand the highest stresses and strains. All the results of experiments in the present work were designed by using the response surface methodology (RSM) and the analysis of variance (ANOVA) technique, and the P-values were less than 0.0500 implies that the models are significant. The following conclusions can be deduced from the results of the current research:

1) The results showed for all the fabricated nano bio-composites systems, that output performance parameters, including the compression fracture strengths, the micro-Vickers hardness (H_v), the stress safety factor and the fatigue lives values were increased by increasing the process input parameters, i.e. Nano ceramic powder (TiO_2), the adding of zirconia ceramic nano filler (ZrO_2), the compounding pressure and the hot pressed temperature. And the vice versa for the strain energy and equivalent elastic strain values, the nano ceramic powders compositions represented the main factor influencing the results.
2) With the increase of the TiO_2 contain from 1% to 10%, the compression fracture strength value increased by 50%. With adding of 2% partial stabilized zirconia (Y-PSZ), this value was increased by 28.21%.
3) When increasing the nano TiO_2 ceramic content from 1% to 10%, the micro-Vickers hardness increased by 8.45% and when adding 2% of zirconia (ZrO_2), an additional increase in micro hardness by 40.19% was achieved.
4) When using 10% TiO_2 + 2% ZrO_2/HDPE bio composite at the highest compact temperature of 200 °C and a compounding pressure of 90 MPa, the strain energy reduced by 82.69 % when compared with the using of 1 % TiO_2 + 2 % ZrO_2 / HDPE bio composite. While, when increasing the nano ceramic content from 1% to 10% without adding the ZrO_2 nano filler, it reduced by 142.25%.
5) When increasing the nano TiO_2 ceramic content to 10%, the equivalent elastic strain value reached to 0.0205 mm/mm, which is lower than when using 1% TiO_2 ceramic content by 67.81%. The equivalent elastic strain values reduced further in its value by 14.53% when adding 2% of zirconia (ZrO_2).
6) The maximum equivalent von –Misses Stress obtained is equal to 39.957 MPa. Experimental results manifested that when increasing the nano ceramic content from 1% to 10%, the stress safety factors increase by 58.38% and when adding 2% of zirconia (ZrO_2), the stress safety factors reached its maximum value, with an additional increase in its value by 21.42%.
7) The maximum fatigue lives values of the modeled femur bone reached 4.3247×10^{10} cycles, which is equivalent to actual service of the activity during the normal movement of the patient after the operation for more

than 28 years. This value is the case when using 10% TiO_2/2% ZrO_2/HDPE nano composite and it is more than when using 1% TiO_2 content by 46.28% and more than if not used 2% ZrO_2 nano filler by 69.40.

The results obtained allow the biomedical engineering designers to choose the appropriate and the successful bio composite substances for in vivo tests and for a better life performance in line with the age, the patient degree of injury status, the clinical situation and therefore the required static and dynamic loads when designing a material to repair or replace the fractured bones partially or totally due to the different types of accidents.

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