



Research Article

Pre-fabrication analysis using ansys in dental implants for enhancing mechanical stability and clinical success

Naveen ANKEGOWDA^{1,*}, Rakshith GOWDA D. S.¹, Nithyananda B. S.¹

¹Department of Mechanical Engineering, Vidyavardhaka College of Engineering, Karanataka, 570002, India

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ABSTRACT

There has been a wider scope for the development of dental implants with high bioactivity and low toxicity. The current study strives to address the issue by designing a dental implant with a pathway to inject the bioactive agent. The safety and reliability of the proposed design are tested for different materials using a finite element approach. Modeling of the implant is done in SOLIDWORKS®. To perform engineering analysis, ANSYS Workbench 2023 R1® software is used. The reliability and safety of the design are tested with three implant materials, including Titanium Grade 5 (Ti 6Al 4V), (y-tzp), and HGC-1-C. Static structural analysis is carried out to investigate the Von Mises stress, maximum principal strain, total deformation, and factor of safety. Modal analysis results show that the Ti-6Al-4V exhibits the highest natural frequency for the proposed design. The Ti-6Al-4V model shows a remarkable alloy composition and demonstrated minimal total deformation. From the analysis of these results, we deduce that the design is indeed safe. The fabrication is conducted with an emphasis on ensuring a secure design.

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INTRODUCTION

Bioactive materials for dental implants are specially designed to interact positively with biological tissues, promoting integration, healing, and sometimes even regenerative effects at the implant site. Bioactive materials play a significant role in enhancing the performance and longevity of dental implants. These materials are designed to promote osseointegration, reduce infection risks, and support tissue regeneration [1-3]. These materials are crucial in dental implantology for

achieving both mechanical stability and a biological bond with the surrounding bone and soft tissue. Chewing is a multidimensional biomechanical process that engages various structural systems, including geometrical factors of bones, muscles, joints, and teeth. This process entails the movement of the jaw when food is present in the mouth, triggering the chewing cycle [4]. Titanium alloy is the most used as an implant material in ortho and dentistry and which also hold good for cranial restoration [5-7]. Beside Titanium, Zirconium based dental implants gaining attention because of their anti-corrosion

*Corresponding author.

*E-mail address: naveen@vvce.ac.in

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behaviour which is further improved by having calcium phosphate and hydroxyapatite coatings which augment osteogenic potential at the defect sites [8]. Ahmed M. Abdelrhman et al. investigated the mechanical behaviour of 3D-printed polylactic acid (PLA) as an alternative to titanium dental implants, which results in moderate compressive and tensile strength. Finite element results show the elevated stress concentration, which leads to limited ability to withstand in vivo conditions [9]. It is also necessary to consider the compatibility of dental implants with bioactive material to avoid the adverse biological reactions. Ahmed Binobaid et al. developed a novel bioactive material, which is a mixture of calcium silicate and zirconia, to enhance the bioactivity that leads to bone bonding and elasticity, and they demonstrated a favourable improvement in resisting mechanical load during oral activities [10]. Hydroxyapatite (HAp) nano particles are the recent advancements in the bioactive material which provides antimicrobial functionality with Zirconia implants and accelerate the enamel mineralization with titanium alloy implant which is crucial in avoiding the dental cavities [11]. Komal Gupta et.al study gave insights on the Hydroxyapatite coating on the dental implants, and which enhances the interfacial bonding between bone and jaws. Toxicity and inflammations are the major worries in the dental implants which are effectively addressed by coating the HAp on implants [12]. The Surface modification of the implant is necessary to ensure the durability of the implant. In view of this Ravinder S. Saini et.al utilized the polyetherketoneketone to modify the surface of the implant as it possesses high stiffness and can accommodate natural movements [13]. Nano structured materials are incorporated into the dental composites which offers good strength and improves aesthetics. Bioactive glasses are extensively used as a biomaterial in oral implants which helps in repair of damaged dentin [14]. Consequently, dental implants endure a significant number of stress cycles over their functional lifespan. This induces structural instability and mechanical degradation of the material, diminishing its resistance and exposing it susceptible to microcrack initiation, ultimately leading to fracture propagation [15]. Fatigue behaviour is one the important factor to study. Chewing is loading conditions until food in mouth. Load acting on tooth surface is not homogeneous or uniform [16]. This process also contributes to fatigue, but this can be addressed during structural analysis using analysis software like ANSYS which is based on finite element analysis for optimal implant design [17-19]. Zhe Zhou et.al conducted a FE study to simulate the stress and strain around the carbon fibre reinforced PEEK dental implants and found that the bone tissue tends to be more stressed by oblique force than by axial load [20]. Chih-Ling Chang et al. investigated the stability of the bones of three different qualities using FEA and showed that the stress increases while the Young's modulus decreases [21]. In their investigation of the stress distribution between dental implants and alveolar bone, Yen-Wen Shen et. al [22] found that while the stress levels in both cortical and cancellous bone showed relatively small fluctuations, larger abutment screw diameters resulted in higher stress levels on the screws.

Nazrah Maher et al. provide insight on the carbon-based coatings on the dental implants, which improve osseointegration but still lag in antibacterial properties [23]. Cheng Zhang et. al clinically investigated the effect of bioactive agent on osseointegration. Controlled release of bioactive agent is necessary to have high bioactivity and low toxicity which require the modification in the design of the dental implant. Controlled release of bioactive agents is necessary to have high bioactivity and low toxicity, which requires modification in the design of the dental implant [24]. Fu-Yuan Teng et. al developed the Ti-alloy based dental implant with interconnected channel structure to inject BMP-2 bioactive agent using 3D printing which results in better osteogenesis [25]. Cristina Falcinelli et al's study shows that understanding the dentistry and consideration of the entire geometry of the jawbone is important to investigate the long-term stability of a dental implant without an internal channel under oblique and compressive force [26]. The engineering study of a dental implant model in ANSYS entails a sequence of simulations to assess the mechanical performance and biological compatibility of the implant under diverse physiological situations. This analysis is essential for refining the implant's design, material selection, and surface properties to guarantee stability, longevity, and biocompatibility prior to production [27]. The material properties, such as Young's modulus and yield strength, significantly affect stress distribution and fatigue behaviour under masticatory forces. Alongside its longevity, restorative capabilities, and enhancement of dental aesthetics, contemporary science has facilitated continuous advancement by using emerging technologies that have transformed the profession of dentistry. Emam et al. developed the titanium dental implant with cell signalling pathways to enhance osseointegration and showed that the advances in Omic technology make the implant technology still challenging [28]. While designing the dental implant, damping layer consideration poses an important step to address the stress under cyclic load [29]. The current study strives to address the issue by designing a dental implant with a pathway to inject the bioactive agent. The safety and reliability of the proposed design are tested for different materials using finite element approach. The current work has the potential scope in clinical research of dentistry.

MATERIALS AND METHODS

The present work starts with the design of dental implant referring to the geometrical parameter provided in the Internal Hex brochure of Adin company [30]. 3D modelling of the implant is created in SOLID WORKS including the screw threads, surface texture, and other geometric features [19]. Followed by the finite element analysis using ANSYS Workbench 2023 R1® software for the three different materials of the dental implant [19]. Static structural and modal evaluations are performed by applying appropriate boundary condition to assess the performance and stability of the implant design.

Modelling of Dental Implant

A 3D model of a dental implant is developed using CATIA V5 in accordance with the geometrical specifications provided in Internal Hex brochure as shown in Table 1 [31-34]. The skeleton model and 3D model of the

implant with internal passage is shown in Figure 1 and Figure 2 respectively.

Finite Element Analysis

The dentistry materials considered for the analysis are Titanium Grade 5 (Ti 6Al 4V), Yttrium Stabilized Tetragonal Zirconia (Y-TZP), and HGC-1-C depicted in Table 2 along with their respective properties.

Table 1. Geometrical specifications

Description	Detail
Length, L	16 mm
Diameter, D	4.05 mm
Implant Diameter, ϕ	5 mm
Pathway inlet and outlet diameters	0.2 mm
Chamfer parameters	0.25mm, 45°
Type of thread	V – Thread
Pitch	0.80 mm
Revolutions	16
Start Angle	180°
Direction	Clockwise
Taper Helix Angle	1.25°

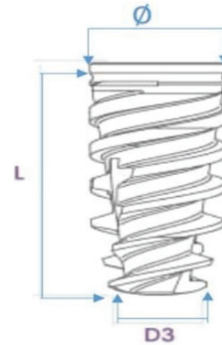


Figure 1. Skeleton of the dental implant.

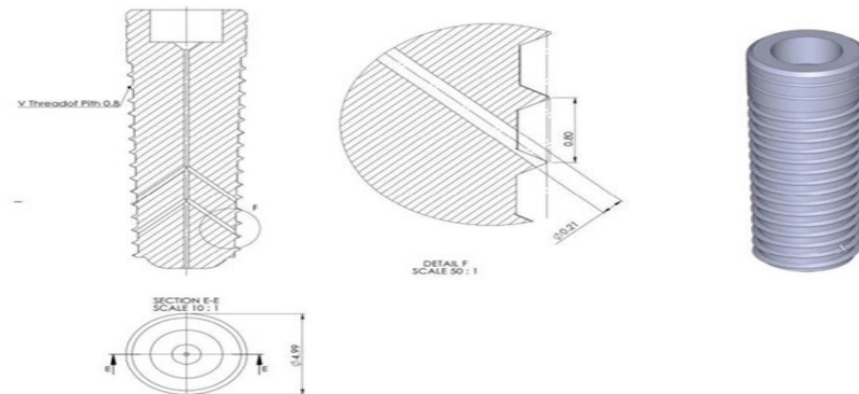


Figure 2. Draft and 3D model of the dental implant with internal passage.

Table 2. Mechanical properties of the material under consideration for the dental implant

Property	Ti-6Al-4V	Y – TZP	HGC-1-C Precious Alloy
Density	4.43 g/cm ³	6.050 g/cm ³	18.6 g/cm ³
Young's Modulus	113.8 GPa	110 GPa	130 MPa
Bulk Modulus	1.2 x 105 MPa	120.04 GPa	135 MPa
Shear Modulus	4.23 x 105 MPa	42.399 GPa	480 MPa
Tensile Yield Strength	880 MPa	880 MPa	300 MPa
Tensile Ultimate Strength	950 MPa	950 MPa	450 MPa
Compressive Yield Strength	970 MPa	970 MPa	480 MPa
Compressive Ultimate Strength	1455 MPa	1455 MPa	720 MPa
Co-efficient of Thermal Expansion	8.6 x 10 ⁻⁶ / K	8.6 x 10 ⁻⁶ /K	1.48 x 10 ⁻⁵ /K
Poisson's Ratio	0.342	0.324	0.34

The engineering study of the dental implant model is conducted utilizing ANSYS Workbench 2023 R1 software. The model is discretised using triangular and quadrilateral elements using the Hex Dominant Method and the details are mentioned in Table 3 [35]. To improve the precision, triangular elements are used to mesh the threads and quadrilateral elements to mesh the top cavity and the region surrounding the pathway hole. The quadratic order of the element was employed. The discretised model of the implant is shown in in Figure 3.

Table 3. Meshing details

Physics Preference	Meshing details
Element Order	Quadratic
Method	Hex Dominant
Type of Elements	Quad/Tri
Number of Nodes	47,303
Number of Elements	24,782

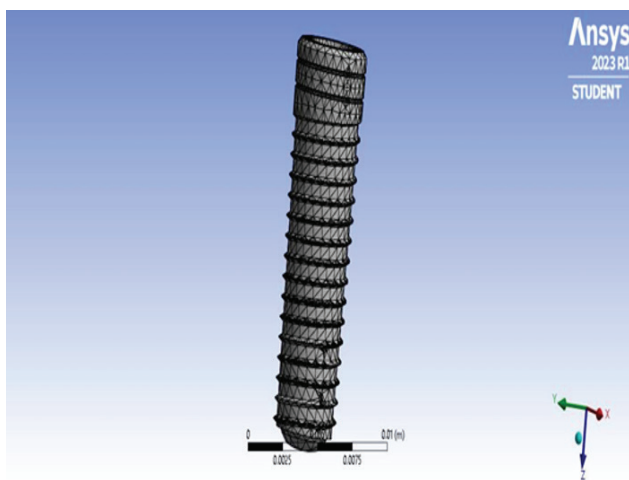


Figure 3. Discretised model of the dental implant.

According to the anatomy of the tooth, the boundary conditions were placed in the bone zone restricting the six degrees of freedom including displacements in U_x , U_y , and U_z and rotations in R_x , R_y , and R_z as shown in Figure 4. Diverse forces were exerted on the model, analogous to the conditions within the real oral cavity. A compressive load of 100 N applied in the longitudinal direction [36], 18N in the lingual direction [37] and 24N in the mesiodistal direction [38, 39] as shown in Figure 5 (a) (b) (c) (d) and (e).

Static Structural Analysis

A static structural analysis is carried out to assesses the impact of the applied static loads on a implant structure. The stress, strain, and deformation of the implant structure is tabulated under the given loading condition. This facilitates the identification of vulnerable regions with insufficient strength and durability during the design phase, hence preventing costly failures. The model is equipped with fixed support at the base, excluding the threads on its body as shown in Figure 6.

Modal Analysis

The modal analysis is carried out to record the natural frequency of the design with three different materials mentioned in Table 4.

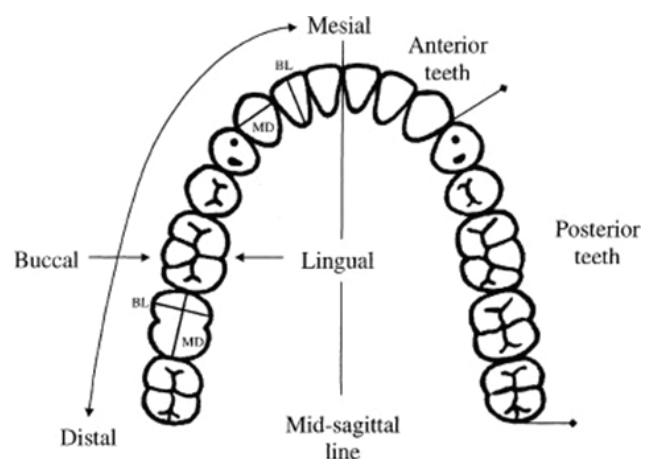
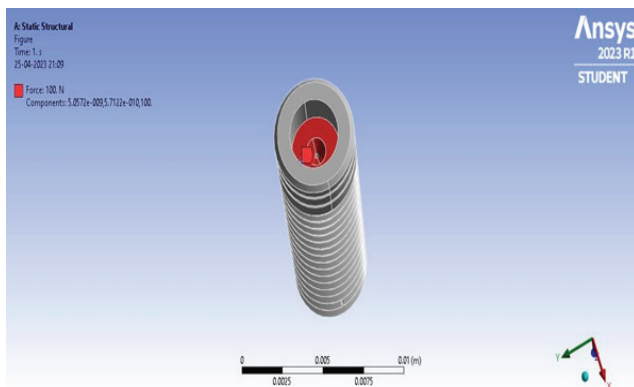


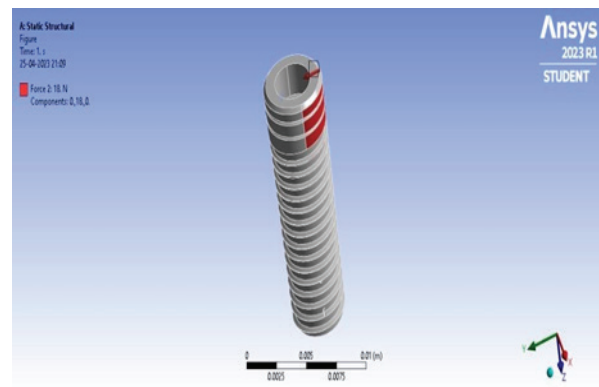
Figure 4. Anatomy of the tooth.

Table 4. Natural frequencies

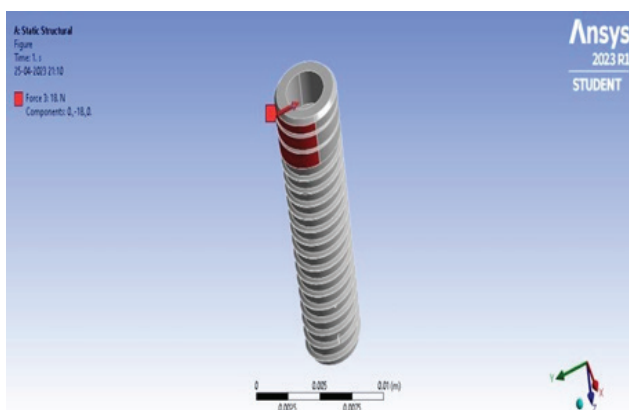
Modes	Ti-6Al-4V - Frequency in Hz	Y-TZP - Frequency in Hz	HGC-1-C - Frequency in Hz
1	196170	228180	3532.9
2	201150	233930	3317.9
3	225840	262760	3725.5
4	228580	265930	3770.5
5	263270	308510	4345.7
6	397320	462270	6563.2



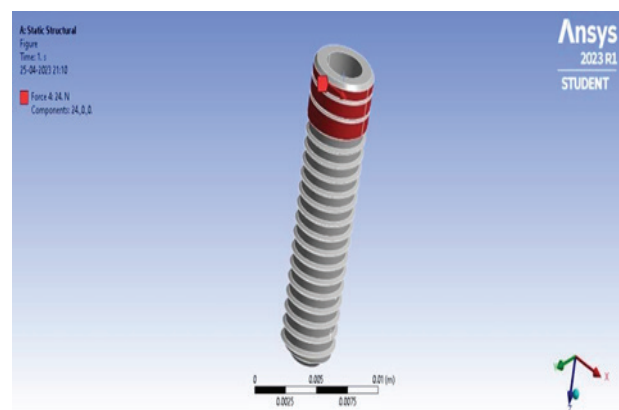
(a)



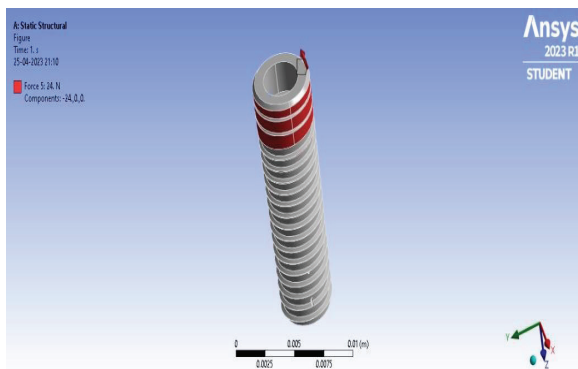
(b)



(c)



(d)



(e)

Figure 5. Application of longitudinal compressive load of 100 N, Load of 18N in the lingual direction 1, Load of 18N in the lingual direction 2, Load of 24N in the mesiodistal direction 1, Load of 24N in the mesiodistal direction 2 in (a),(b), (c),(d) and (e).

RESULTS AND DISCUSSION

Static Structural Analysis

The model's Von Mises Stress, Maximum Principal Strain, Total Deformation, and Safety Factor were all resolved for all the three materials. The von Mises stress determine whether a material will yield or fail under complex loading conditions where a material experiences multi-axial stress. If it crosses yield stress, then it starts

deforming permanently. It was found that the von Mises stress of Ti-6Al-4V is 22.057 MPa, Y-TZP is 21.032 MPa and HGC is 21.958 MPa. Implant design with Ti-6Al-4V alloy perform better under chewing forces, which are complex and multidirectional. The behaviour of the implant design under Von Mises stress is shown in Figure 7 (a), (b) and (c).

Maximum Principal Strain is the maximum normal strain that a material experiences under a particular load

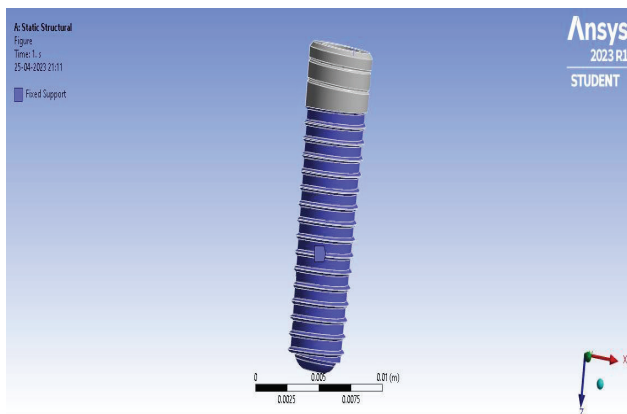
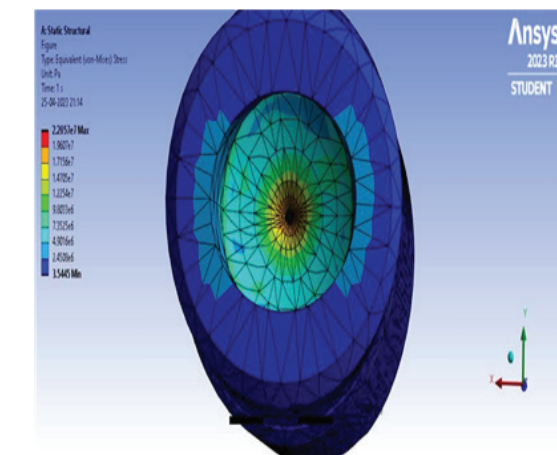


Figure 6. Static structural analysis of the dental implant.

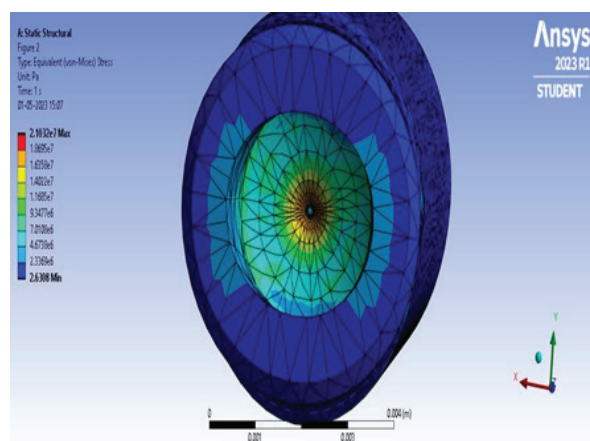
in a particular direction. Analysis of this strain is observed to be 0.000122 strain for Ti-6Al-4V, while material Y-TZP determined of 0.05857 and HGC-1-C Precious Alloy had a value of 0.10627. Ti-6Al-4V exhibit the smallest strain, likely indicating the least deformation and possibly the safest option under normal loading. Implant with different materials under strain is shown in Figure 8 (a), (b) and (c).

Regardless of the coordinate system being employed, total deformation (TD) is the square root of the sum of squared stretching and squared shearing deformations. In Ti-6Al-4V, the total deformation is 0.00022 mm, Y-TZP is 0.00012 mm, and the HGC-1-C precious alloy exhibit deformation of 0.19664 mm. The total deformation observed in the implant is shown in Figure 9 (a), (b) and (c).

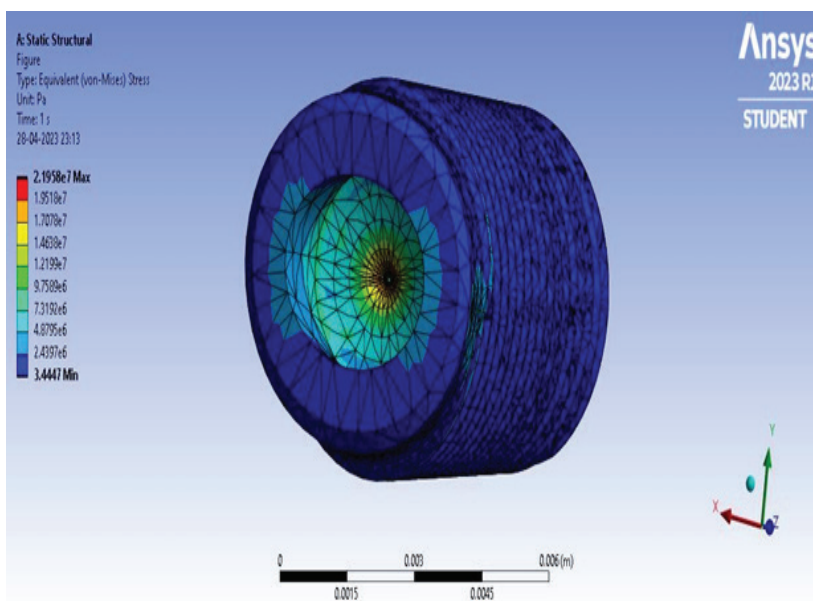
The factor of safety decides the reliability of a design. In Ti-6Al-4V and Y-TZP, the factor of safety is found to be 15,



(a)

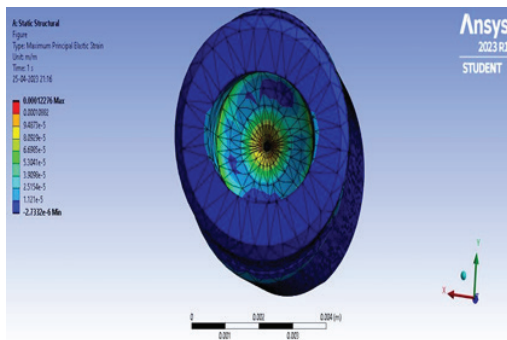


(b)

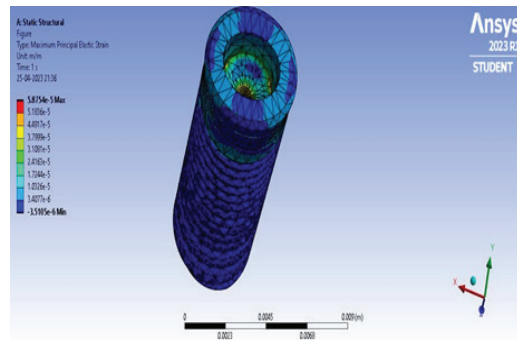


(c)

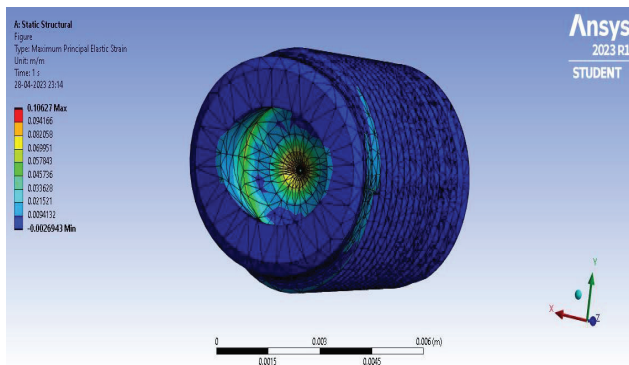
Figure 7. Implant design under Von Mises stress of Ti-6Al-4V, Y-TZP and HGC – 1 – C Precious Alloy in (a), (b) and (c).



(a)

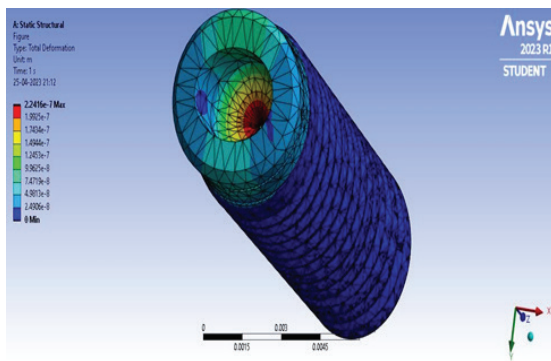


(b)

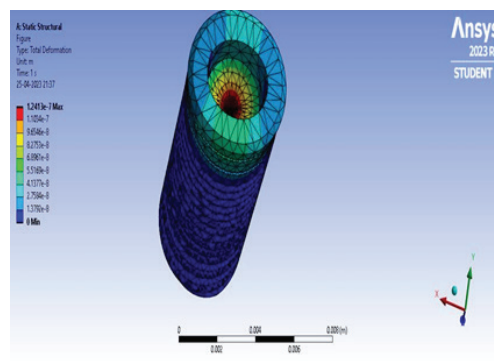


(c)

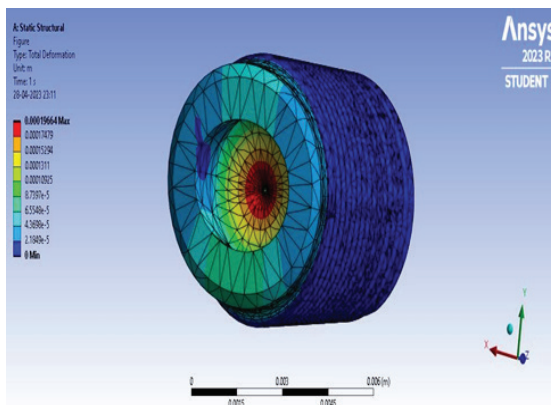
Figure 8. Implant under maximum principal strain of Ti-6Al-4V, Y-TZP and HGC – 1 – C Precious Alloy in (a), (b) and (c).



(a)



(b)



(c)

Figure 9. Implant design under Total deformation of Ti-6Al-4V, Y-TZP and HGC – 1 – C Precious Alloy in (a), (b) and (c).

Table 5. Results of the static structural analysis

Results	Ti-6Al-4V	Y-TZP	HGC-1-C
Von Mises Stress (in MPa)	22.057	21.032	21.958
Maximum Principal Strain	0.000122	0.05857	0.10627
Total Deformation (in mm)	0.00022	0.00012	0.19664
Factor of Safety	15	15	13.66

while in HGC-1-C it is 13. 66. Overall output of the static structural analysis are tabulated in Table 5.

CONCLUSION

The design has been determined to be safe for all three materials: Ti-6Al-4V, Y-TZP, and HGC-1-C precious alloy. The von Mises stress values for all three material models remain significantly below the endurance limit. In a comparative analysis, the Von Mises stress exhibited its highest value in the Ti-6Al-4V model and its lowest in the Y-TZP model. Conversely, the Maximum Principal Strain reached its peak in the HGC-1-C Precious Alloy model, while it was minimal in the Ti-6Al-4V model. The highest total deformation was observed in HGC-1-C. The Ti-6Al-4V model exhibited a remarkable alloy composition and demonstrated minimal total deformation. From the analysis of these results, we can deduce that the design is indeed safe. The fabrication is conducted with an emphasis on ensuring a secure design

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The authors declared no conflict of interest.

ETHICS

There are no ethical issues with the publication of this manuscript.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article.

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