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Finite Element Analysis And Enhanced 3D Modeling Of Biodegradable Implants For Femur Bone Application

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Abstract-*There were 178 million new fractures worldwide in 2019 (up 33.4% from 1990). Many people suffer broken bones each year due to accidents and illnesses. In the majority of these cases, external treatments are not enough to repair the fractures, so non-biodegradable implants such as cobalt based alloys, titanium alloys are used to repair the fractures. The biological behaviour of these implants has been observed to be superior to that of the conventional implants. However, they must be removed from the human body once the bone healing process is completed. In this project, a fractured femur is modelled with a biodegradable implant and the stress, strain, and total deformation distributions of two biodegradable materials (Mg and Zn alloys) are compared using ANSYS Workbench environment.*
Index Terms—*3Dmodelling, femur bone, finite element analysis, biodegradable*

INTRODUCTION

An osteosynthesis, or osteotomy, is a surgical procedure that anchors the bone and cuts away the bone with metal implants. These metal implants are usually removed nine to twelve months after the first surgery. Due to significant medical expenditures, routine implant removal does not seem to be a favored alternative. There is no need to discard the mended fractured bone when employing biodegradable implants that break down in the body. This guarantees substantial financial benefits for both the public health systems and the patients. The femur consists of three parts such as proximal distal and shaft. Because the distal femur connects to the knee bone and the proximal femur connects to the hip, fractures in these parts can also affect the hip and knee. Fractures are broadly classified into oblique fractures, transverse fractures, spiral fractures, comminuted fractures, compound fractures, and open fractures, and multiple grades of treatment are required depending on the type of fracture. Surgery performed on a fractured femur is called intramedullary nailing, in which rods and screws are placed to hold the bone in place. The material chosen should have biocompatibility, mechanical strength close to that of bone, and low cost. Materials selected to replace or support bone growth should be tested for mechanical stability parameters such as tensile strength, modulus and compressive strength. There are classes of materials available for bone replacement, including metals, polymers, ceramic and composites. In orthopaedics, biodegradable materials provide an alternative to durable materials for resolving clinical concerns with secondary surgery and stress shielding. Modeling and simulating biological objects have benefited from the development of the Finite Element Method (FEM) as an analytical tool. Biological objects are challenging to model, whereas artificial ones are simple and straightforward to create. The anisotropic and nonlinear properties of biological items make meshing and analysis difficult. Degradable implants offer the benefit of full tissue healing and function restoration. A permanent implant will restore function, but because it remains in place permanently, complete tissue regeneration is not achievable. This proposed research goes through a three- step process to accomplish its objective. In the ANSYS Workbench environment, CAD model of a shattered human femur and implants are initially constructed. After choosing a material based on the implant's characteristics, a Finite Element Analysis (FEA) was performed on the model. Third, different implant material's efforts on stress distribution over the broken femur bone are identified and contrasted.

RELATED WORKS

The finite element model, which was developed by integrating MRI data and modelling tools to investigate the stress in femoral bone under diverse circumstances and to choose an appropriate composite material for human femur bone, was generated using ANSYS software[1].The impact and significance of biodegradable magnesium alloys, going over their history, the key features that make them so appealing for applications like orthopaedic implants, as well as the qualities that need to be adjusted (like corrosion rate and mechanical properties) in bid to achieve the best possible product. It concentrates primarily on the mechanisms and elements pertaining to the corrosion behaviour of magnesium alloys, electrochemical characterization techniques and methodologies, as well as perspectives for enhancing the mechanical characteristics and corrosion behaviour of these sorts of biodegradable alloys[2].The procedure to gain understanding of the parametrically conceptualised design of biodegradable bone implant and to take into consideration the characteristics of the Bone Biodegradable Implant Interface (BBII), traditional design and FEA approaches for implant and healing behaviour, manufacturing techniques, and real- time surgical simulations[3].

A 3D model can be generated using the CAD configuration, and ANSYS can be used as a staging area to analyze how mechanical practices have evolved as a result of stacking. The findings of a hip embed made of two distinct materials at the stem and acetabular cup are acquired using ANSYS V18.1. CoCr+PMMA (Cobalt Chromium in combination with Polymethylmethacrylate), [Si.sub.3][Ni.sub.4]+PMMA (Silicon nitride in combination with Polymethylmethacrylate), and ZTA+ZTA are the other materials used in the comparison study. Ti+UHMWPE, the currently most popular material for bone implants, is used as the reference material (Zirconia Toughened Alumina)[4].The process for creating an iron- based, biomechanically specific, degradable sponge-like (or cellular) implant for bone replacement. A cylindrical cellular implant with phosphor as an alloying ingredient is created using a metal powder sintering method [5].When a person is at a normal weight, the femur, which has a length of 25% of their height, is responsible for supporting the majority of their body weight. This uses the 3D slicer and Blender software to revive a typical femur bone from DICOM information from a CT scan. Analyses and meshing are done on the ANSYS Workbench environment [6].

In this work, binary Zn alloys containing the alloying elements Mg, Ca, Sr, Li, Mn, Fe, Cu, and Ag correspondingly are screened systemically by in vitro and in vivo investigations because they have higher mechanical qualities than biodegradable polymers for use as bone implants [7].Using ITK-Snap software, a three-dimensional CAD model of the human femur bone was created for biomechanical research. While the model is NASTRAN 10.0, pre- and post-processing procedures are carried out utilizing HYPERWORKS. Three materials are examined: natural bone material, AZ31 (magnesium alloy), and CP Ti (Commercially Pure Titanium Alloy) [8]. The inherent degradability, good biocompatibility, and advantageous mechanical properties of magnesium and its alloys have made them stand out as potential materials for bone implants. However, the excessively rapid deterioration rate frequently leads to a premature loss of mechanical integrity and local hydrogen accumulation, which restricts their use in clinical bone healing [9]. The replacement of damaged bone is done by design of bone then analyzing its properties. During daily activities, the skeletal system is subjected to a complicated loading exerted by the different loading conditions[10].

Historically, orthopaedic and cardiovascular implants have been made from inert metals like titanium, stainless steel, and cobalt alloys because of their superior corrosion resistance and suitable mechanical qualities in relation to nearby biological tissues. Modern metallic implants made from inert materials are intended to replace the original tissues and stay permanently inside the body. However, this idea of complete tissue replacement does not take into account situations when temporary supporting function is all that is needed until complete tissue healing has taken place. The use of permanent inert materials to provide the temporary supporting function has resulted in a number of issues, including stress-shielding over time, which weakens bone and distorts diagnostic pictures, as well as additional surgery to remove the implant [11].

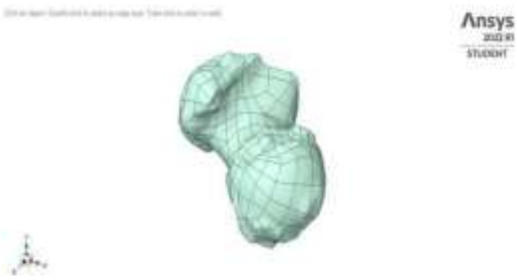
MATERIALS AND METHOD

A. CAD model

The femur and implants are modelled using the ANSYS Workbench environment to analyzetotal deformations, stresses, and strains distributed throughout the femur after implant placement. There are individual differences in the cross-sectional size of implants, and it is not possibleto generalize.The typical implant femoral head size ranges from 22 to 54 millimetres, with a liner thickness of 2 to 10 millimetres and a shell thickness of 1 to 4 millimetres. A 17 mm implant rod and seven 7 mm screws

are modelled in this work.3D model of a fractured femur bone was illustrated in fig.1 as it shows in four different parts which includes an implant rod, fractured femur bone are modelled and third part represents the implant placed in the fractured femur bone.

(a)



(b)

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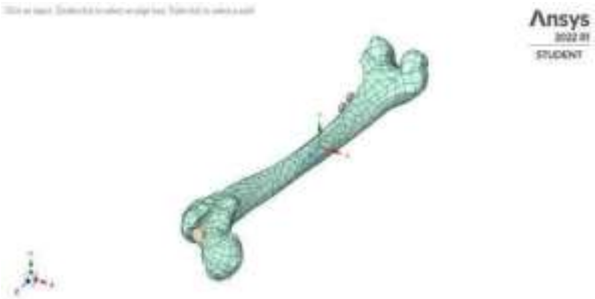


(d)

Fig.1.3D Model of (a) an implant (b) & (c) fractured femur bone and (d) fractured femur with an implant

B. Meshing

Partial Differential Equations (PDEs) can be used to address the majority of physical events, but the majority of real-world issues are exceedingly challenging to solve in this way. Because continuous objects have unlimited Degrees of Freedom (DOF), they cannot be solved manually. So, inorder to compute the solution, FEA constructs a mesh that subdivides the domain into a finite number of components. Following that, the data is interpolated over the domain. To accurately discretize the stress gradients, the elements in the mesh must take into consideration a variety of factors. Because the design is more accurately sampled across the physical domain, smaller mesh sizes typically produce more accurate solutions. In fig.2. A 3D model's meshing is demonstrated.

Fig.2.Meshing of a 3D model

C. Material Properties Magnesium

The permanent metal implant's substance has a Young's modulus that is excessively high relative to the nearby cancellous bone's (Young's modulus 10-30 GPa), whereas the biodegradable magnesium material has a density of 1.738g/cm3 and a melting point of approximately 650 degrees. Magnesium-based alloys for medical applications are lightweight materials with densities close to cortical bone's, 1.75-2.1g/cm3 [9]. One of the lightest metals is magnesium (Mg), and a great deal of research has been done on its alloys. Mg alloys with high specific strength, ductility, and creep resistance are used in engineering. However, Mg alloys are anticipated to have strong biocompatibility, high initial mechanical strength, and delayed mechanical property depreciation when implanted in vivo because they are biodegradable materials [12].

Zinc alloy

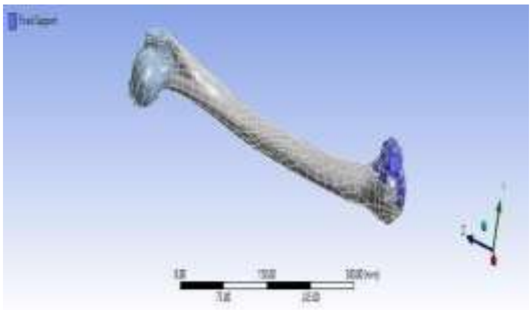
Biocompatibility, osteogenesis, antibacterial, antifungal, and anticancer capabilities are only a few of the advantageous biological characteristics of zinc-based biomaterials that make them suitable for therapy and regeneration. Zn-based biodegradable metals have good rates of degradation and biocompatibility, and alloying can increase their mechanical strength and ductility, making them interesting for orthopaedic and cardiovascular applications[14]. Three metals iron, zinc, and magnesium are used as the foundational components of metal biodegradable implants in medicinal applications. One of the nutrients that the human body needs most is magnesia. In addition, Mg is the primary choice of components to strengthen Zn because Mg-based alloys have been used for decades as biodegradable metallic materials. [13]. Iron is a fascinating contender for biodegradable implant materials due to its mechanical characteristics. Due to its great elasticity, it also possesses a high radial resistance. When creating materials with thin walls, this is helpful. Iron is also quite ductile, which is advantageous when the material goes through plastic deformation during implantation. Alloys based on zinc might also make good biodegradable implant candidates. The key benefits of zinc-based metal alloys are their reactivity and low melting point. As a result, they can be produced through simple melting, pressure casting in gravity or the air, or thermoforming. Zinc alloys don't have any toxicity or other biocompatibility, either locally or generally. Materials of natural bone, magnesium and zinc alloys assigned to each 3D model of femur including implants properties are listed in table 1.

TABLE 1. Material properties of bone, magnesium and zinc alloy.

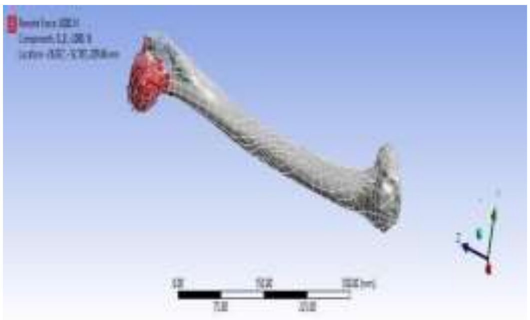
Materials	Density (g/cm3)	Young's Modulus (GPa)	Compressive Strength (MPa)
Natural Bone	1.8–2.1	3-20	130- 180
Magnesium	1.74–2.0	41-45	65-100
Zn-Fe-Mg Alloy	6.5–7.1	90-96	140- 200

D. Applying a load

Standing causes the femur to experience compressive and tensile forces on different sides of bone because the acetabulum distributes the weight load lateral rather than directly along the axis. In compression, the human femur has an ultimate compressive strength of 205 MPa, which can be measured under compression along its length before it begins to fracture or tear. In tension along the length of the femur, the ultimate tensile strength is 135 MPa. The Von Mises stress is used to determine maximum force before yielding. The deformation of the material in relation to the applied force is also analyzed. In this model, the load on the femur is 2000Na long the *z*-direction of the femur, firmly supported by the lateral condyle.



(a)



(b)

Fig.3. (a)fixed support and (b)apply a force

I. Analysis

Stress – strain analysis is a powerful tool for quantifying the changes of a material under the effects of various loading conditions. Stress is the force applied to a material, divided by the material's cross-sectional area. It is given in the equation (1).

$\sigma = F/A_0$

where, σ –Stress (Pa)

F–Force (N) A_0– Cross-sectional area (m^2)

Strain is the deformation or displacement of material that results from an applied stress. It is given inequation (2).

$\epsilon = L - L_0 / L_0$

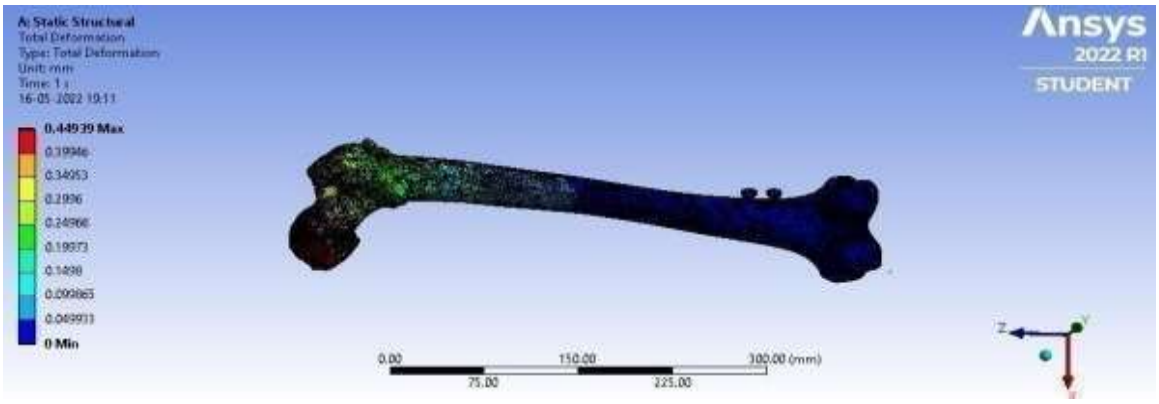
where, ϵ-Strain

L–Length after the load is applied (mm) L_0–Original length (mm)

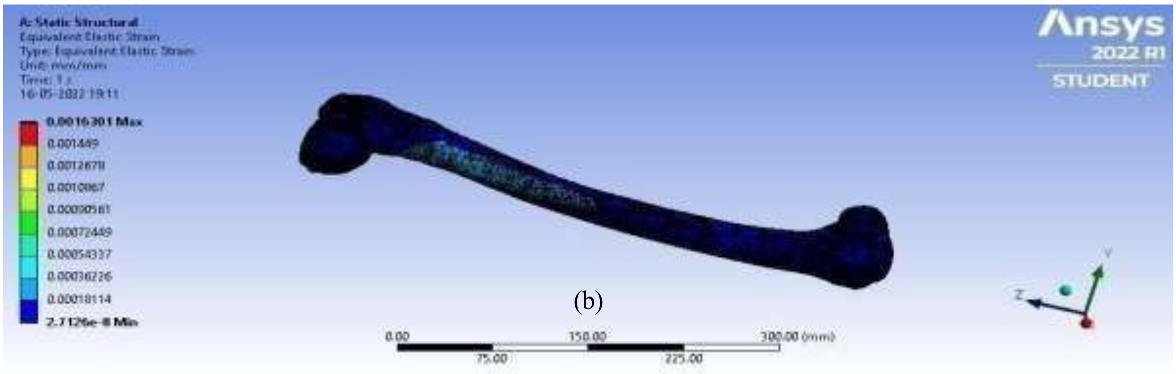
The total deformation, stress strain has been analyzed for the femur bone model by assigning two biodegradable materials such as Mg and Zn alloy.

RESULTS AND DISCUSSION

The human femur bone and its implants are made of a variety of components. Several studies were cited in order to identify a particular material attribute of the bone and the biodegradable implant material, which contains an alloy of magnesium and zinc. Despite having a reputation for having poor corrosion resistance, magnesium has been chosen as an implant material because of its excellent osseo integration properties. The combination of zinc, iron, and magnesium (Zn-Fe-Mg), known as zinc alloy, was the other material selected for study. It is mostly utilised for orthopaedic applications requiring load bearing due to its strength, which is comparable to pure titanium (Ti). To compare the stress, strain and the total deformation for these two biodegradable implant materials, a fractured femur bone and an implant as rod and screws are modeled and FEA analysis has been performed using ANSYS. One of the most crucial processes in carrying out an accurate simulation using FEA is meshing. A mesh is composed of elements that have nodes – coordinate positions in space that might change depending on the element type that symbolize the geometry's shape. Meshing is the act of transforming irregular forms into more recognized volumes known as elements, which a FEA solver can work with more easily. Implants are analyzed by applying force to the femoral head and analyzing the amount of stress, strain, and global deformation that occurs in different parts of the bone and implant (rod and screws). Forces at an range of 2000N are applied to the femoral head and an equivalent stress, equivalent strain and total deformation results are obtained for two material properties including magnesium and zinc alloys. The values of stress, strain and total deformation for the material such as a magnesium and zinc alloy obtained are illustrated infig.4 and fig.5.



(a)



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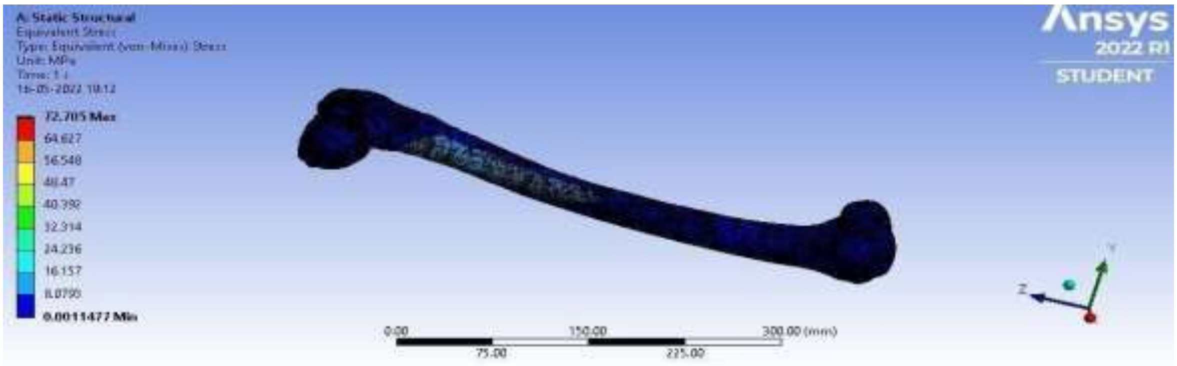
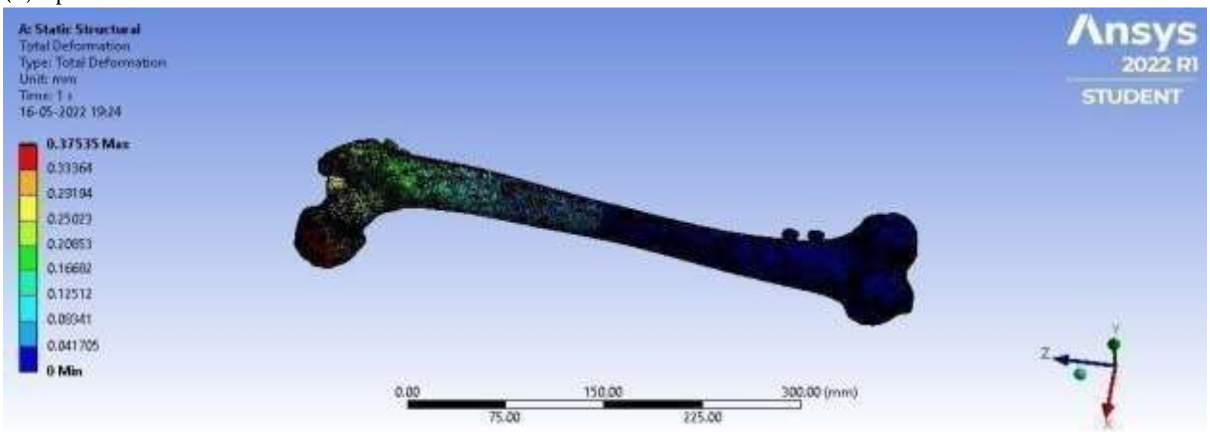
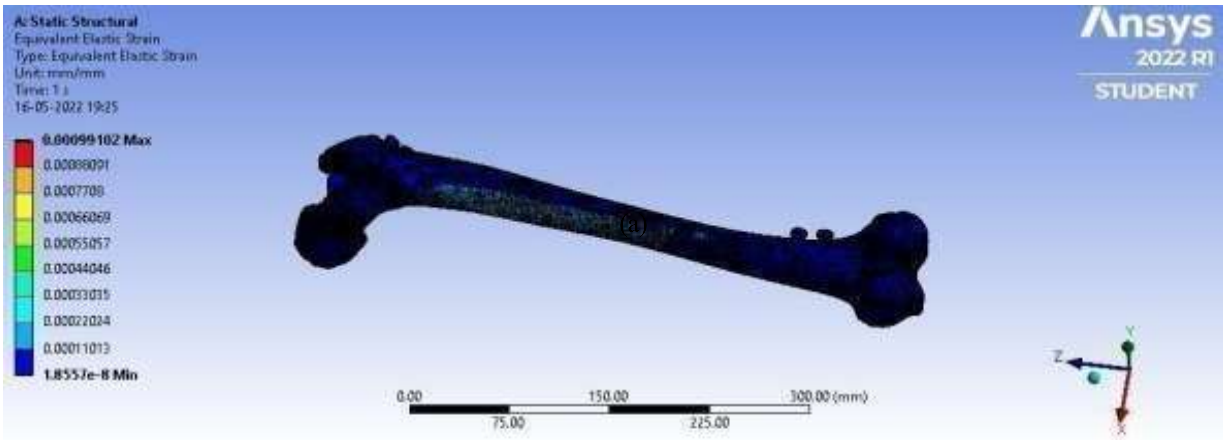


(c)

Fig.4.Result obtained for magnesium as a biodegradable implant material (a) total deformation (b)equivalent strain



and (c) equivalent stress



(b)
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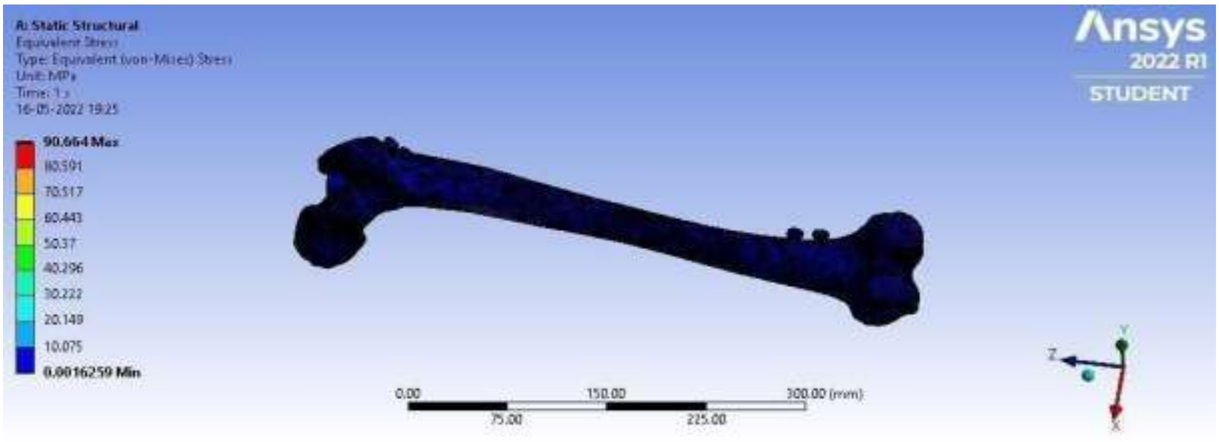

Fig.5.Result obtained for zinc alloy as a biodegradable implant material (a) Total deformation (b) equivalent strain and (c) equivalent stress

TABLE 2. Maximum and minimum values for FEA of magnesium and zinc alloy

Materials	Total Deformation	Equivalent Strain (mm)	Equivalent Stress (MPa)	Total Deformation (mm)	Equivalent Strain (mm)	Equivalent Stress (MPa)
	Max	Min	Max	Min	Max	Min
Mg	0.45	0.05	0.002	0.0009	72.7	8.07
Zn-Fe-Mg Alloy	0.38	0.041	0.0009	0.0006	90.6	10.7

The results obtained using magnesium alloy and zinc alloy materials were compared. The stress, strain and total deformation obtained for the implant (magnesium material) are
72.7 MPa, 0.002 mm and 0.45 mm. Results obtained for implants (zinc alloy material) are 90.6 MPa, 0.0009 mm and
0.38 mm. Comparing these results, it can be seen that the zinc alloy has relatively less deformation and strain than the magnesium implant material. However, the zinc alloy has a large amount of stress distributed throughout the femoral model compared to magnesium.

CONCLUSION

This study compares two biodegradable implants in an attempt to prevent the need to remove on-biodegradable implants after healing. According, to this investigation, magnesium has a greater stress tolerance than zinc alloy when used as an implant material. In the future, magnesium blended with hydroxyapatite due to its good bioactivity, appropriate mechanical stiffness and structure, osteo conductivity, and angiogenic qualities, lack of toxicity and lack of inflammatory or antigenic reactions. This can also be developed further into a bio printing method.

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