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Design and Development of Dental Implant Using Bio Ceramics

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Authors' contributions

This work was carried out in collaboration among all authors. Author KA studied the significance of the nano materials in the dentistry and also performed the detailed analysis study using ansys in various modes. Author BS studied the utilization of Bio ceramics in the dentistry and in orthopedic fields and a detailed description about the bio ceramics and wrote the first draft of the manuscript. Author MA designed the dental implant (tooth) in a design software called solid works 2019, also detailed information about the nano materials for the outermost layer of the implant. All authors read and approved the final manuscript

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ABSTRACT

Generally, dental tooth fixtures are made of conventional metals like titanium, gold, silver etc and also some other materials like Acrylic and porcelain. These fixtures are either too expensive to make or are delicate and would deteriorate after a certain number of cycles. Therefore, a possibility of using composite materials was looked at owing to its high strength to weight ratio under compressive conditions, durability and cost. On conducting research on various materials available, Hydroxyapatite in combination with Zirconia was chosen to be the ideal material. This pair was tested for the weaker one among them and the results are established conclusively which confirmed that it is indeed a viable option to go for.

Keywords: Bio ceramics; dental implants; design; analysis; fatigue; reliability; nanomaterial.

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1. INTRODUCTION

Ceramic materials have been used for a long time in dentistry for the production of dental restorations due to their excellent biocompatibility, their good mechanical properties, and their aesthetic appearance, very similar to that of natural teeth.

In the last 15 years, the technological evolution behind the development of this class of materials has been remarkable and their use is becoming even more intensive, due to the growing request of patients around the world asking for metal free solutions. The development of totally metal free solutions is one of the main research topics in the field of dental materials and, even though metal alloys are still extensively used, their unnatural color and the insurgence of unwanted chemical–biological interactions connected with their use is encouraging the use of ceramics even more[1]. At now, among the new research trends, there is the development of zirconia-based ceramics and composites having a nanometric structure, since several studies have demonstrated that nanostructured materials' properties are different and generally improved, in respect to that of conventional materials.

1.1 Classification

1.1.1 Bio ceramics [2]

Bioceramics are mainly classified into 3 categories they are:

1. Inert
2. Bioactive
3. Biodegradable

1.1.1.1 Inert bioceramics

These ceramics have inherently low levels of reactivity compared with other materials such as polymers and metals as well as surface reactive or resorbable ceramics. Due to their excellent frictional properties technical ceramics are nowadays mainly used in endoprosthetics.

Examples of Inert Bioceramics are Al2O3, ZrO2, Sintered Hydroxyapatite, Carbons, CaAl2O4, Silicon carbide, Silicon Nitride.

1.1.1.2 Bioactive ceramics

Bioactive ceramics are generally regarded as ceramics that are designed to induce specific biological activity for repairing damaged organs. For repairing bone tissues, the *bioactivity* is regarded as the capability to make direct contact with living bone after implantation in bony defects.

Examples of Bioactive ceramics are Hydroxya patite, Hydroxycarbonate Apatite, Bio-glasses, Apatite-wollastonite.

1.1.1.3 Biodegradable ceramics

Chemically broken down by the body and degraded. The resorbed material is replaced by endogenous tissue. Chemicals produced as the ceramic is resorbed must be able to be processed through the normal metabolic pathways of the body without evoking any deleterious effect.

Examples of Biodegradable ceramics are CaSo4, Coral-Caco3: aragonite, Ca-phosphates: alpha-Tricalcium phosphate, beta-Tricalcium phosphate, Octacalcium phosphate.

2. VARIOUS MATERIALS OF THE BIO CERAMICS [3]

2.1 Inner Material

2.1.1 Zirconia (ZrO2)

The use of Zirconia (Zirconium dioxide, ZrO2) has considerable significance in dental science. It has similar metallic properties and color like a tooth. Zirconia is a chemical oxide which is insoluble in water. Thus, it reduces the bacterial adhesion and has low cytotoxicity.This makes ZrO2 as a widespread biomaterial for dental implants. Zirconia implants encompass glorious resistance against corrosion and carry, as well as sensible biocompatibility. Moreover, high fracture resistance can be acquired by ZrO2 because of energy retention properties throughout the conversion of polygonally shaped molecules into monoclinic ones. Zirconia NPs is a bio inert material, the encapsulation by animal tissue is weak and also the unleash of remains virtually unnoticeable. Additionally, Zirconia is osseo conductive, thereby facilitating bone formation.

Besides ZrO2 NPs various nanocomposites are also used in various applications of dentistry. Nano zirconia-alumina materials combine the physical and chemical properties of ceramic material.In these NPs, a low percentage of tetragonal ZrO2 particles is in an aluminum oxide matrix. Thus, the toughness and longevity which are the principal interest in the dentistry are retained.Alumina/zirconia nanocomposites are new implant materials which show better efficacy as compared to the ceramic materials. Zirconia oxide nanoparticles are found to have anti-biofilm activity against certain bacteria (such as *Enterococcus faecalis*) and therefore they can be effectively used as a polishing agent in dental practices.

2.1.2 Alumina (Al2O3)

Alumina has received considerable attention and has been historically well-accepted as biomaterials for dental and medical applications.Alumina, also called Aluminium oxide, is the only solid oxide form of aluminium (Al2O3). It has been a technologically significant ceramic material throughout human history. Alumina was first introduced in the1970s,but early clinical applications showed a fracture rate as high as 13% . Failure in this first generation of ceramics was due to the fact that they could not be processed to fullfinal density. A second improved generation of ceramics,developed in the late 1980s, resulted in higher density and smaller grains. The fracture rate associated with the second generation of alumina decreased to less than 5% .Finally, today a third generation of ceramic components isavailable, characterized by high purity, full density and finer microstructure.

2.1.3 Sintered hydroxyapatite

Hydroxyapatite ceramics and nano particles have been used widely in medicine and dentistry. It's similar composition with teeth and bone make it a biocompatible substance for the physiological process. This is the main composition of mineralized tissues of the human body (Ca10 (PO4)6·2(OH)). It is a natural calcium phosphate ceramic, predominant in 97% enamel. The hardest tissue of our body is tooth enamel which has HAp nanocrystals as the building blocks. Teeth are acellular in nature, thus it cannot be logically repaired like a bone. Thus regenerating the enamel surface is a significant challenge.

2.1.4 Silicon nitrides (Si3N4)

Silicon nitride (Si3N4) is biocompatible and stable *in vivo*, and these properties, when combined with its superior mechanical properties, make Si3N4 an attractive ceramic implant material in some healthcare applications, particularly in orthopedic surgery. Si3N4 is used in spinal fusion surgery, is under development for use as bearings in joint replacement, and is being considered for use as dental implants. While Si3N4 implants are currently created using conventional ceramic processing techniques, additive manufacturing provides the capacity to create custom implants with the required anatomical shape, precise dimensions, and well-controlled microstructure. Si3N4 can be created with a smooth or micro rough surface topography, and its surface chemistry can be varied from a silica-rich to a predominantly silicon-amine composition, which can influence the response of cells, tissues, and bacteria *in vivo*.

2.2 The Outer Layer Material

Material chosen for the outer material for the tooth is Hydroxyapatite (HAp) due to its overall advantageous properties compared to other materials.

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The recently developed interest in nanotechnology is providing new insights about the application of nano-hydroxyapatite in dentistry. The nano sized HAp particles can easily integrate into the dental tubules. The function of the tubule is to seal the opening and thus prevents the nerves to expose towards external stimuli. Thus, HAp helps to reduce dental hypersensitivity. HAp NPs have greater surface area, as a result of which they can bind strongly with proteins as well as with bacterial and plaque fragments. Their high biological activity and reactivity enable them to bind to the dentin apatite and tooth enamel. Hydroxyapatite nanoparticles can fit well with the very small cavities present in the enamel originated by acidic erosion. The HAp NPs are adsorbed robustly to the enamel of the teeth and thus retard auxiliary erosive demineralization. Various toothpaste, mouth-rinsing solutions integrate these nanocrystals to repair the enamel surfaces. The biomimetic function of hydroxyapatite is to protect the teeth by making a film of artificial enamel around the tooth. The granular hydroxyapatite is employed in dental clinical rehearsal to reform periodontal shortcomings.

Biocompatibility studies indicated that hydroxyapatite has the ability to bind to bone and do not lead to any inflammatory response, either local or systemic nor toxic phenomena. Some scientists have shown that the hydroxyapatite, as like tricalcium phosphate, does not go through any resorption. Due to its chemical property and ability to form crystals with inorganic components of teeth, it can build chemical bonds and make sure the immediate integration of titanium implants to the teeth and the tissues around it. Several studies have put forward the role of hydroxyapatite in facilitating the method of step integration.

Hydroxyapatite can be synthesized via several methods, such as wet chemical deposition, biomimetic deposition, sol-gel route (wet-chemical precipitation) or electro depo sition [6]. Yagai and Aoki proposed the hydroxyapatite nanocrystal suspension can be prepared by a wet chemical precipitation reaction following the reaction equation below:

$$10\ Ca(OH)_2 + 6\ H_3PO_4 \rightarrow Ca_{10}(PO_4)_6(OH)_2 + 18\ H_2O$$

2.2.1 Biological function

2.2.1.1 Mammal/primate/human

Hydroxyapatite is present in bone and teeth; bone is made primarily of HA crystals interspersed in a collagen matrix—65 to 70% of the mass of bone is HA. Similarly HA is 70 to 80% of the mass of dentin and enamel in teeth. In enamel, the matrix for HA is formed by amelogenins and enamelins instead of collagen.

Hydroxyapatite deposits in tendons around joints results in the medical condition calcific tendinitis.

2.2.1.2 Cosmetic

Hydroxyapatite is added to some variations of cornstarch based baby powder such as Johnson's Aloe & Vitamin E powder. According to the website, the mineral is added as an emollient to "help moisturize and soften skin.

2.2.1.3 Medical

Flexible hydrogel-HA composite, which has a mineral-to-organic matrix ratio approximating that of human bone.

HA is increasingly used to make bone grafting materials as well as dental prosthetics and repair. Some implants, e.g. hip replacements, dental implants and bone condu ction implants, are coated with HA. As the native dissolution rate of hydroxyapatite in-vivo, around 10 wt% per year, is significantly lower than the growth rate of newly formed bone tissue, in its use as a bone replacement material, ways are being sought to enhance its solubility rate and thus promote better bioactivity.

Hydroxyapatite is added to special toothpastes as an additive to prevent tooth decay and to counteract tooth sensitivity.

2.2.1.4 Supplement

Microcrystalline hydroxyapatite (MCHA) is marketed as a "bone-building" supplement with superior absorption in comparison to calcium.

It is a second-generation calcium supplement derived from bovine bone. In the 1980s, bone meal calcium supplements were found to be contaminated with heavy metals, and although the manufacturers claim their MCHA is free from contaminants, it isn't recommended because its effect in the body has not been well-tested.

3. DESIGN AND ANALYSIS

3.1 Methodology

The design of the tooth crown is done in a certain way that it should be highly reliable comparatively than other dental fixtures made with Acrylic, Polycerilean and others. Inorder to design a tough tooth, we have reduced the sharp edges and also designed the tooth in two layers.

The innermost layer comprises the maximum volume which is Zirconium, It is a bio ceramic and widely as an orthopedic implants and the outermost layer is very thin in thickness which is Hydroxyapatite, it is very similar to the Enamel, that is naturally occurred furthermore it is a Nanoparticle used in Dentistry.

3.2 Design

The design of the tooth was done in the SOLIDWORKS 2019,For designing the model of the tooth, the premolars were chosen since it is the one on which high compressive forces are applied. The average size of a molar gets enclosed in a 0.75*0.75*0.75 [6,7] cubic cm volume and hence the model was made accordingly.

3.3 Analysis

The analysis done on the tooth is static structural using Ansys Workbench 19.0. So designed a tooth crown structure, we gave the possible curves as the crown structure changes from person to person, the properties of Zirconia Ceramics were taken from Math web and Azom Websites.

Hydroxyapatite properties from various journals mentioned in references. The structure of the tooth crown is too complex and generating surfaces on it using SOLIDWORKS are troubled while generating mesh because of the intersection of few surfaces with each other. So we suppressed the surface and used a surface coating option available in Ansys Mechanical, giving a 0.5mm thickness to the layer.

The meshing is changed from 10 mm to 5 mm until obtaining a consistent value with an error of 0.02 in the results. The surface mesh and surfaces where force is applied the mesh is reduced to 1 mm to get a better result at those locations The Force applied 800N as the mastication is highest in chewing Nuts and Mutton and the base of the crown is fixed. The solution used Soderberg Equation in Fatigue tool to find life in terms of cycle and safety factor of the crown. The force is set to Zero-based as we know the only force on teeth is compressive and Shear.

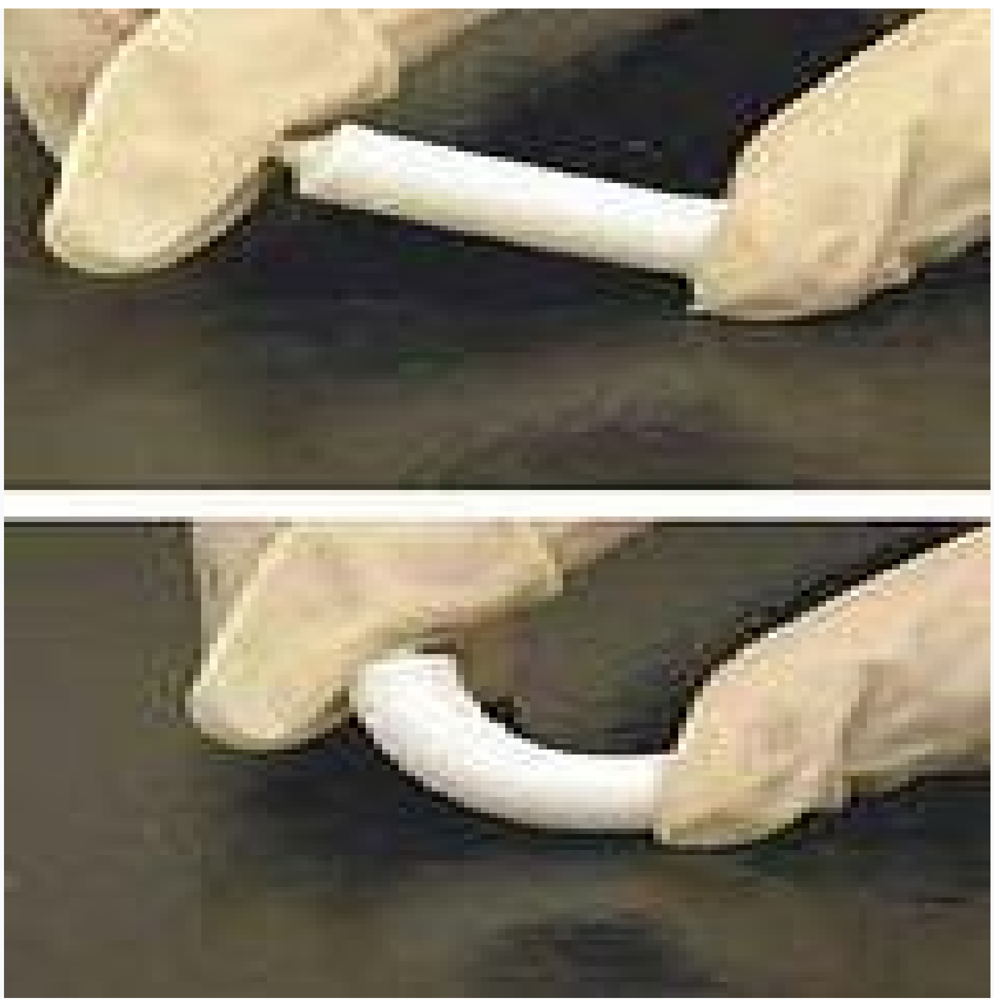

Fig. 1. Hydrogel-HA composite flexibility

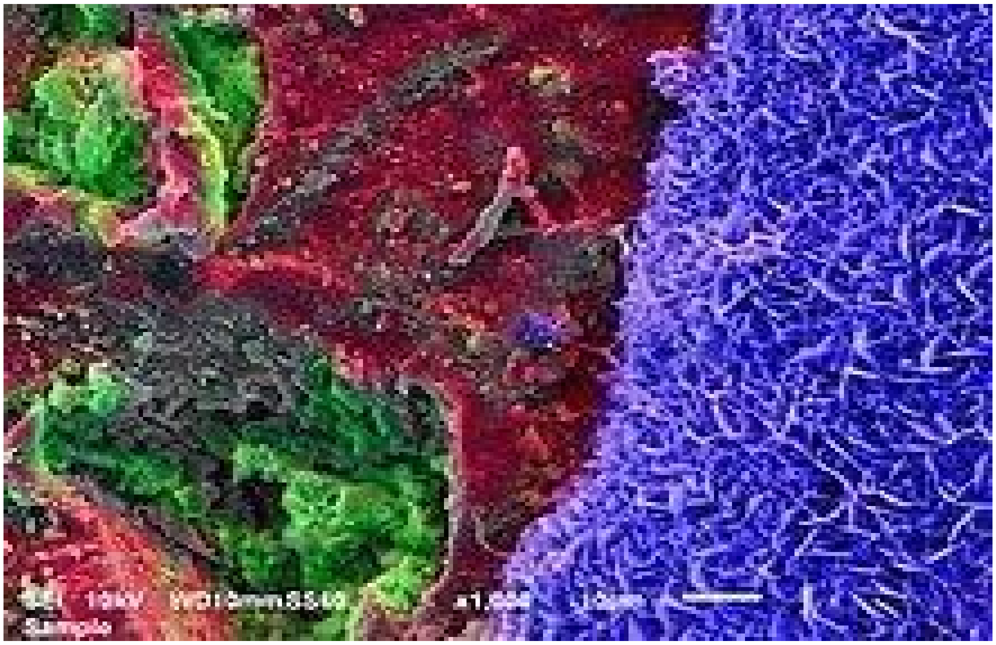

Fig. 2. Hydroxyapatite overgrowing the biomaterial

According to IMA (Indian Medical Association)

The average human bites his teeth [8] 32*15*4*20*365= 14 * 10e6 times with an average pressure of 98 psi and a maximum of 162 psi.

- Average number of grinds per chew = 32
- Average number of chews = 15
- Average number of meals = 4
- Average number of years a tooth remains intact = 20
- Number of days in a year = 365
- The average number of bites an affordable fixture can sustain is less than 1/3 of 14 * 10e6 with restrictions on the consumption of certain foods [9].

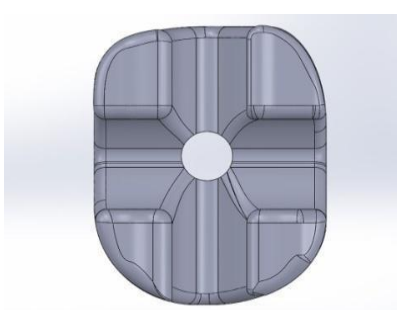

Fig. 3. Top view of tooth

Fig. 4. Font view of tooth

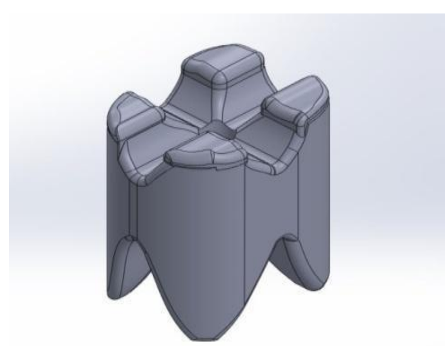

Fig. 5. Isometric view of tooth

Table 1. Mechanical properties of various bio ceramics [4]

Material parameter	Zirconia (zrO2)	Alumina (Al2O3)	Hydroxyapatite (HA)	Silicon Nitride (Si3N4)	Silicon Carbide (SiC)
Density (kg/m^3)	6150	3980	3150	3250	4840
Poisson's Ratio	0.32	0.33	0.27	0.28	0.37
Modulus of elasticity	250	413	700	297	137
Yield strength (MPa)	711	665	340	525	1240
Compressive strength(MPa)	3000	2900	670	2500	1395
Thermal Conductivity (W/m-k)	2.7	38.5	0.5	40	20.7
Flexural Strength (MPa)	930	350	250	900	205

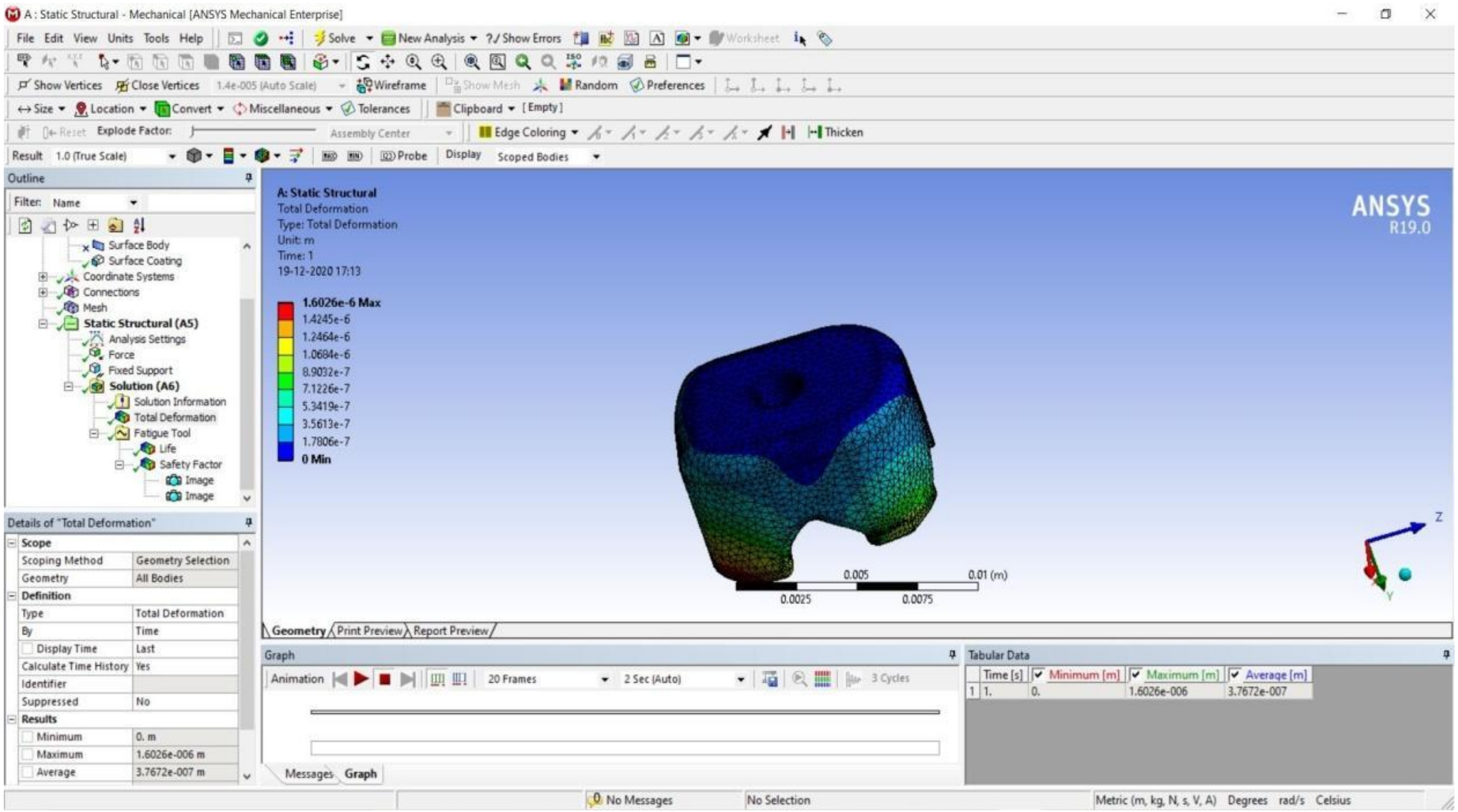

Fig. 6. Total Deformation in static structural analysis

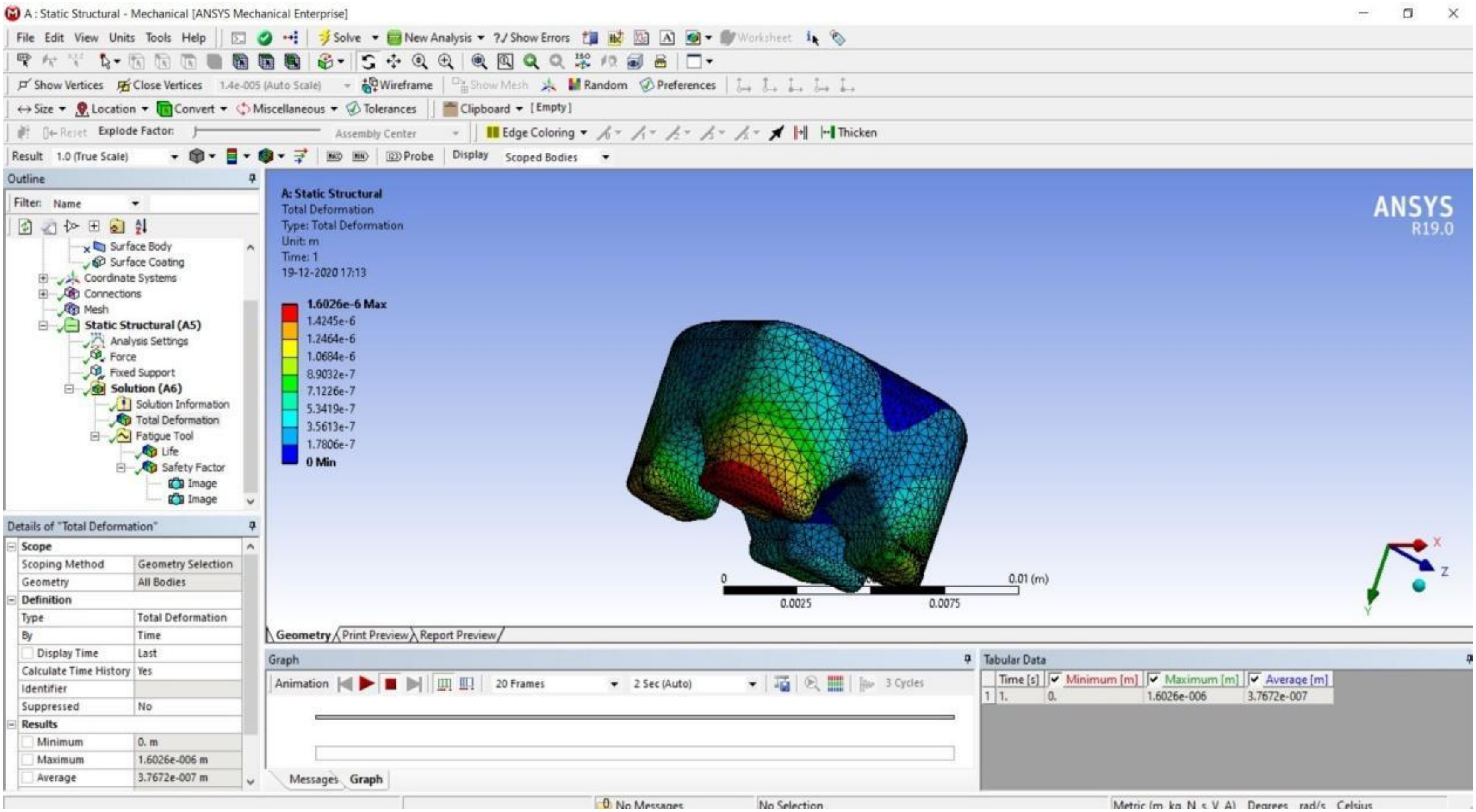

Fig. 7. Total deformation in static structural analysis

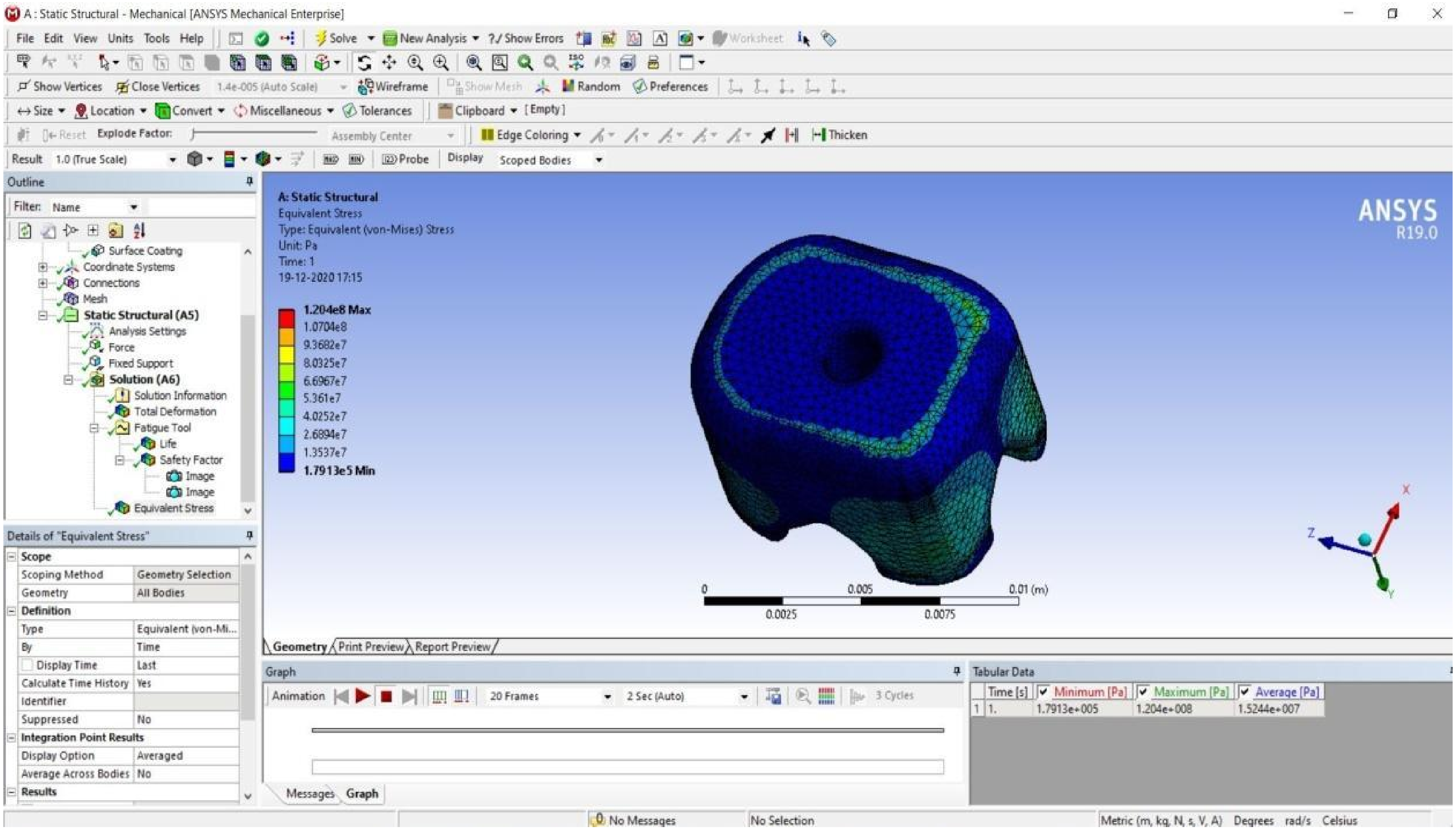

Fig. 8. Fatigue analysis by von mises method

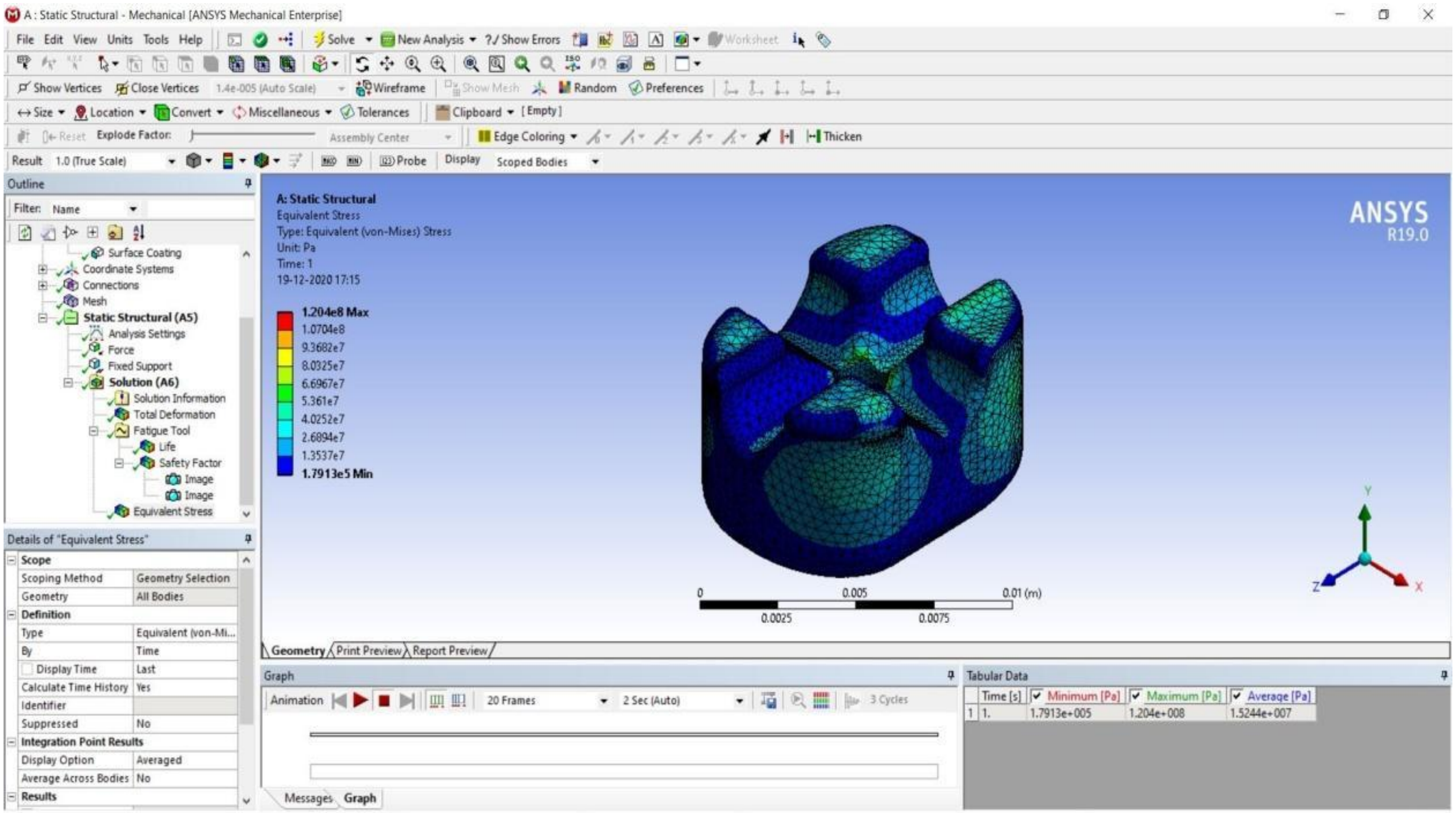

Fig. 9. Fatigue analysis by Von mises method

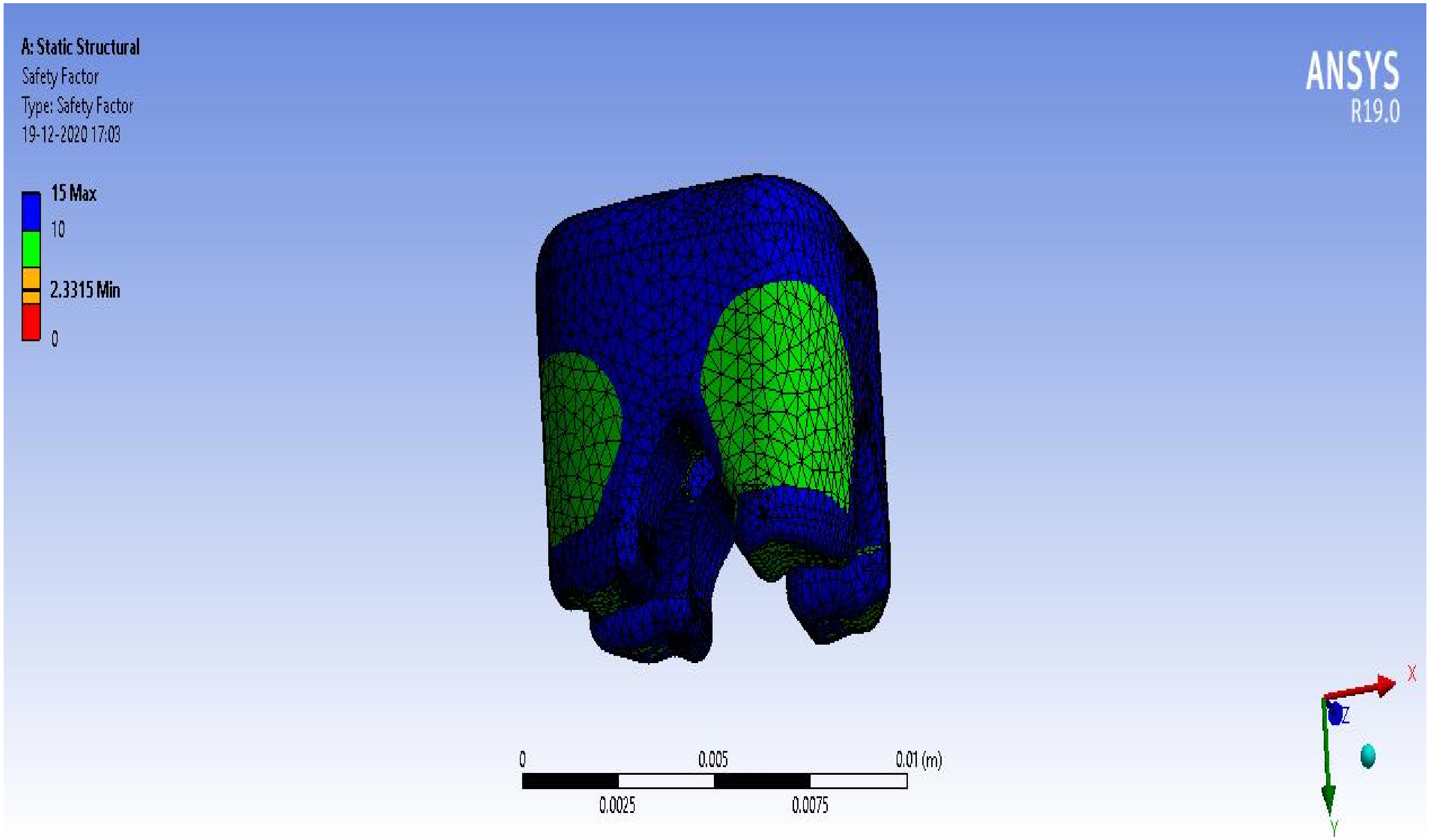

Fig. 10. Factor of safety

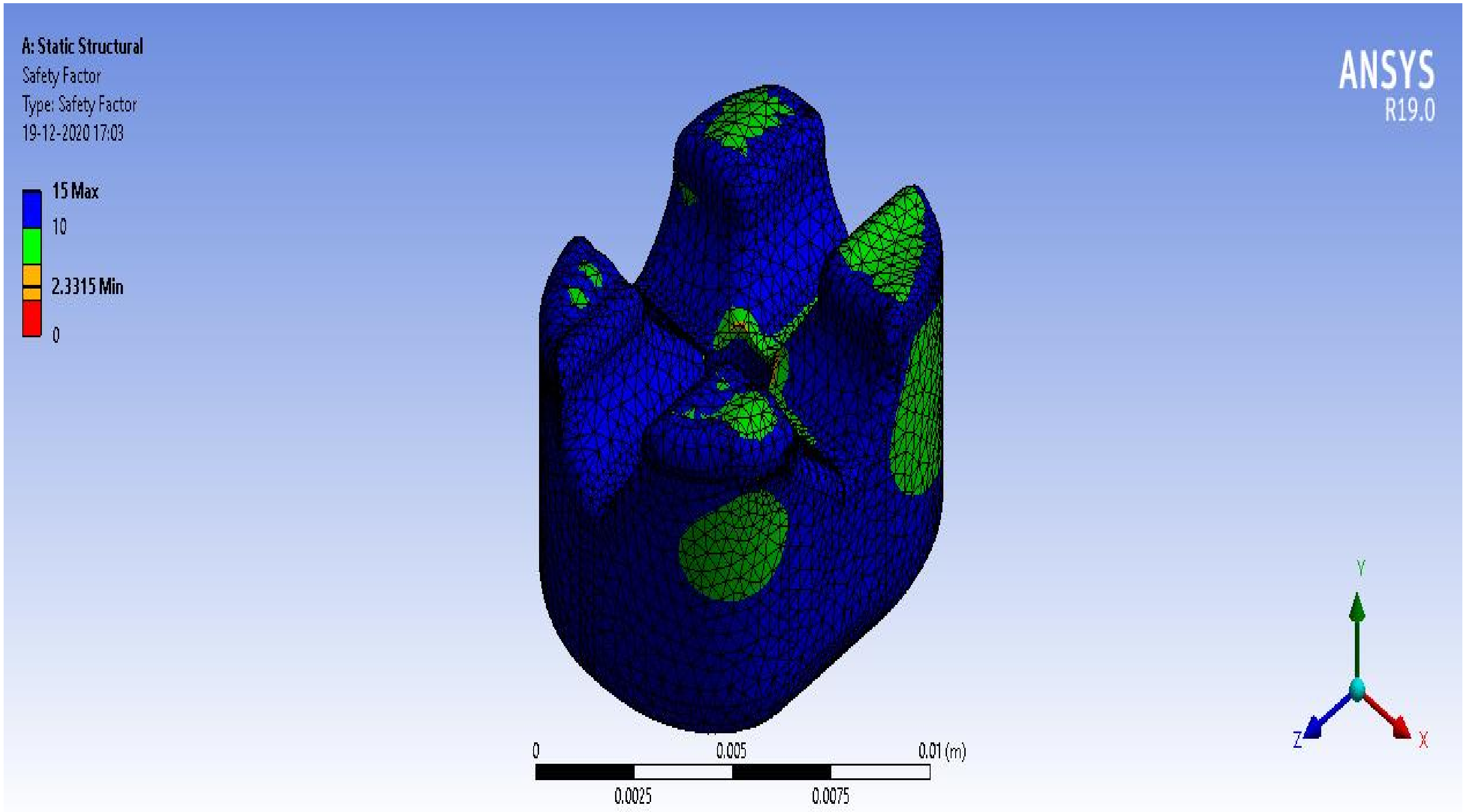

Fig. 11. Factor of safety

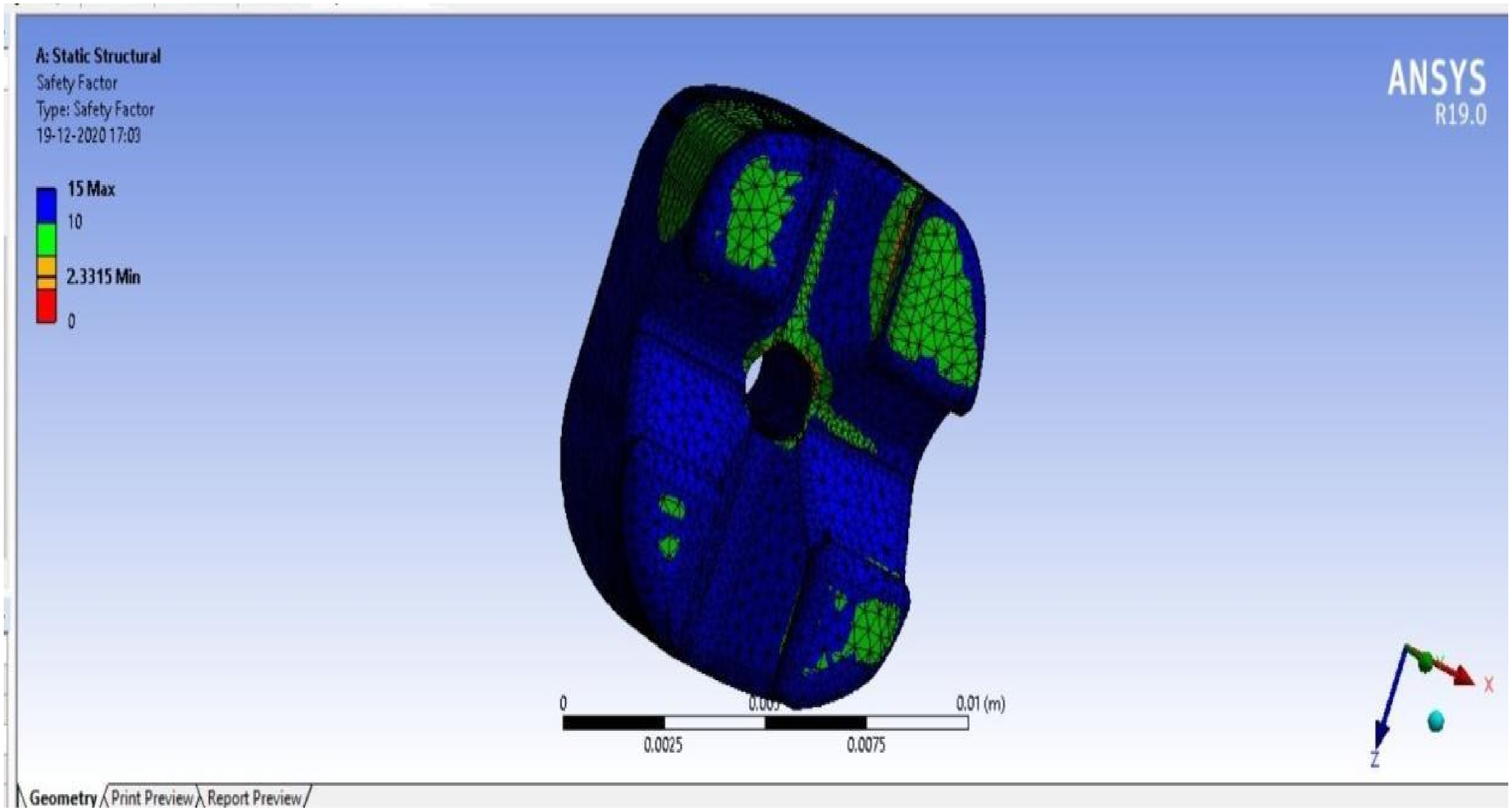

Fig. 12. Factor of safety

Table 2. Properties of nanoparticles [5]

Name of NP	Compressive strength, Malleability, ductility	Physical property	Chemical property
Carbon nanotubes	Carbon nanotubes can offer tensile strength because of the hexagonal arrangement yet it has the malleability of rubber, high tensile ductility (8–13%), good mechanical strength.	Surface area is large, ultra-light weight, heat stability, high strength, lower density.	Heat transmission efficiency Strong bond between carbons atoms make this material quite stable; the carbon atoms in nanotubes are arranged in hexagonal rings.
Graphene	Graphene is transparent, flexible (high malleability and ductility) and very stable.	The unique structure gives rise to a high planar surface area, superior mechanical strength, electronic properties are remarkable and alluring optical characteristics.	Single, thick carbon sheets of honeycomb lattice orientation having two-dimensional (2D) origin make up the grapheme structure. Due to the structure, graphene has acquired a number of unique and exceptional characters.
Hydroxyapatite (HAp)		Greater surface area, hexagonal structure.	It is a calcium phosphate. It is quite stable when compared to other calcium phosphates.
Zirconia	The ductile, soft and malleable matter which provides great resistance to corrosion.	Zirconium nanoparticles are lighter and less susceptible to embrittlement by hydrogen.	Available in the form of nanodots, Nano fluids nanocrystals with the white surface area. Provide great resistance to corrosion by acids, alkalis, salt water and other agents.
Silica	Compressive strength–1600 MPa with minimal ductility and significant hardness.	Two types based on their structure – P-type and S-type. P-type is characterized by numerous Nano pores whereas S-type has a smaller surface area. P-type nano silica is having comparatively higher UV reflectivity.	Chemical composition- Silica- 46.83% Oxygen- 53.33% Molar mass- 59.96 g/mol Density- 2.4 g/cm^3
Titania	Having a compressive strength of about 3675 MPa with null ductility, quite hard and an elasticity limit of 367.5 MPa.	Found as nanocrystals or nano drops having large surface area, exhibit magnetic properties.	Chemical composition Titania- 59.93% Oxygen- 40.55% Insoluble in water and organic solvent
Silver	Silver nanoparticles have high ductility and malleability. They are also good conductors.	Small in size, the surface area is large, having exceptional optical, electrical and thermal conductivity.	Chemically very stable having catalytic activity, unique surface chemistry which helps them better act as an antimicrobial agent.

Table 3. Results for the Analysis

Parameter	Obtained result
Total deformation	1.6026 Micrometer
Von-Mises stress induced	120.4 Mpa
Number of cycles for 800N	10^7 cycles
Factor of safety	2.3315

4. RESULTS

After performing Static structural analysis on the crown structure in tooth the following results has been tabulated accordingly.

5. CONCLUSION

Advanced materials are going to be an essential part of clinical dental practice. At present Bio ceramics such as zirconia ,alumina etc. have been used as many dental and orthopedic implants due to their inert nature with human cells and also their mechanical properties. So some advanced Bio ceramic like zirconia has been integrated with a nano material like Hydroxyapatite layer by layer, which makes this synthetic tooth much stronger and tougher than natural tooth and also highly reliable than conventional implants which has very less life cycles than 10^8 cycles with 800N per bite. Some of the nanoparticles act as antimicrobial agents thus preventing bacterial growth. Nanodentistry attracts patients towards dentistry, since it will be cost effective, time-saving and prevent the patient from mental trauma, The effect of Bio ceramics and nanotechnology in the treatment of oral disease is limited, and which will have a rapid breakthrough in the future.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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