

MODELING AND ANALYSIS OF TOOTH CROWN WITH DIFFERENT MATERIALS USING FEM

¹Mr. M.S.S.S.CHAITANYA, ²Mr. CH.CHANDRA RAO

¹PG Student, ²Assistant Professor
Department of Mechanical Engineering,
Sir C.R.R.College of Engineering, Eluru-534007, A.P.

Abstract: The term dental crown stands for a type of dental restoration, which completely caps a tooth. Crowns are often used to restore the health of a tooth that is threatened for example by a large cavity or damaged by accident. Crowns are anchored to the tooth using dental cement and can be made of a variety of materials. Metal is a common material choice.

The purpose of this study was to examine the stress distribution in tooth crown with various loading conditions and materials. In our project, first, three dimensional geometry of the straumn system model (contained crown, abutment, abutment screw, implant, and supporting bone) is built in CATIA V5 parametric and the analysis was done in ANSYS-19.2. Using materials in this project Titanium (abutment, abutment screw), Gold alloy, Ni-Cr alloy, Zirconium (crown).

We estimate the load bearing capacity of crown by applying the different loads i.e. (axial load, 30°, 45° oblique load) and by observing von-missies stresses, strains and deformations generated from static analysis in ANSYS 19.2. Finally concluded the suitable material.

Keywords: Finite element method, CATIA, Tooth crown, ANSYS, Dental implants.

1. INTRODUCTION

An implant is a medical device manufactured to replace a missing biological structure, support a damaged biological structure, or enhance an existing biological structure. Medical implants are man-made devices, in contrast to a transplant, which is a transplanted biomedical tissue. The surface of implants that contact the body might be made of a biomedical materials.

1.1 Different Biomedical implants



Fig.1.Different types of biomedical implants

Metals and their alloys are widely used as biomedical materials. On one hand, metallic biomaterials cannot be replaced by ceramics or polymers at present. Because mechanical strength and toughness are the most important safety requiriements for a biomaterial under load-bearing conditions, metallic biomaterials like stainless steels, Co-Cr alloys, commercially pure titanium (CP Ti) and its alloys are extensively employed for their excellent mechanical properties. On the other hand, metallic materials sometimes show toxicity and are fractured because of their corrosion and mechanical damages [1]

Therefore, development of new alloys is continuously trialed. Purposes of the development are

- To remove toxic element;
- To decrease the elastic modulus to avoid stress shield effect in bone fixation
- To miniaturize medical devices.
- To improve tissue and blood compatibility

2. Human Teeth Anatomy

There are 32 permanent teeth. There are 16 teeth on both the top and bottom jaw. Each jaw consists of specific teeth, which are incisors (cutting teeth), canines (tearing teeth) and molars (grinding teeth).From the midline of one side of each jaw consists of 2 incisors, 1 canine, 2 premolars and 3 molars (fig.2).

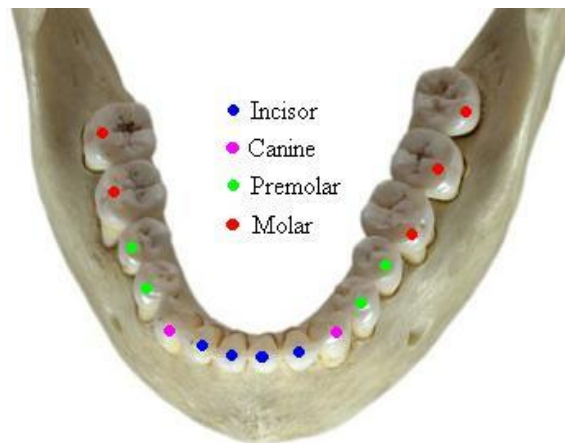


Fig.2 Human Teeth Anatomy

2.1 Tooth Structure:

The anatomy of the tooth consists of root (hidden in the gums) and crown (visible part of the tooth). The root of the tooth functions as an anchor for the tooth and allows for blood and nerve supply to enter the tooth to maintain its viability. The crown is the surface that allows for food breakdown as opposing teeth are brought together when chewing. The crown and root consists of hard and soft tissue. The hard tissue covering the crown is called enamel, a hard mineral surface, whereas the root is covered by cementum, a hardy mineral surface, however, it is softer compared to enamel. The next layer under both enamel and cementum is dentin, the main bulk of the tooth.

Fig.3 Tooth Structure

2.2 Dental implant:

Dental implants are mechanical devices that have been designed to substitute for individual missing teeth. They function as an artificial tooth root, on top of which some type of dental prosthesis (a dental crown, bridge or denture) can then be placed.



Fig.4. Dental implant system which is composed of three components: crown, abutment and implant.

2.3 Dental crown:

Dental crowns are fixed prosthetic restorations made to restore a damaged tooth to its original shape and size. They're permanently cemented on teeth that have cracked, extensively decayed, or otherwise been damaged. Although they sometimes extend down onto the root surface, crowns essentially replace the outer aspect of the "crown" part of a natural tooth, so it makes sense that the restorations are called "crowns."

When affixed, the crown fully encases the portion of the damaged tooth that sits above the gum line. Crowns are custom made to fit over each tooth. They can be made of a variety of different materials, including ceramics, porcelain-and-metal, gold, or resin.

3. MATERIALS AND METHODOLOGY

3.1. Problem Identification:

- The conventional materials are, heavier in density and improper which fails within prescribed period
- Gold alloys (Au-Ag) are idle but high cost compared to other materials.
- Ni-Cr alloy is low cost but causes eczema.
- Zirconium has improved material strength, enhanced esthetic, and high biocompatibility and avoids toxic effects.

3.2. Objective of the project:

- Modeling of a Dental implant using existing specifications.[6]
- Obtaining design of Dental implant using CATIA V5 R20 software and then imported into ANSYS 19.2 workbench
- Meshing of design model using ANSYS 19.2.
- Analysis of Dental crown by using Static analysis.
- Comparing the performance of three different materials (Au-Ag), (Ni-Cr), (Zirconium) under static analysis process at different loading conditions are (axial load, 30°, 45° oblique load) and we are taking boundary conditions is 100 Newton's.
- From the Results we identify the suitable material for Dental crown.

3.3 Material Properties:

Dental implant consists of three parts:

1. Crown Material: (Ni-Cr) alloy, (Au-Ag) alloy, Zirconium.
2. Abutment component Material: (Ti-6Al-4V) alloy.
3. Dental fixture component Material: (Ti-6Al-4V) alloy.

Material properties	Ni-Cr	Au - Ag	Zirconium	Titanium(Ti-6Al-4v)
Density (Kg/m ³)	8400	8000	4560	4500
Poisson's ratio	0.325	0.33	0.26	0.3
Young's modulus(Gpa)	245	91	97	102
Yield strength(Mpa)	2100	800	810	830
Ultimate tensile strength (Mpa)	2300	855	939	900

Table.1. material properties

4. CATIA V5 R20 INTRODUCTION

4.1 Introduction

CATIA (Computer Aided Three Dimensional Interactive Application). As a new user of this software package, you will join hands with thousands of users of this high-end CAD/CAM/CAE tool worldwide. If you are already familiar with the previous releases, you can upgrade your designing skills with the tremendous improvement in this latest release.

CATIA V5, developed by this assault Systems, France, is a completely re-engineered, Next-generation family of CAD/CAM/CAE software solutions for Product Lifecycle Management. Through its exceptionally easy-to-use and state-of-the-art user interface, CATIA V5 delivers innovative technologies for maximum productivity and creativity, from the inception concept to the final product. CATIA V5 reduces the learning curve, as it allows the flexibility of using feature-based and parametric designs.

4.2 CATIA V5 provides three basic platforms:

P1, P2, and P3. P1 is for small and medium-sized process-oriented companies that wish to grow toward the large scale digitized product definition. P2 is for the advanced design engineering companies that require product, process, and resource modeling. P3 is for the high-end design applications and is basically for Automotive and Aerospace Industry, where high quality surfacing or Class-A surfacing is used. The subject of interpretability offered by CATIA V5 includes receiving legacy data from the other CAD systems and even between its own product data management modules. The real benefit is that the links remain associative. As a result, any change made to this external data gets notified and the model can be updated quickly

4.3 CATIA V5 WORKBENCHES

CATIA V5 serves the basic design tasks by providing different workbenches. A workbench is defined as a specified environment consisting of a set of tools that allows the user to perform specific design tasks. The basic workbenches in CATIA V5 are Part Design, Wireframe and Surface Design, Assembly Design, Drafting.

4.4 MODELLING OF A Dental implant IN CATIA V5 R20

Each set of the model containing the gold alloy crown, cement-type titanium abutment, implant, and abutment screw received a 35-N preload. For the crown restorations, an 86% gold alloy (Aquarius; Ivoclar Vivadent AG, Schaan, Liechtenstein) was used as the material of the metal crown. The crown morphology was designed to imitate the maxillary second premolar. The angles of inner inclination of the buccal and palatal cusps were designed to be 30 to the occlusal. The fit between the abutment and the crown restoration was assumed to be intimate contact. The rough surface of the testing fixtures about 10 mm long were totally embedded in the bone, and interface conditions between the bone and implant were assumed to be fully osseointegrated. The crown margin to the crestal bone level was designed with the same distance.

ATOS 3D Scanner

Optical 3D coordinate measuring machines are replacing tactile measuring systems and gages in many areas of industry. They capture more detailed and easily interpretable quality information of an object with significantly shorter measuring times.

ATOS sensors are used in many industries for the inspection of parts such as sheet metals, tools and dies, turbine blades, prototypes and injection-molded and pressure die-cast parts



Fig.5. ATOS 3D Scanner

4.1. Design of Dental implant

An implant supported acrylic resin crown for the second premolar was constructed. Mandibular bone segment and the crown were scanned using an advanced topometric sensor digitizer, ATOS II (Capture3D, Costa Mesa, CA, USA) and point clouds of the crown and mandibular section were obtained and saved as Cat part files. The Cat part file of point clouds was transferred to CATIA to create digitized 3D models of mandible and crown. The combined 3D solid model was saved as a Model file in CATIA

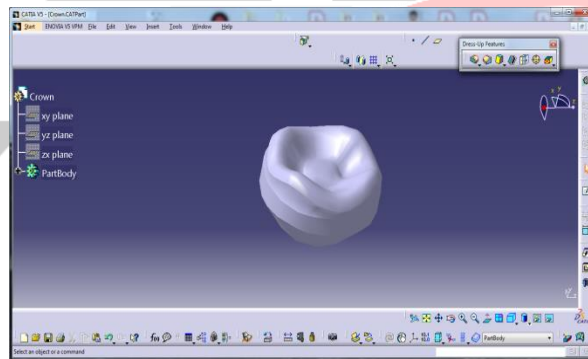


Fig.6 Design of Crown.

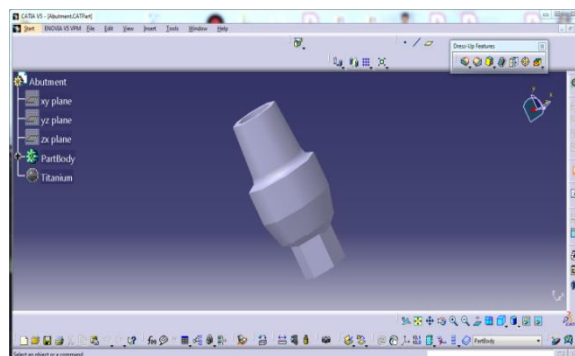


Fig.7 Design of Abutment component.

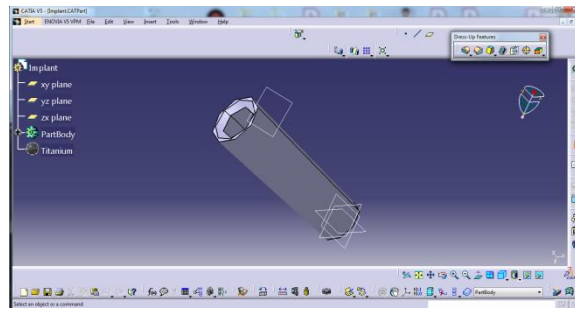


Fig.8 Design of Dental fixture component.

4.4.4. Assembly of Dental implant

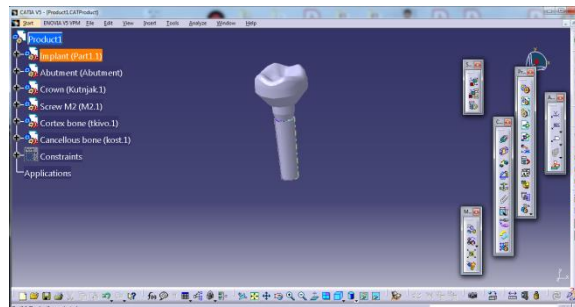


Fig.9.Assembly of three components Crown, Abutment, Fixture

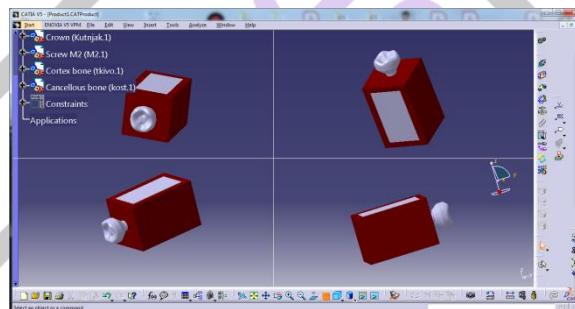


Fig.10 Assembly of Dental implant in multi view

5. STRUCTURAL ANALYSIS OF Dental Crown

5.1. ANSYS INTRODUCTION

Ansys is a general purpose software, used to simulate interactions of all disciplines of physics, structural, vibration, fluid dynamics, heat transfer and electromagnetic for engineers. So ANSYS, which enables to simulate tests or working conditions, enables to test in virtual environment before manufacturing prototypes of products. Furthermore, determining and improving weak points, computing life and foreseeing probable problems are possible by 3D simulations in virtual environment. Also, it can work integrated with other used engineering software on desktop by adding CAD and FEA connection modules.

5.2. Tasks to be done ANSYS

1. Each part in the Dental implant components has to be capable of holding both tensile and Compressive loads successively.
2. Stresses and deflection should be within the permissible limits.
3. Perfect contact pair should be formulated.
4. Parts of the component should always be bonded to each other.
5. Converges of the model should be achieved.

5.3. Meshing

The design that is saved in igs format is imported in Ansys work bench and engineering data is applied and by generating mesh. Element type of the mesh was SOLID 187. The node count of the meshed model was 95352, whereas the element count was 54016. The areas of the model which have irregular surfaces were selectively refined to get a better mesh quality without compromising the accuracy of the results due to increase in the mesh stiffness. It must be mentioned that it was not possible to generate a perfect mesh for a geometry as complicated as that of a tooth. However, the parameters used were efficient enough to provide good results.

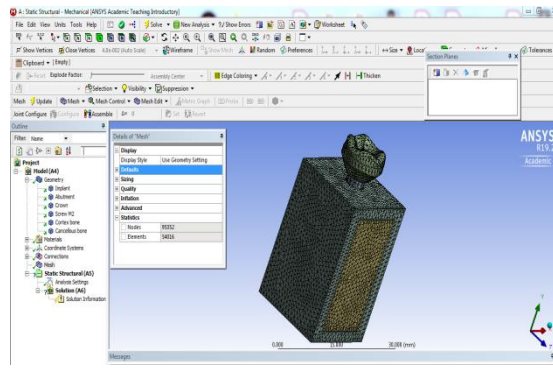


Fig.11 Meshing

5.4. Loads and Boundary conditions:

Mastication involves a repeated pattern of cyclic impacts that causes loading to the implant components and distributes the force to the bone interface. When applying FE analysis to dental implants, it is important to consider not only axial loads and horizontal forces (moment-causing loads) but also a combined load (oblique occlusal force) because the latter represents more realistic masticatory pattern and will generate considerable localized stresses in compact bone. Bite force studies indicated considerable variation from one area of the mouth to another and from one individual to the next. The boundary condition that are given to the Dental implant in Ansys structural analysis work bench bottom fixture component is fixed and apply 100N load axially, at 30deg, 45deg and horizontally.

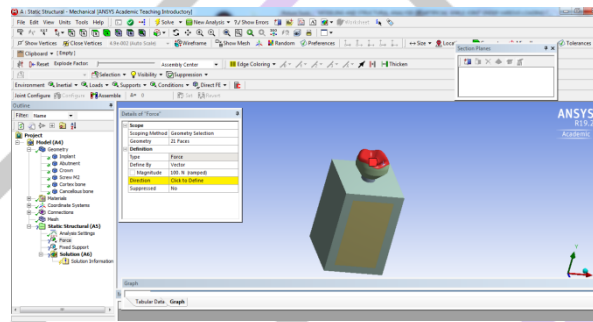


Fig.12 Loads and Boundary conditions

6. RESULTS AND DISCUSSIONS

We are analyzing dental crown and finding Von mises stress and Total deformation at different loading conditions and different materials by Static analysis. The below figures are at Axial load 100N position

6.1 At Axial load for Ni-Cr Material

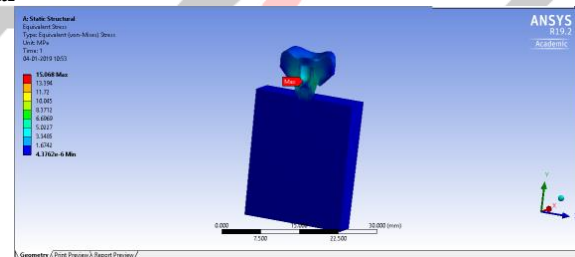


Fig.13 Von-mises stress of Ni-Cr Material at Axial load

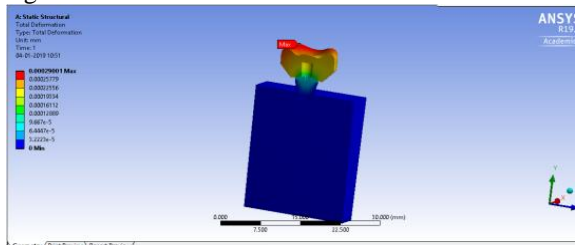


Fig.13 Total deformation of Ni-Cr Material at Axial load

6.2. At 30deg oblique load for Ni-Cr Material

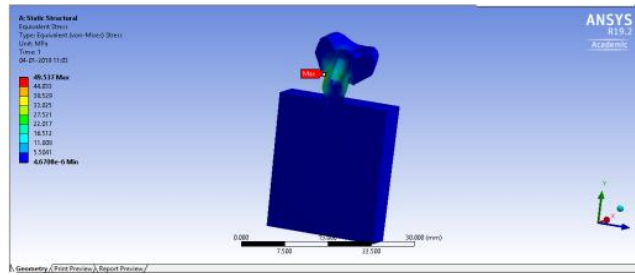


Fig.14 Von-mises stress of Ni-Cr Material at 30deg oblique load

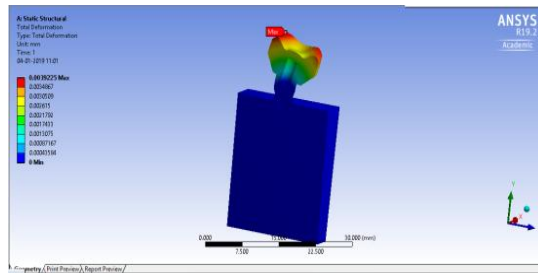


Fig.15 Total deformation of Ni-Cr Material at 30deg oblique load

6.3. At Axial load for Au-Ag Material

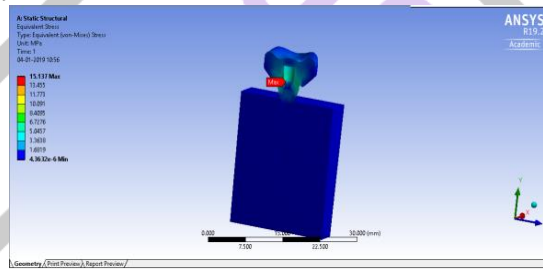


Fig.16 Von-mises stress of Au-Ag Material at Axial load

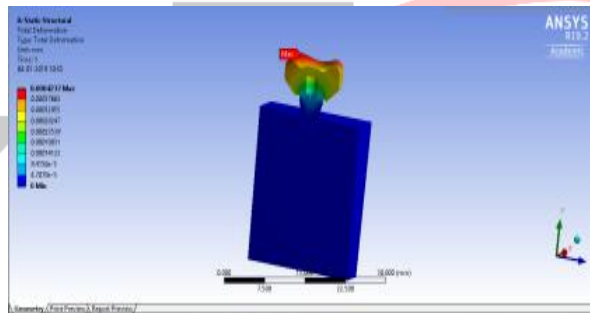
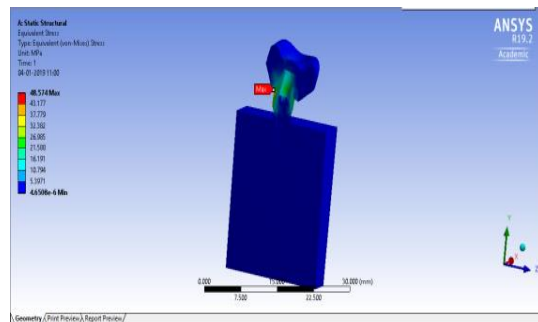


Fig.17 Total deformation of Au-Ag Material at Axial load



At 30deg oblique load for Ni-Cr Material
Fig.18 Von-mises stress of Au-Ag Material at 30deg oblique load

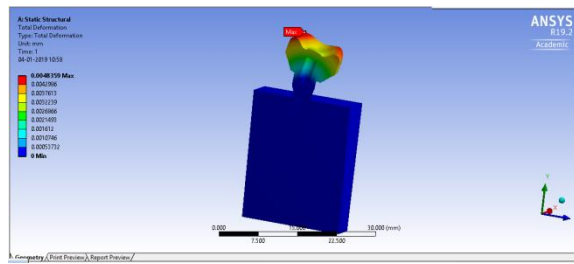
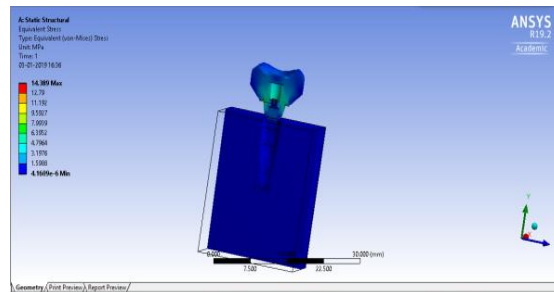


Fig.19 Total deformation of Au-Ag Material at 30deg oblique load



At Axial load for Zirconium Material

Fig.20 Von-mises stress of Zirconium Material at Axial load

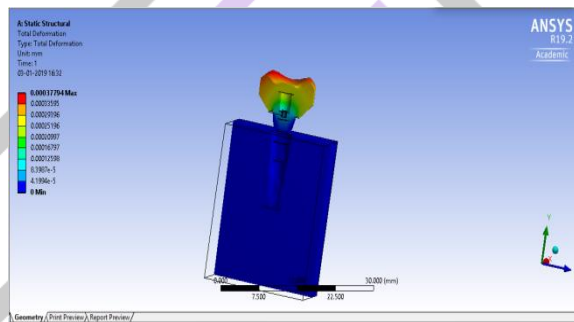


Fig.21 Total deformation of Zirconium Material at Axial load
At 30deg oblique load for Zirconium Material

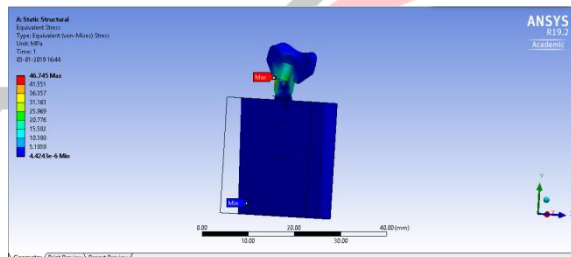


Fig.22 Von-mises stress of Zirconium Material at 30deg oblique load

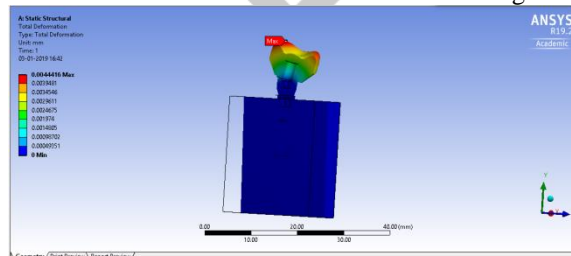


Fig.23 Total deformation of Zirconium Material at 30deg oblique load

6.4.1 Von mises stress (MPa) at different loading conditions and different materials

Direction	Ni-Cr Material	Au-Ag Material	Zirconium Material
Axial	15.068	15.137	14.389
30 deg	49.537	48.574	46.745
45 deg	68.056	68.179	64.895
Horizontal	106.11	106.19	105.95

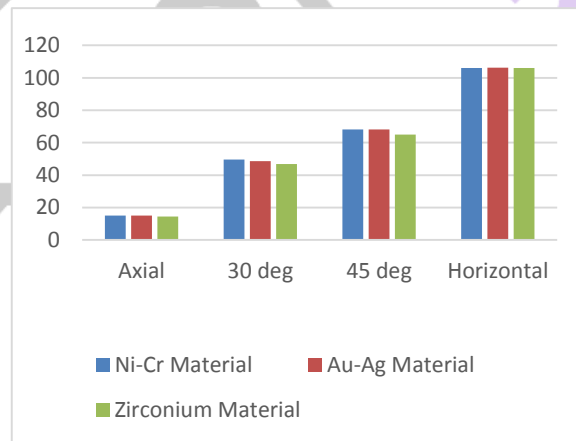
Table.2 Von-mises stress(MPa)

6.4.2 Total Deformation (mm) at different loading conditions and different materials

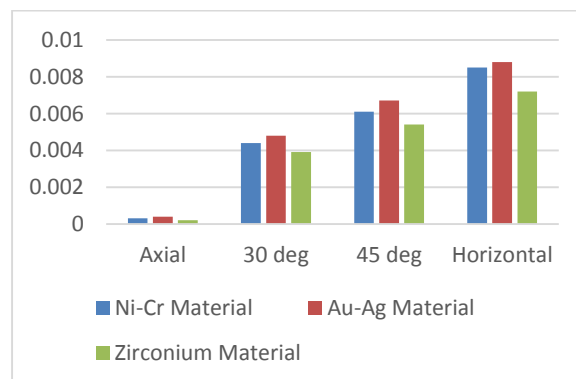
Direction	Ni-Cr Material	Au-Ag Material	Zirconium Material
Axial	0.0003	0.0004	0.0002
30 deg	0.0044	0.0048	0.0039
45 deg	0.0061	0.0067	0.0054
Horizontal	0.0085	0.0088	0.0072

Table.2 Total deformations (mm)

6.4.3 Von-mises stress and Total deformation Graphs



Graph.1 Von-mises stress (Mpa)



Graph.2 Total Deformation(mm)

CONCLUSIONS

The static structural analysis of the dental crown has a great significance, In this project, the design approach for a 3-component dental implant using CATIA V5 R20 software, Analysis work was supported by ANSYS 19.2

- Static structural analysis is to be performed
- Among the Static structural analysis, considered on materials, Au-Ag Material exhibited the maximum stress 106.19 Mpa and maximum deformation of 0.0088mm at Horizontal load 100N applied.
- Ni-Cr Material exhibited the maximum stress of 106.11 Mpa and maximum deformation of 0.0072 mm at Horizontal load 100N applied.
- Zirconium Material exhibited the maximum stress of 105.95 Mpa and maximum deformation of 0.0085 mm at Horizontal load 100N applied.

From the Static analysis results Zirconium produces less stress compare to other two materials, Because of low young's modulus and the use of Zirconium material we avoid both toxic and stress shielding effect. Finally we conclude that Zirconium is better material suitable for Artificial ankle joint implant.

Suggestions for Future Works

Using finite element method to analyze stress distribution in the above mentioned models; so many assumptions were made such as 100% osseointegration which is very ideal. Modeling the more realistic contact condition of bone and implant is highly recommended for future works.

REFERENCES

1. Steinemann S. The properties of titanium In: Schroeder A, Sutter F, Biser D, Drekel G, ed. Oral implantology. Basics. ITI Dental Implant system. 2nd edn. New York: Thieme Medical Publishers, 1996; 37-59
2. Bozkaya D, Müftü S. Mechanics of the tapered interference fit in dental implants. *Journal of Biomechanics*, 2003; 36 (11): 1649-58
3. McClarence E, Close to the Edge-Branemark and the Development of Osseointegration, Quintessence Books, Berlin, Germany, 2003
4. Rosen DB, Practice Limited to Periodontics & Dental Implants, 2003, <http://www.periodont.com/implants.htm>
5. Sahin S, Cehreli MC, Yalcin E. The influence of functional forces on the biomechanics of implant-supported prostheses da review. *J Dent* 2002;30:271 e82.
6. Cehreli M, Sahin S, Akca K. Role of mechanical environment and implant design on bone tissue differentiation: current knowledge and future contexts. *J Dent* 2004;32:123 e32.
7. Chee W, Jivraj S. Failures in implant dentistry. *Br Dent J* 2007; 202:123 e9.
8. Hoshaw SJ, Brunski JB, Cochran GVB. Mechanical loading of Branemark implants affects interfacial bone modeling and remodeling. *Int J Oral Maxillofac Implants* 1994;9:345 e60.
9. Huang HM, Pan LC, Lee SY, Ho KN, Fan KH, Chen CT. Natural frequency analysis for the stability of a dental implant by finite element method. *J Med Biol Eng* 2001;21:61 e7.
10. Vagkopoulou T, Koutayas S, Strub J. Zirconia in dentistry: Part 1. Discovering the nature of an upcoming bioceramic. *Eur J Esthet Dent* 2009;4(2):130 e51.
11. Piconic Maccaur G. Zirconia as ceramic biomaterial. *Biomaterials* 1999;20(1): 1 e25.
12. Evans AG, Heuer AH. Review of transformation toughening in ceramics: martensitic transformations in crack-tip stress fields. *J Am Ceram Soc* 1980;63(4):241 e8.
13. Kelly JR, Denry I. Stabilized zirconia as a structural ceramic: an overview. *Dent Mater* 2008;24(3):289 e98.
14. Denry I, Robert Kelly J. JR. State of the art of zirconia for dental applications. *Dent Mater* 2008;24(3):299 e307
15. Ming-Lun Hsu and Chih-Ling Chang (2010). Application of Finite Element Analysis in Dentistry, Finite Element Analysis, David Moratal (Ed.), ISBN: 978-953-307-123-7, InTech, Available from: <http://www.intechopen.com/books/finite-element-analysis/application-of-finite-element-analysis-in-dentistry>
16. S. Mohanty, A. Rameshbabu, and S. Dhara, 2013, *Ceramics International*, Vol. 39, pp. 8985–8993
- B.K. Biswas, S. Bag, S. Pal, Biomechanical analysis of normal and implanted tooth using biting force measurement, *IJEAS*, August 2013. Vol. 4, No. 2