Mechanical Strength Evaluation Analysis of Stainless Steel and Titanium Locking Plate for Femur Bone Fracture

D.Amalraju
Lecturer, Mechanical Engineering Department
Karpagam University
Coimbatore, India

Dr.A.K.Shaik Dawood
Professor, Department of Mechanical Engineering
Karpagam University
Coimbatore, India

Abstract - Femur is leg bone of the human body undergoing more deformation. Being longest and heaviest in size, failure of femur neck is the most common among bone failures in human. Orthopedic implantation is done in case of failure. Before implantation it is necessary to analyze the perfectness in case of its material property, size and shape, surface treatment, load resistance and chances of failure. Analysis is done for the stresses formed in Femur Distal Locking Plate Implant of Ti-6Al-4V and S.S-316L material under static loading condition using ANSYS software. Since each femur carries 1/2 the body weight, analysis is done for 60kg, 70kg, 80kg, 90kg, 100kg, 110kg, 120kg, 130kg, 140kg, 150kg, 160kg, 170kg, 180kg, 190kg, 200kg loads, including the cases of patient carrying certain weight. From analysis it is found that the loads have no effect on failure of implant, since the values of stresses and deformation are very low. Thus failure of implant is maximum by wearing, corrosion and all due to improper material selection of implant. And based on the analysis it can be concluded that, since Ti-6Al-4V is a low density material (4520kg/m3) for implantation, it makes the patient feel free to move his leg. Analysis is done for the stresses formed in femur implant of Ti-6Al-4V and S.S-316L material under static loading using FEA techniques. Since each femur carries half of the body weight, we have taken the extreme weights, that is, the least possible weight and the heaviest possible weight. From analysis it is found that the loads have no effect on failure of implant since the values of stresses and deformation are very negligible. Since TI-6AL4V is a low density material, which has excellent bio compatible and mechanical properties, it is ideal for the use of an implant in surgeries. Finally the success of implantation depends on implant material and size, implantation method and its handling by the patient.

Key words:- CAD, FEA,, implants,Femur Bone, Bio-Materials.

I. INTRODUCTION

The Femur is the longest and strongest bone in the skeleton is almost perfectly cylindrical in the greater part of its extent. Femur fracture to occur, either a large force must be applied or something is wrong with the bone. In patients with normal bone strength, the most common causes of femur fractures include: Car accidents, Falls from a height. The treatment of a femoral shaft facture is almost always with surgery. The most common procedure is to insert a metal rod down the center of the thigh bone. This procedure reconnects the two ends of the bone, and the rod is secured in place with screws both above and below the fracture.

The intrameduallary rod generally remains in the bone for the life of the patient, but can be removed if it causes pain or other problems. A locking plate is a good option, especially in osteoporotic bone and for fractures with a short end segment. Such a locking plate need not be contoured to fit the bone precisely since it functions as an internal fixator. Attaching it to the bone does not alter fracture alignment, since the screws do not pull the main bone fragments to the implant. Before implantation of implants in a human body it is very crucial that implant material properties should be analyzed.

Most common material is used in Indian implants are Titanium and stainless steel. Indian implants are not mechanically investigated appropriately to identify the properties. This project helps to discover the properties of these materials and mechanical properties comparison analysis of Titanium Implant with Stainless Steel.

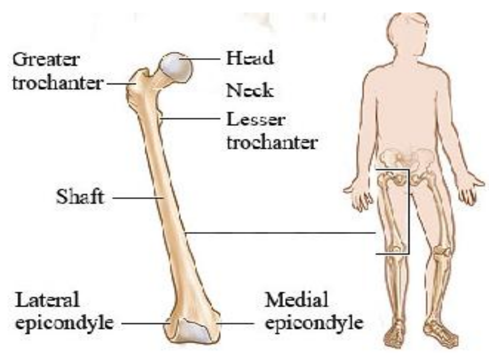


Fig 1 Anatomy of Femur Bone

II. LITERATURE SURVEY

The purpose of this work is to investigate the alternative materials for human Orthopedic Implants which is Bio-Compatible. These implants are expected to be Bio-Compatible & they should not cause inflammation or rejection. An improved understanding of the mechanical parameters on different alternative materials used for implants and comparing obtained results with existing medical reports. Best alternate material for human orthopedic implants will be suggested. Since Ti-6Al-4V material cost more, Titanium coat over the S.S can be used as an alternative for femur implant locking plate.

2.1 Implants

An object made from non living material that is deliberately inserted by a surgeon into the human body where it is intended to remain for a significant period of time in order to perform a specific function is called Implant. Fig 1shows the anatomical locations of Femur bone. Despite great number of metals and alloys known to man, remarkably few warrant Preliminary consideration for use as implant materials. The relatively corrosive environment combined with the poor tolerance of the body to even minute concentrations of most metallic corrosion products eliminates from discussion most metallic materials. Of the possible metallic candidates, tantalum and the noble metals do not have suitable mechanical properties for the construction of most orthopedic tools and implants, while zirconium is in general too expensive

Today, titanium, cobalt chrome, zirconium and stainless steel 316 are the most frequently used biomaterials for internal fixation devices because of a favorable combination of mechanical properties corrosion resistance and cost effectiveness [17] when compared to other metallic implant materials.

2.2 Distal Locking Plate

Locking plate [7] [9] is a biomedical device, which is designed to support, fix two or more broken bones so that it can withstand the associated movement and stress and to enhance mobility and decrease pain shown in fig 2. The surface of implants that contact the body might be made of a biomedical material such as titanium, silicone, and stainless steel [16].

Fig 2 Distal Femur Locking Plate

Normally Ti-6Al-4V and S.S-316L are used as implant materials [1], In India Mostly used material is S.S-316L, because it is economical when compared to Ti-6Al-4V. But it is important to know the mechanical properties and its strength of the material, So that we can find out the complications of a foreign material when placed inside a human body [6].

TABLE 1 Property comparison of TiA14V & S.S 316L

Material	Density (kg/m3)	Young's modulus 'E' (GPa)	Poisson's ratio'γ'
Ti6Al4V	4430	895	0.342
S.S316L	8000	193	0.30

TABLE 2 Property comparison of TiA14V & S.S 316L

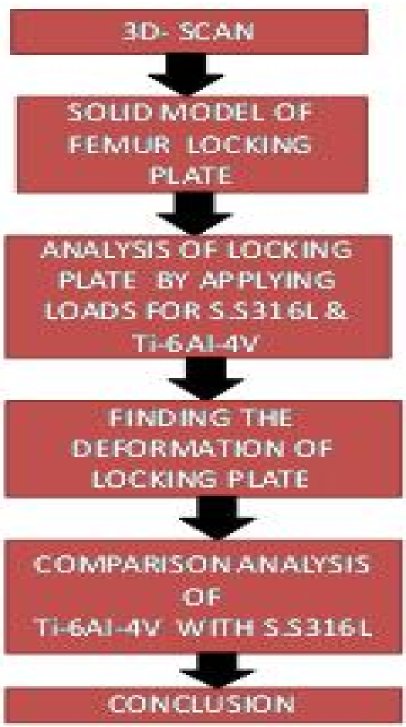
Material	Thermal expansion	Tensile strength (Mpa)	Compressive Strength (Mpa)
Ti6Al4V	8*10-6/K	993	1086
S.S316L	15.9*10-6/K	485	570

III. Experimental Methods

A biomaterial is any matter, surface, or construct that interacts with biological systems. Biomaterials must be compatible with the body, and there are often issues of biocompatibility which must be resolved before a product can be placed on the market and used in a clinical setting. Because of this, biomaterials are usually subjected to the same requirements of those undergone by new drug therapies. All manufacturing companies are also required to ensure traceability of all of their products so that if a defective product is discovered, others in the same batch may be traced. The most common metal alloys used in orthopedic implants are stainless steels, cobalt-chromium alloys, and titanium alloys [19].

Femur bone is the longest bone in human body subjected to maximum compressive stresses and hence deformation. It's important to find out the stress concentrations and deformation zones of implant of femur bone. So FEA using ANSYS is the best method for analysis of stresses and deformations for **Ti-6Al-4V** and **S.S-316**. Using this evaluation shown in fig 3 Project flow chart, we can find which material has got more deformation to leave the implant for long period time in a human body [13].

3.1 Flow Chart



3.1.1 3D scan

3D Scan is a device that analyzes a real-world object or environment to collect data on its shape and possibly its appearance (i.e. color). The collected data can then be used to construct digital, three dimensional models useful for a wide variety of applications. The scanned image is shown in fig 4 scanned model of locking plate. The purpose of a 3D scanner is usually to create a point cloud of geometric samples on the surface of the subject. These points can then be used to extrapolate the shape of the subject (a process called reconstruction).

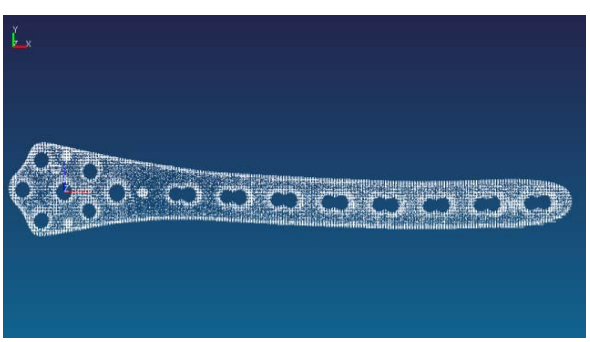


Fig 3 Scanned model of Locking Plate

3.1.2 Scanning Model of Distal Locking Plate

The point clouds produced by 3D scanners can be used directly for measurement and visualization in the architecture and construction world. Most applications, however, use instead polygonal 3D models, NURBS surface models, or editable feature-based CAD models.

In a polygonal representation of a shape, a curved surface is modeled as many small faceted flat surfaces. Polygon models also called Mesh models are useful for visualization. The next level of sophistication in modeling involves using a quilt of curved surface patches to model our shape. These might be NURBS, T-Splines or other curved representations of curved topology Using NURBS, our sphere is a true mathematical sphere. From an engineering/manufacturing perspective, the ultimate representation of a digitized shape is the editable, parametric CAD.

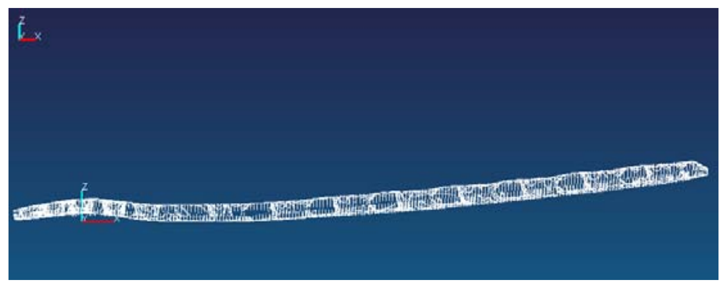


Fig 4 Point Cloud data of Locking Plate

3.1.3 Solid model of femur locking plate in CATIA

Solid modeling of the femoral locking plate is done using CATIA-V5 [20].CATIA is one among the latest modeling software. By this we can create any type of complicated 3D solid models with good quality. With all available dimensions of the implant the 2D model is drawn in sketcher. Than 3D models created in part body using all the required 3D options of CATIA.

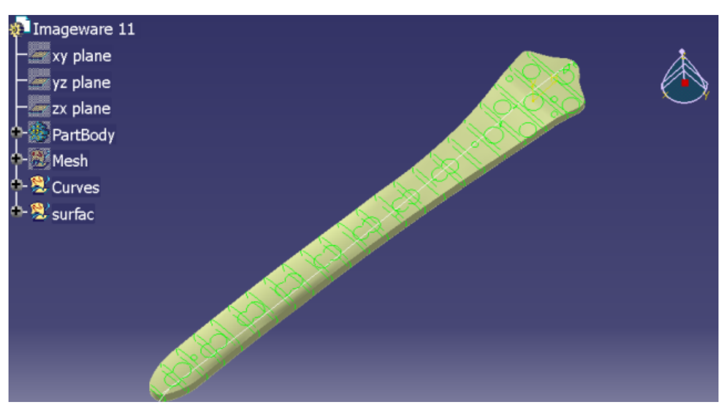


Fig 5 Generated curve of locking plate

The step by step procedure for creating a solid model is shown below:

1) Fig 5 Generated curve of locking plate shows point cloud data 2) Fig 6 Meshed model of locking plate describes Polygon mesh model 3) Fig 7 Surface model of locking plate defines Surface model 4) Fig 8 Solid model of locking plate shows Solid CAD models.

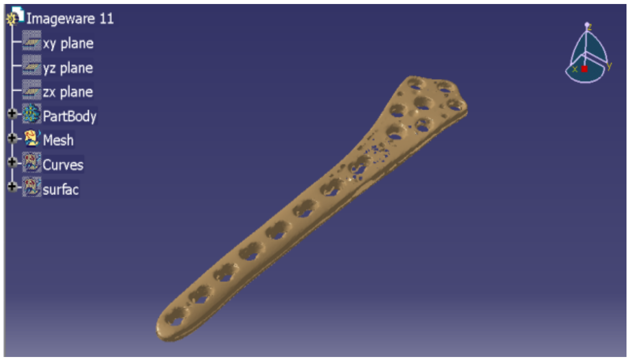


Fig 6 Meshed model of locking plate

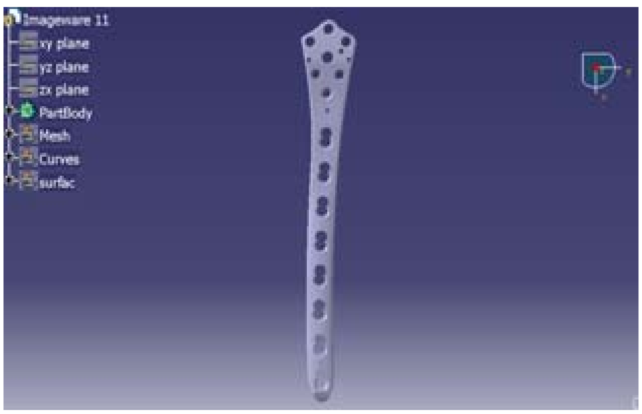


Fig 7 Surface model of locking plate

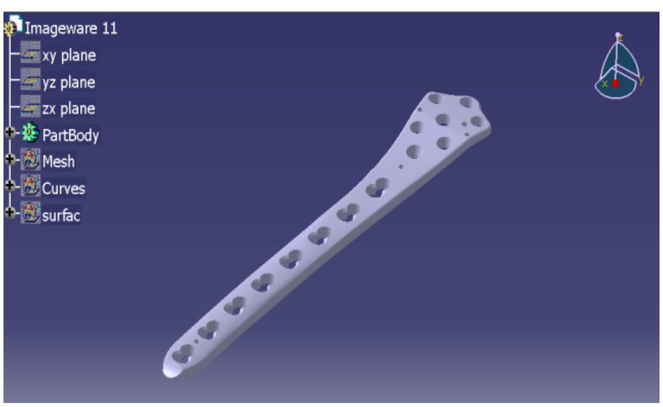


Fig 8 Solid model of locking plate

3.1.4 Analysis of Distal Locking Plate using ANSYS

Femur bone is the longest bone in human body subjected to maximum compressive stresses and hence deformation. It's important to find out the stress concentrations and deformation zones of implant of femur bone. So FEA using ANSYS [18] is the best method for analysis of stresses and deformations. In this analysis, **Ti-6Al-4V** and **S.S-316** material [12] is applied to Locking plate for deformation test. The load is applied gradually based on the patient weight. Finally deformation and von-mises of the two materials will be taken for the mechanical strength analysis [14]. The following figures identify the various deformation takes place while applying gradual loads.

Fig 9 Locking plate implant

3.1.5 Finding Deformations in Analysis

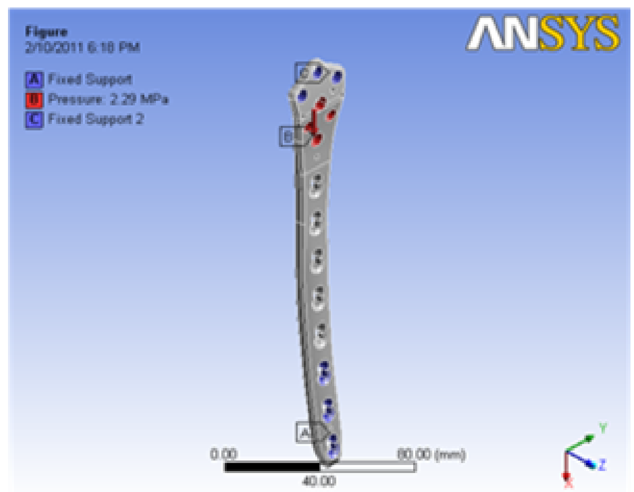


Fig 10 Boundary condition

Fig 11 Meshed model

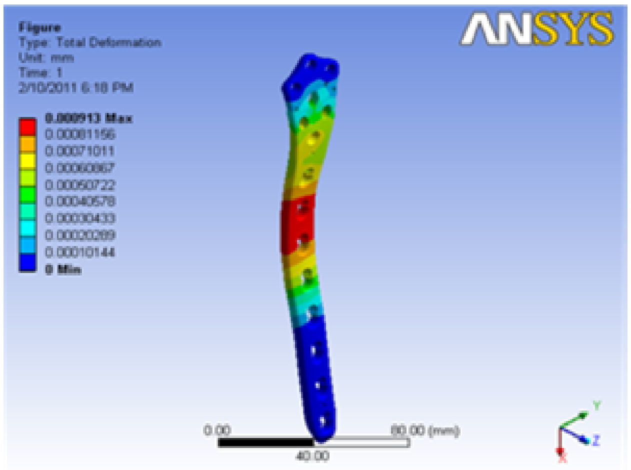


Fig 12 Displacement

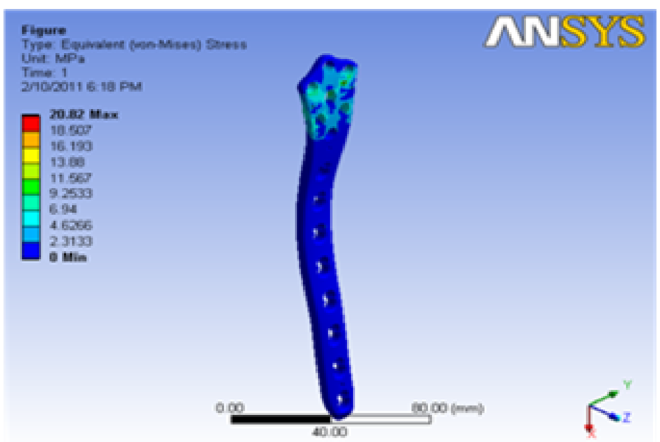


Fig 13 Von-Mises Stress

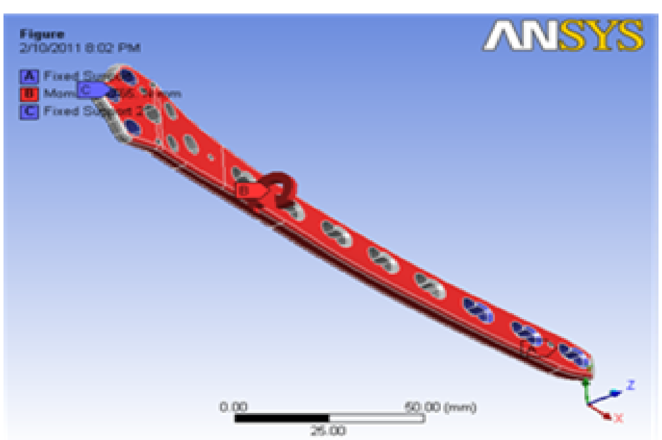


Fig 14 Torque Constraint

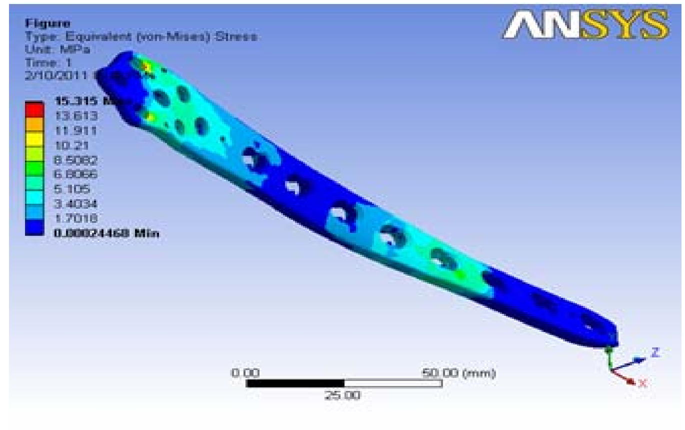
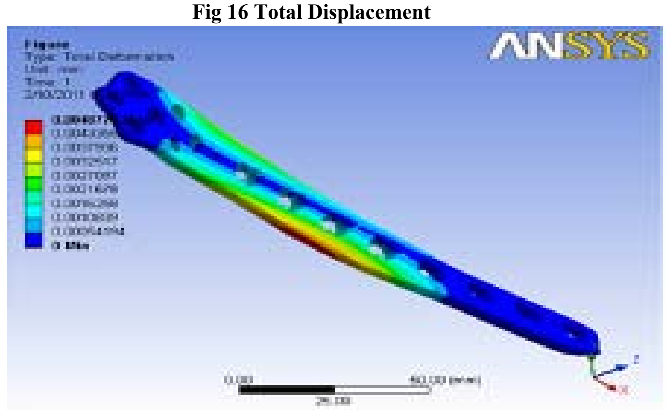


Fig 15 Von-Mises Stress

Fig 16 Total Displacement



3.1.5 Finding Deformation of locking plate

TABLE 3 Deformation Results of S.S 316L

Patient Weight (kg)	Load (N)	Displacement (mm) (Max)	VonMises Stress (N/mm2) (Max)
60	588.6	9.13E-04	20.82
70	686.7	1.06E-03	24.21
80	784.8	1.22E-03	27.72
90	882.9	1.37E-03	31.23
100	981	1.52E-03	34.62
110	1079.1	1.67E-03	38.13
120	1177.2	1.82E-03	41.64
130	1275.3	1.97E-03	45.03

140	1373.4	2.13E-03	48.54
150	1471.5	2.28E-03	52.05
160	1569.6	2.43E-03	55.44
170	1667.7	2.58E-03	58.95
180	1765.8	2.73E-03	62.85
190	1863.9	2.88E-03	65.85
200	1962	3.04E-03	69.36

TABLE 4 Deformation Results of Ti6Al4V

Patient Weight (kg)	Load (N)	Displacement (mm) (Max)	VonMises Stress (N/mm2) (Max)
60	588.6	1.95E-03	19.92
70	686.7	2.26E-03	23.17
80	784.8	2.59E-03	26.52
90	882.9	2.92E-03	29.88
100	981	3.24E-03	33.13
110	1079.1	3.57E-03	36.49
120	1177.2	3.90E-03	39.85
130	1275.3	4.21E-03	43.09
140	1373.4	4.54E-03	46.45
150	1471.5	4.87E-03	49.81
160	1569.6	5.19E-03	53.05
170	1667.7	5.52E-03	56.41
180	1765.8	5.85E-03	59.77
190	1863.9	6.17E-03	63.02
200	1962	6.49E-03	66.38

3.1.5 Comparison analysis of Ti6Al4V with S.S 316L

By comparing the above two results and properties, through this analysis, it is clear that the displacement and stress values are low for titanium and high in case of stainless steel shown in table 5, so Titanium is the best suitable material to be left inside the human body for a long term.

TABLE 5 Stress Comparison of Ti-6Al-4V with S.S-316

Material	Patient Weight (kg)	Load (N)	Displacement (mm) (Max)	Von Mises Stress (N/mm2) (Max)
Titanium Ti-6Al-4V	**130**	**1275.3**	**4.21E-03**	**43.09**
Stainless Steel S.S-316	**130**	**1275.3**	**1.97E-03**	**45.03**

IV. *RESULT AND DISCUSSION*

The applications of titanium and its alloys have become more widespread as they possess high strength, low modulus, lower density, and a good combination of mechanical and outstanding corrosion resistance. In general more than 1000 tones (2.2 million pounds) of titanium devices are implanted in patients worldwide every year and also the medical grade titanium alloys have a significantly higher strength to weight ratio than competing stainless steels. It has been well established that titanium is completely inert and immune to corrosion by all body fluids and tissue and is thus completely biocompatible. High modulus of elasticity of the conventional alloys has resulted in the stress shielding effect and the failure of the implant [11].

The modulus of elasticity of titanium based alloys is such lower and closer to that of the bone when compared to Stainless Steel and hence they are more preferred for long term applications. As of now, they are used as implants for joint replacements, bone fixation, dental implants, heart pacemakers, artificial heart valves, stents and components in high-speed blood centrifuges because of their high specific strength and chemical stability. However, these implants such as artificial joints and bone plates are likely to be damaged mostly due to fatigue and cyclic loading conditions.

Considering all these Bio-compatible and mechanical properties of Titanium and stainless steel shown if table 3 and 4, it is suggested that it would be the best suitable material for Indian Implant locking plate [5].

By comparing the above two results and properties, through this analysis, it is clear that the displacement and stress values are low for titanium and high in case of stainless steel shown in table 5, so Titanium is the best suitable material to be left inside the human body for a long term.

V. CONCLUSION

Selection of locking plate material for surgical implants plays a vital role in Femur shaft fracture healing process. Mostly used materials are Stainless Steel and Titanium. Through this static loading condition and material comparison analysis we have found out the Titanium Implant mechanical properties is better than Stainless Steel. So it can be left in the human body for a long term. In opposite way if Stainless Steel implant is left for a long term it may fail due to cyclic loading conditions. Since Ti-6Al-4V material cost more, Titanium coat over the S.S can be used as an alternative for Re-Engineered Indian femur implant locking plate.

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Mr.D.Amalraju is a P.G Scholar in Engineering Design from Anna University of Technology, Coimbatore. Presently he is working as a Lecturer in Department of Mechanical Engineering, Karpagam University, Coimbatore. He has published two papers in National Conferences. He has 6 years of experience in teaching and 2 years in industry. His research includes Bio-Mechanics and non-conventional energy sources.

Dr.A.K.Shaik Dawood is doctorate in Mechanical Engineering from PSG College of Technology, Coimbatore which is affiliated to Anna University Chennai. Presently working as Professor in Mechanical Engg, Karpagam University, Coimbatore.
He has got 13 years of teaching experience. He has published 10 papers in international journals & national journal and also has published 14 papers in international & national conference. His research interests include Robotics, CFD, Industrial Engg, Metallurgy and Production. He is a Registered PhD supervisor of Anna University, Coimbatore and Karpagam University. He is currently guiding 8 PhD research scholars.