# Analysis and Development of Implant for a Human Mandible

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**Abstract:** ***A computational study to build the 3D model of the mandible from DICOM files. The files were imported to the slicer4D software and the model was built by thresholding each slice of the file. Then the model was imported into the Siemens UG-NX software for the convergent modelling, to convert the facets into the single solid model. And Material optimization analysis is done with boundary conditions of hinged supports on the condylar region by using Titanium, PMMA and PEEK. Suggesting the appropriate material for the implant from the analysis by the comparison of the results with the value actual bone and the different materials used.***

**Keywords:** DICOM images, convergent modelling, Finite Element Analysis

## 1. Introduction

Mandible is the lower jaw connected to the skull .it is the largest and the strongest bone in the facial skeleton that supports the lower teeth. Mandibular defects are the frequent in the dental practice which can severely affect the masticatory function. Mandibular fractures are about 2397% in the facial bone .and more than 50% of the patients suffer from more than one fracture. The factor that causes fractures in the mandible is as follows:

1) Vehicular accidents-43%
2) 
3) Assaults -34%
4) Sports accidents-5%
5) Diseases and miscellaneous -18%

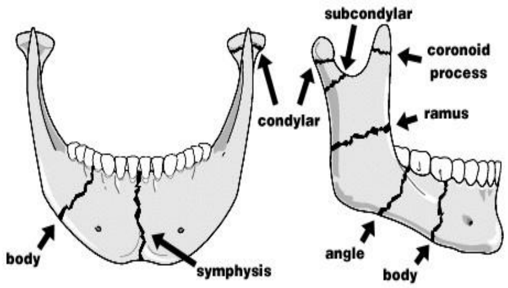


**Figure 1:** Fracture areas of the mandible

Bio-modeling is done to replicate the biological structure. The integration of CAD and the medical technology is called Bio-CAD modeling which includes the concepts of reverse engineering, bio- manufacturing. Earlier to fix the dental fractures some plates and screws were designed and manufactured, but the Implants such as plates and screws fails to preserve the strength of the jaw. The design of the implants does not fulfil the requirement of the surgeon as they differ for a person to person. And there is a complexity to attain the strength for more than one fracture. It is complex to completely rely on CAD-CAM technology for human bone fabrication. But rapid prototyping helps us to reconstruct the physical object accurately.

The aim of this study is to apply reverse engineering concept and builds a 3D model of the human mandible and to suggest the best alternative material for the implant using Finite Element Analysis, which serves the same function of the actual mandible.

## 2. Methodology

### a) Patient

A 65-year-oldIndianmale, diagnosed was included in the study. It had the slice thickness of about 0.3mmwith a resolution of 800*800image matrix.

### b) Schematic of study

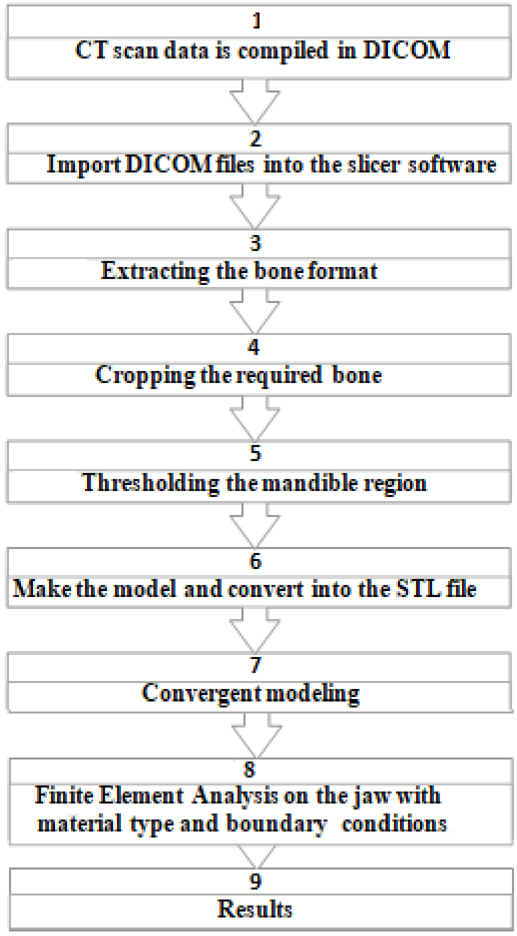


**Figure 2:** Schematic of work flow

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Computer Tomography is an imaging technique which uses X-rays in the production of the cross-sectional images of an object. CT scanners are today widely used by the radiologists all over the world. The CT scan of the head (skull) is taken and segmented on digital Imaging and Communications in Medicine (DICOM) data to find maximum homogeneity in grey levels within regions identified. Once the CT-scan images were saved as the DICOM file and imported to SLICER software for image processing and 3D model reconstruction

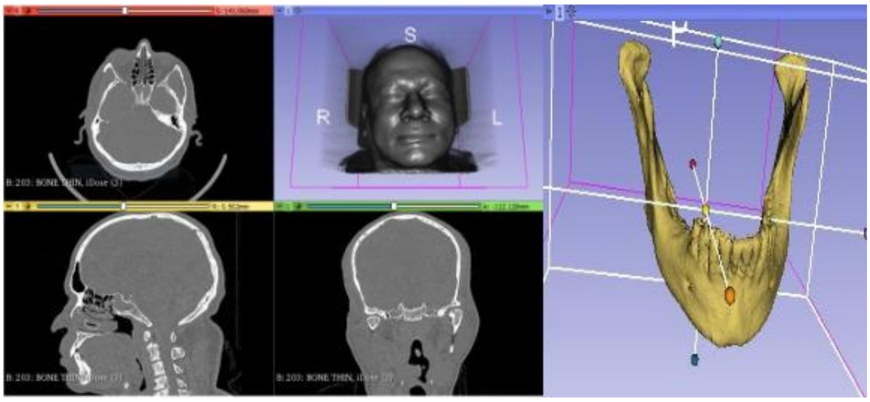


**Figure 3:** Three-Dimensional model of mandible reconstructed from the CT images

The size of the bone in X, Y and Z directions is 125mm X 85mm X 80mm.the 3D model can be stored in STL file format which can be used for 3D printing, convergent modeling or FEM analysis.

**Convergent Modeling**

Convergent modeling is called such because it “converges” meshes and solids into a single model. The reconstructed bone is imported to the NX-11 software and facets formed in the reconstructed converted into the single convergent model. and the model is saved in the IGES file format

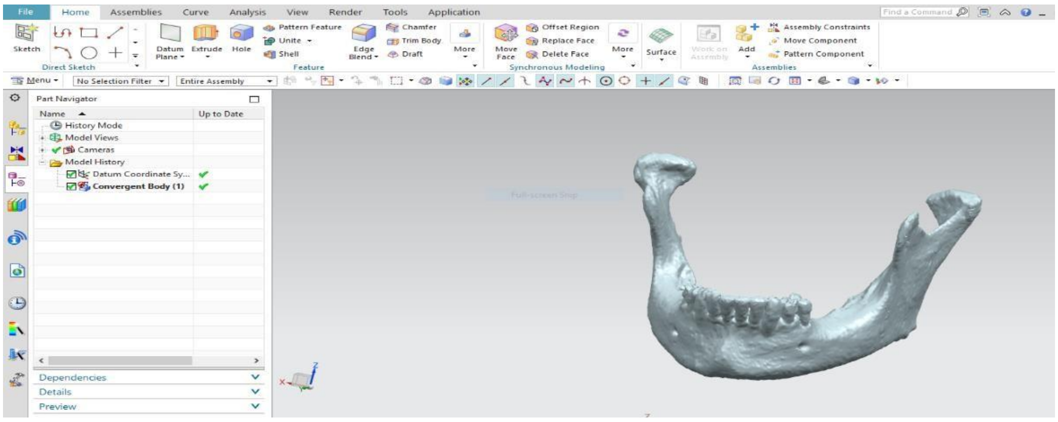


**Figure 4:** Showing the convergent model in UG-NX-11

Convergent modelling is designed to deliver three key benefits to designers:

1) Optimize part design for 3D printing
2) Speed up the overall design process.

**Finite Element Analysis on the Human Mandible**

Finite element analysis is technique for obtaining a solution to complex mechanical problems by dividing the domain problem into a collection of much smaller and simpler domain the convergent mandible bone is imported into the Ansys Mechanical –APDL 2019-R1 software for the analysis and the engineering data for the different materials is as shown in the table.1

**Table 1:** Material Properties of the different materials selected for the Analysis.

| Materials | Density (Kg/mm3) | Young’ Modulus (MPa) | Poisson’s Ratio |
|---|---|---|---|
| Bone | 1850e-9 | 3000 | 0.3 |
| Titanium Alloy | 4430e-9 | 110000 | 0.3 |
| Pmma | 1180e9 | 3000 | 0.38 |
| Peek | 1360e-9 | 4000 | 0.4 |

The analysis on the jaw is performed to estimate and study the stresses and the strains on the jaw during mastication with different materials selected. Finite Element Model of the mandible was imported in the software using the IGES file extension. And by using the material properties in the terms of density, poisons ratio and young’s modulus were given as the input mentioned in table.1 for the mandible. Meshing on the mandible is done using tetrahedral elements with the element size 2mm shown in fig .5. The analysis comprises of the boundary condition using fixed supports as shown in fig.6 on the condylar region of the mandible.

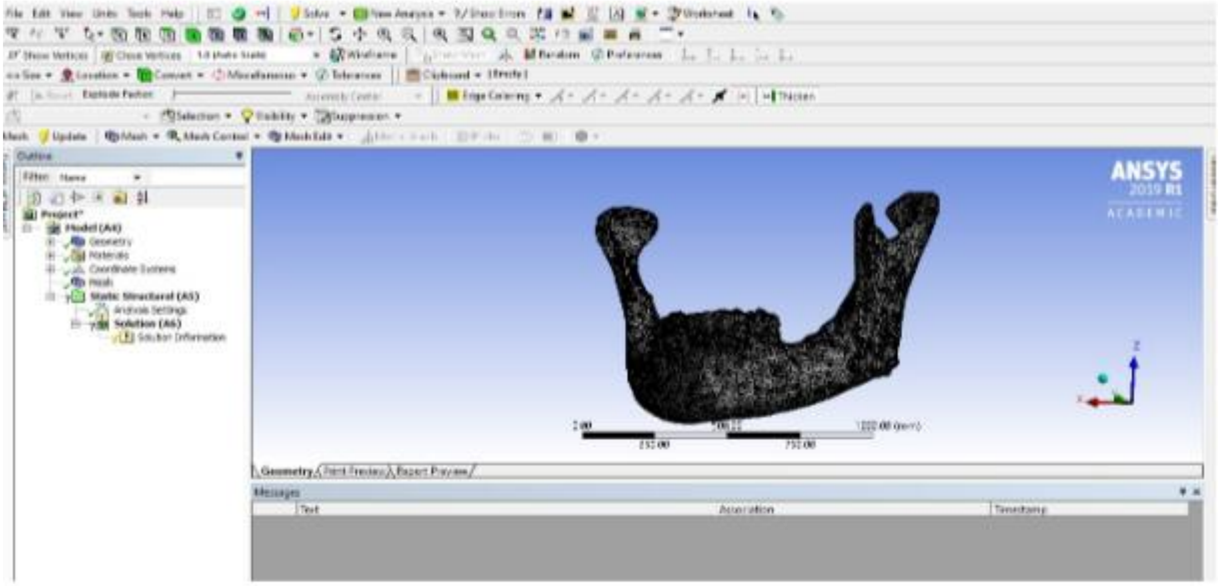



**Figure 5:** Tetrahedral meshed mandible in ANSYS WORKBENCH software

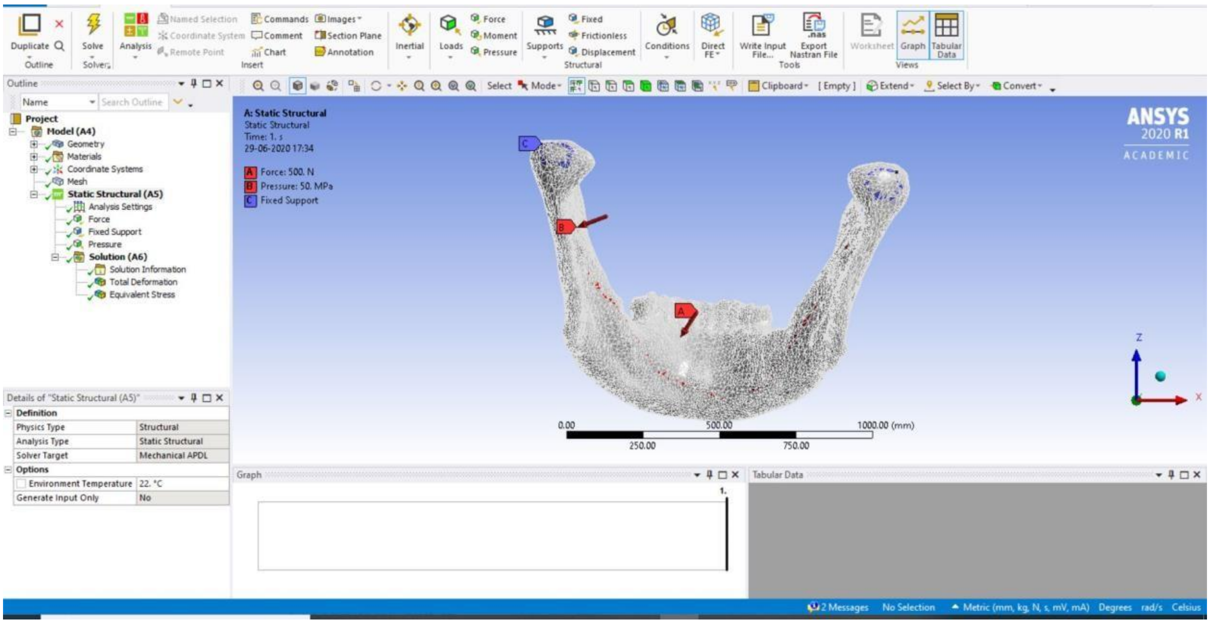



**Figure 6:** Fixed end Boundary conditions and load application on the jaw during mastication

In this chapter, as per work specified analysis and development of mandible implants, the implant materials have been taken into the study, and analysis was performed on the jaw with different implant material, which suits the best alternative for the jaw implants were Titanium Alloy, PMMA and PEEK. The analytical results are concluded by representing the various materials and their total deformation values and the Equivalent von Mises stress values. The static structural analysis was carried out on the lower jaw in Ansys Workbench 2019 R3 gives the results as shown in the table.2

**Table 2:** Static structural analysis results of the jaw with different materials

| Material | Boundary condition | Total deformation (mm) | | Equivalent stress (Von-Mises) (MPa) | |
|---|---|---|---|---|---|
| | | Min | Max | Min | Max |
| BONE | Fixed End | 0 | 7.6348 | 3.84e-5 | 26.339 |
| PMMA | Fixed End | 0 | 7.5703 | 4.57e-5 | 24.415 |
| PEEK | Fixed End | 0 | 5.6605 | 5.149e-5 | 23.884 |
| Ti -Alloy | Fixed End | 0 | 2.0822 | 3.8413e-5 | 26.339 |

In this analysis the deformation and stress on the jaw helps us to estimate out the implant material suitable for the bone, following fig 7 (a) and 7 (b) shows the total deformation and the equivalent von mises stress on the jaw with **BONE** material properties.

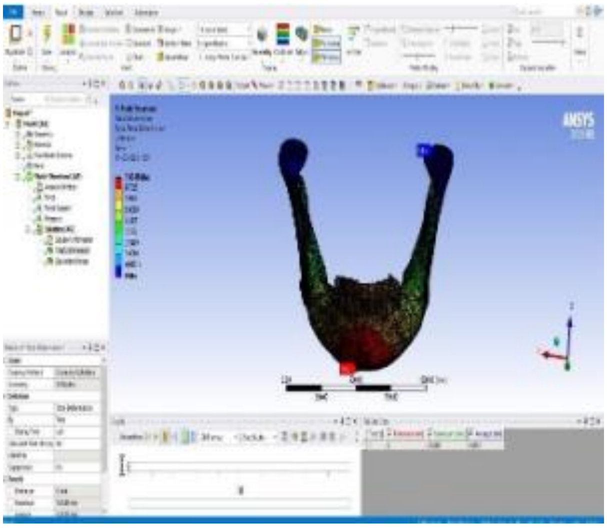


**Fig 7 (a)** total deformation on the jaw with bone properties

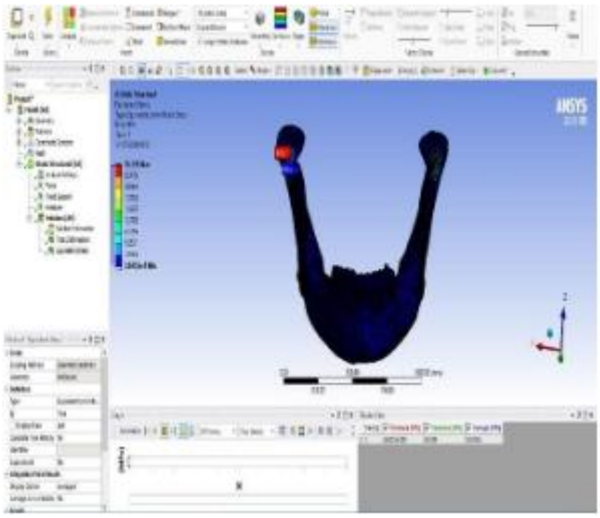


**Fig 7 (b)** Equivalent Von-Mises stresses on the jaw with bone properties

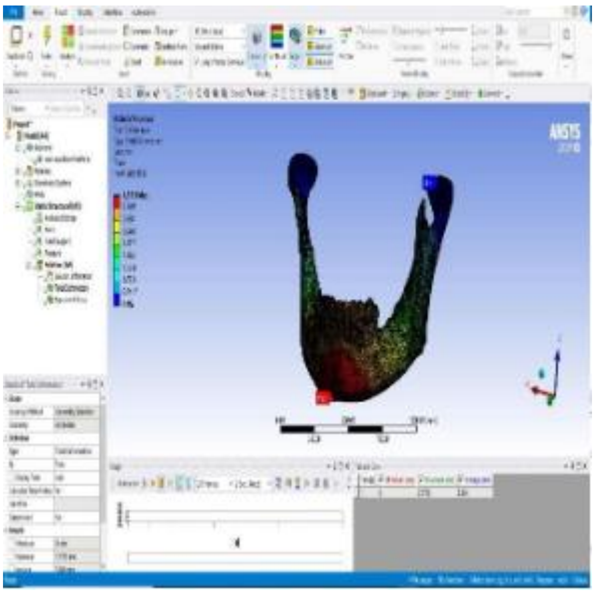


**Fig 8 (a)** total deformations on the jaw with PMMA properties

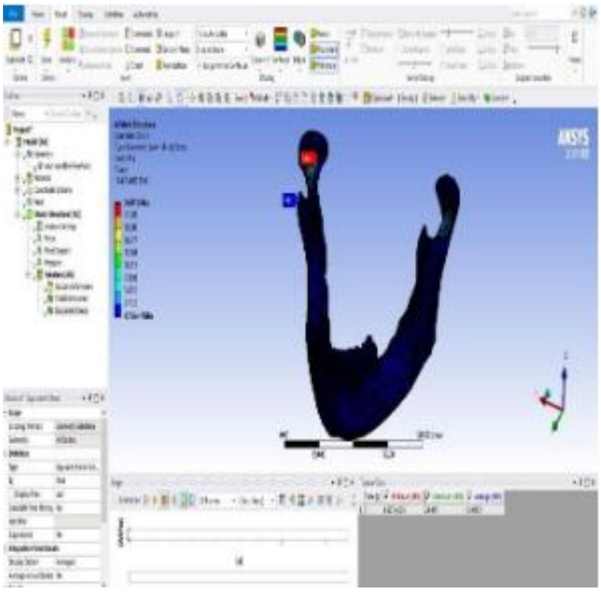


**Fig 8 (b)** Equivalent Von-Mises stresses on the jaw with PMMA properties

Following fig 8 (a) and 8 (b) shows the total deformation and the equivalent von mises stress on the jaw with PMMA material properties.

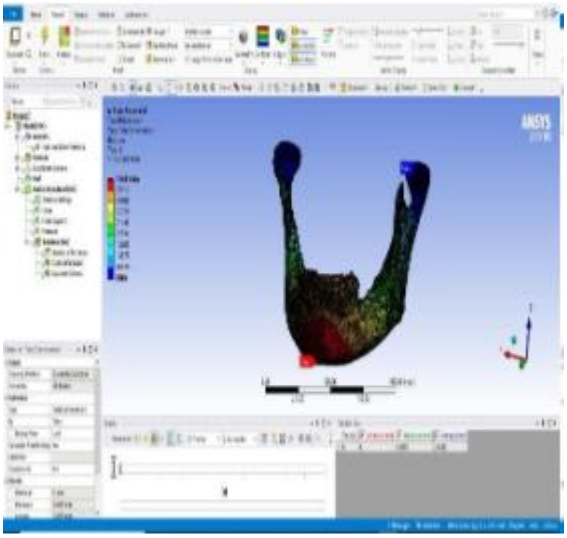


**Fig 9 (a)** total deformation on the jaw with PEEK properties

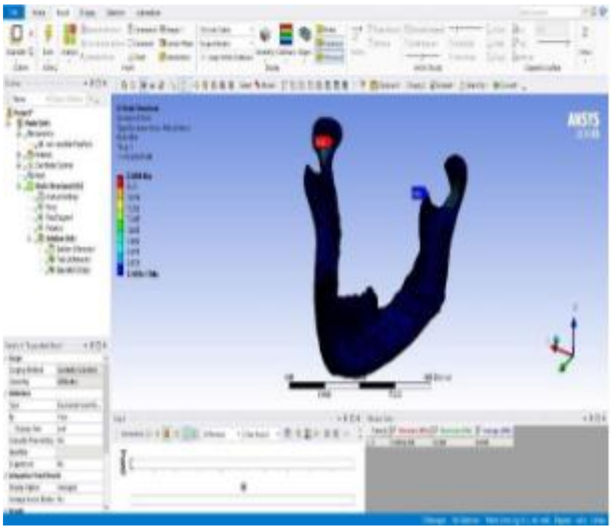


**Fig 9 (b)** Equivalent Von-Mises stresses on the jaw with PEEK properties

Following fig 10 (a) and 10 (b) shows the total deformation and the equivalent von mises stress on the jaw with Titanium Alloy material properties.

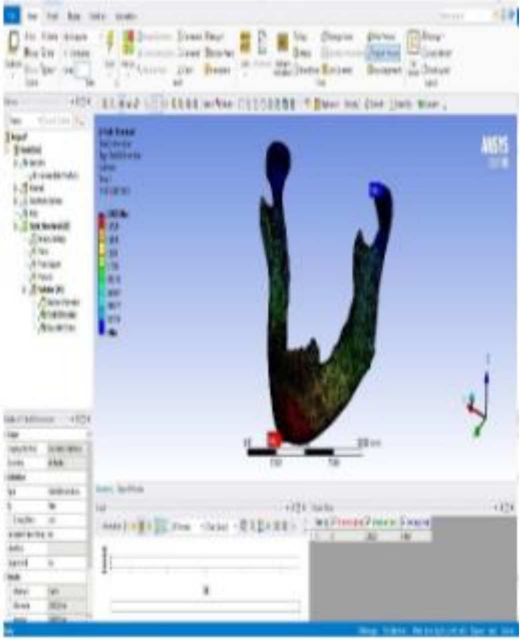


**Fig 10 (a)** total deformations on the jaw with TITANIUM ALLOY properties

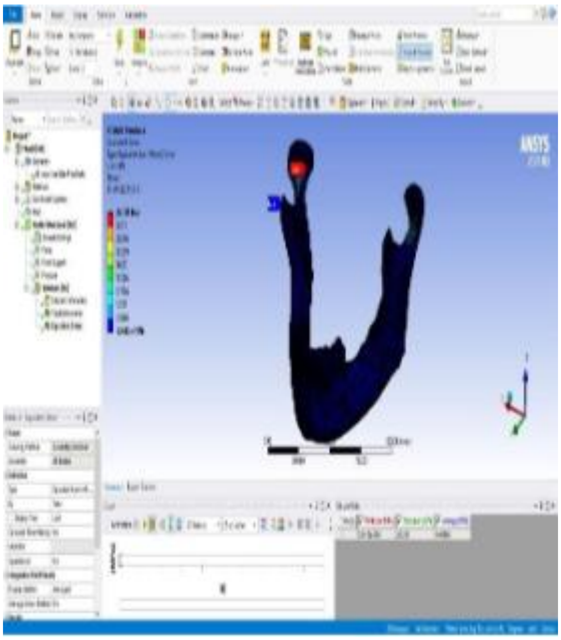
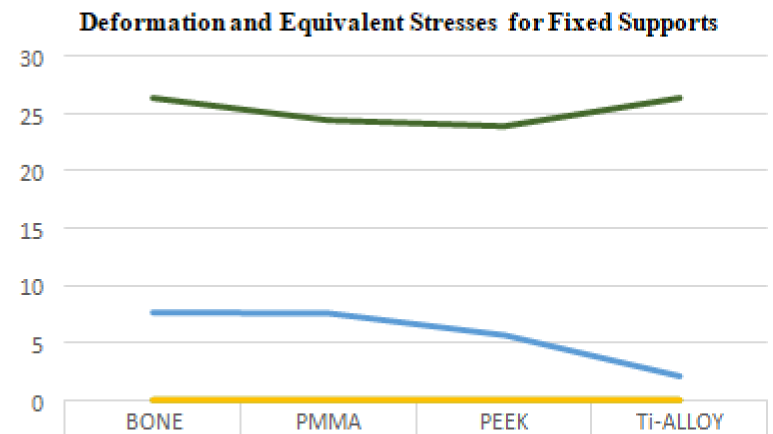


**Fig 10 (b)** Equivalent Von-Mises stresses on the jaw with TITANIUM ALLOY properties

From the above analysis, discussed earlier, the mandible jaw was subjected to boundary conditions with fixed supports at the condylar region of the jaw. Two load conditions were applied to the jaw on both boundary conditions they are 500N as the point load and 0.5MPa as the static pressure on the jaw maximum load required for mastication. The analysis was done using four materials they were Bone, PMMA, PEEK and Titanium Alloy (Ti6Al4V), the results were compared with the maximum and minimum deformation values and maximum and minimum Equivalent stress of two cases solved in ANSYS- Workbench 2019R3.From the table2, we can compare the values for two cases chosen for the study of the project. For Fixed end conditions the maximum deformation values are 7.6348mm for bone, 7.5703mm for PMMA, 5.6605 mm for PEEK and 2.0822mm for Ti-alloy respectively .while the Equivalent Von Mises stresses, the minimum and maximum values are 3.845e-5 & 26.339MPa for bone, 4.57e-5 & 24.415MPa for PMMA, 5.149e-5 & 23.884MPa for PEEK and 3.845e-5 & 26.339MPa for Titanium Alloy respectively. The variation of deformation and equivalent stress for different material with same load but with fixed supports is shown in graph




| | BONE | PMMA | PEEK | Ti-ALLOY |
|---|---|---|---|---|
| MIN DEFORMATION (mm) | 0 | 0 | 0 | 0 |
| MAX DEFORMATION (mm) | 7.6348 | 7.5703 | 5.6605 | 2.0822 |
| MIN EQVIVALENT STRESS (MPa) | 0.000038 | 0.000045 | 0.000051 | 0.000038 |
| MAX EQUIVALENT STRESS (MPa) | 26.33 | 24.41 | 23.88 | 26.33 |

## 3. Conclusion

The static structural analysis was carried on the mandible with input data of different materials suitable for implant under fixed boundary conditions using Ansys Workbench2019R3. The deformation on the jaw with properties of bone found to be 7.634mm as maximum under fixed end condition and Equivalent stress (Von-Mises) were 0.000038MPa min and 26.33MPa max, Titanium alloy has the suitable properties to be replaced by the bone, but due to its high cost it would not be affordable. The next alternate material for the bone implants, are of PMMA has the lesser cost and nearly matches the values as that of bone.

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