Finite Element Analysis on Stainless Steel and Titanium Alloy Used as Ankle Joint Replacement Implant Materials

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***Abstract* - Total ankle replacement is a procedure in which an injured ankle joint is replaced with a plastic and metal joint. Available data suggest that total ankle replacement has a relatively short lifespan. Presently SS316L, Ni-Cr Alloys, Ti-6Al-4V are used as implant material in ankle replacement surgery. The materials are conventional material, heavier in density which fails within prescribed period and costly. The objective of this study is to analyse stresses on implant of the ankle joint. A three-dimensional finite element method (FEM) model of the implant will be developed for the study. The analysis of the FEM model found stress concentrations in the implant. To obtain the results by considering the different loads exerted by human body weight on ankle joint implants while walking, running, jumping. From the results of analysis on implant, it can be concluded that stainless steel have minimum stresses as compared to alumina but density is heavier considered to Titanium alloy. As metal alloys are heavier in density the bone cannot withstand that. The ankle replacement material requires less deformation and low density. The low density materials are recommended for better life and performance. Developing a new material with low density (PMC) may the future of this work.**

***Keywords* – Alumina, Finite element method, Stainless steel, Stress, Titanium alloy, Total ankle replacement**

I. INTRODUCTION

Total ankle replacement is a procedure in which an injured ankle joint is replaced with a plastic and metal joint. The human ankle joint consists of tibia, fibula and talus as shown in fig. 1. The plastic and/or metal joints used as ankle joints are known as bio-implants. The procedure has been used as an alternative to surgical fusion in patients with loss of ankle function and pain that is refractory to medications, especially because of rheumatoid arthritis. In recent years, total ankle replacement has developed as another option. However there are limited long-term data on the effectiveness of total ankle replacement.

Available data suggest that total ankle replacement has a relatively short lifespan. Presently SS316L, Ni-Cr Alloys, Ti-6Al-4V are used as implant material in ankle replacement surgery. The materials are conventional material, heavier in density which fails within prescribed period and costly. The aim of this work is to provide a computational approach for evaluating the effect ankle replacement implant in different condition. The typical biomaterials being used for ankle replacement implant linear finite element procedure is carried out using generic bone and implant geometry to quantitatively predict the effect of mechanical properties of the biomaterials on implant behaviour. The analysis results showed that the stresses in rear foot of the prosthetic foot-ankle increase to a normal foot-ankle. Whereas, the equivalent stresses of fore foot are decreased. The predicted plantar pressures and von Misses stress distributions for a normal foot were consistent with other FE models [1].

Preliminary analysis has shown that maximum contact stresses and polyethylene deformation occur at 70-75% of the stance phase. In positions under heavy torsional loading, large medial-lateral contact possible stresses will be observed in the talus, which may translate into large shear forces at the talus-bone interface [2].

The use of total ankle replacement for advanced ankle arthritis in patients ages over 50 years with moderately active lifestyle but recommends counselling patients appropriately regarding reasonable expectations, increased complications and lack of long-term results for newer total ankle replacement designs [3].

Early clinical results indicate that the total ankle replacement system can provide significant improvement in pain, quality of life, and functional measures in patients suffering from end-stage ankle arthritis [4].

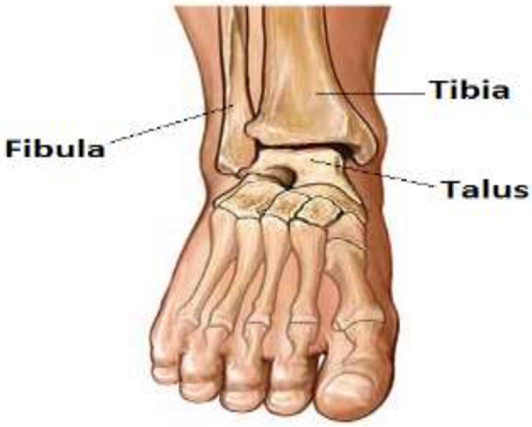


Figure (1) Human ankle joint bone

II. MATERIALS AND METHODS

Implant is subjected to many natural chemicals inside the human body. Some of these chemicals may tend to corrode some materials. In order to implant to perform under these conditions, it must be made from materials that can withstand these forces and chemicals. Whether an implant is designed to replace a joint, or repair a fracture, several physical and biological characteristics are important when selecting the material for the implant

Metallic, ceramic and polymeric biomaterials are used in orthopedic applications. Metallic materials are normally used for load bearing members such as pins and plates and femoral stems etc. However, stainless steel (SS316L) and titanium alloys (Ti-6Al-4V) are the two metals that are used as implant materials for the purpose of analysis. Properties of these materials are shown in table (1) and table (2) respectively.

Ceramics such as alumina and zirconia are used for wear applications in joint replacements, while hydroxyapatite is used for bone bonding applications to assist implant integration. Polymers such as ultra-high molecular weight polyethylene are used as articulating surfaces against ceramic components in joint replacements. Porous alumina has also been used as a bone spacer to replace large sections of bone which have had to be removed due to disease.

Table 1. Properties of SS316L

SS316L Properties	
Density	7980 Kgf/m^3
Young's modulus (*E*)	193 GPa
Tensile strength (σ_t)	515 MPa
Thermal Conductivity	16.3 W/m.K (at 100° C)
Poisons ratio	0.3
Water absorption, 24 hours	<0.1%

Table 2. Properties of Ti-6Al-4V

Ti-6Al-4V Properties	
Density	4400 Kgf/m^3
Young's modulus (*E*)	114 GPa
Tensile strength (σ_t)	1000 MPa
Thermal Conductivity	7.2 W/mK
Poisons ratio	0.342
Water absorption, 24 hours	< 0.1%

1. Modeling of ankle joint implant

The modeling of ankle joint implant is done by the software called CATIA V5. There are three parts in this implant. One part of the implant consists of a hollow pipe like structure which is inserted into the bottom portion of tibia. Other part consists of a semicircular arc shaped structure. There is a small rod like structure extended in concave side of this arc to fix on the top of talus. In between these two parts, there is a thin layer which acts as bearing. The 3D model of the implant is shown in fig. 2.

Figure (2) 3D model of implant

2. FEA of the ankle joint implant

The 3D finite element model required for analysis is created by discretizing the geometric model. The discretization was performed in ANSYS environment.

The 3D geometry of the implant, modeled separately. The model is exported as stp file. This file is imported into the environment where the implant model is opened. Finally model is prepared for the analysis. 86188 elements are created and tria elements are used. Using ANSYS 14.5 different boundary conditions are given and analysis is performed. The fig.3 shows the FEA model of the implant whereas fig.4 shows the boundary conditions given to the model for the analysis.

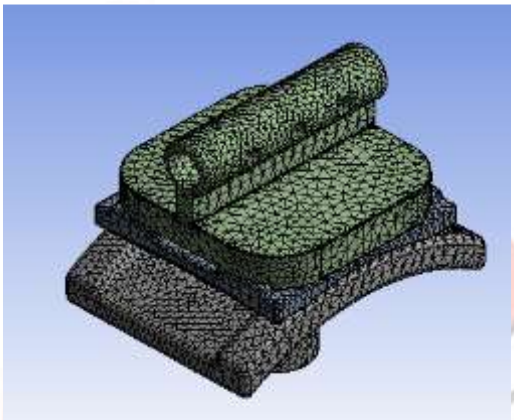


Figure (3) FEA model of ankle implant

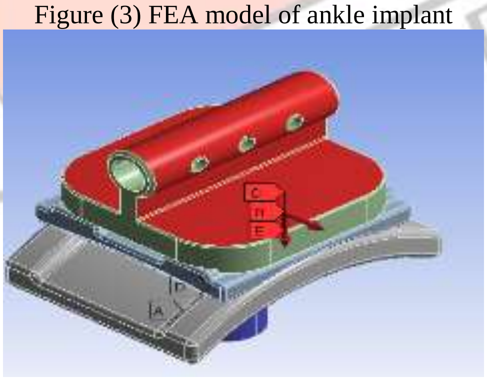


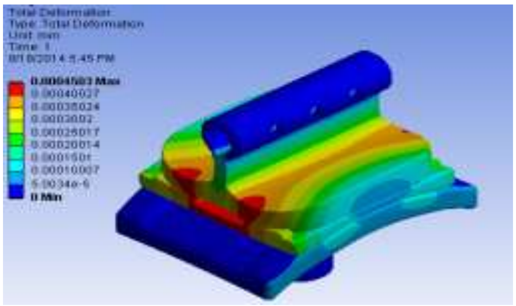
Figure (4) Boundary conditions

III. RESULTS

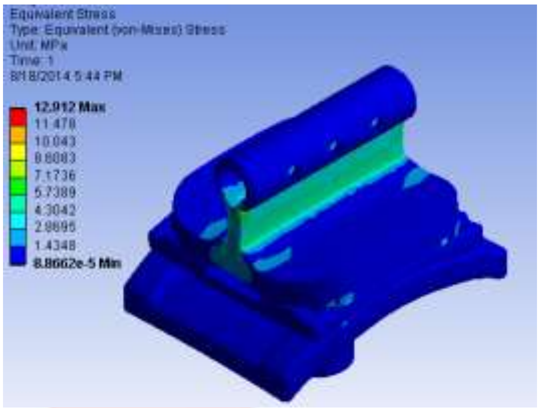
Following results of case-6: Body Weight 100 kg as shown below for all materials-

A. Results of analysis of SS316L under normal walking

1. DISPLACEMENT

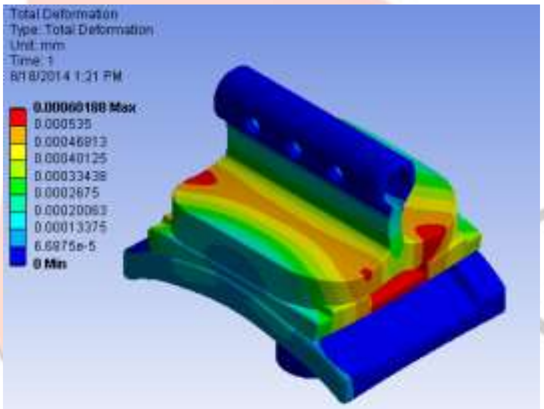


1. VON-MISES STRESS

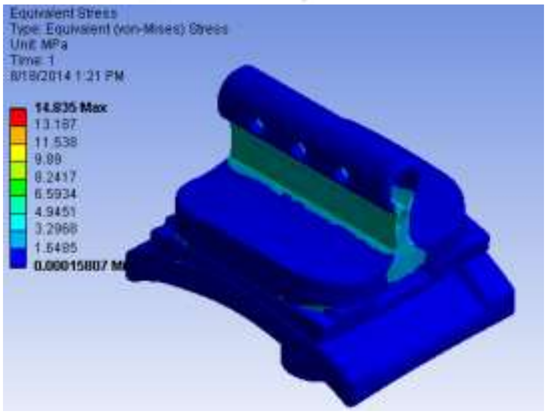


B. Results of analysis of Ti-6Al-4V under normal walking

1. DISPLACEMENT

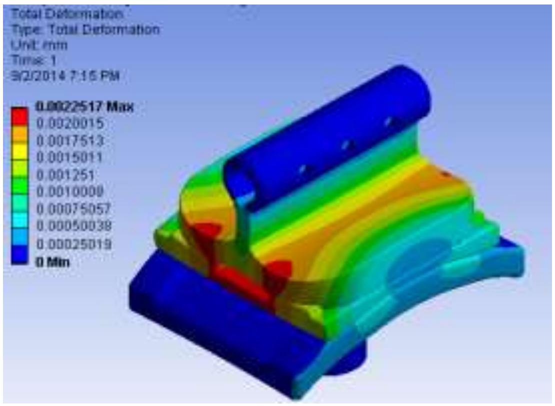


2. VON-MISES STRESS

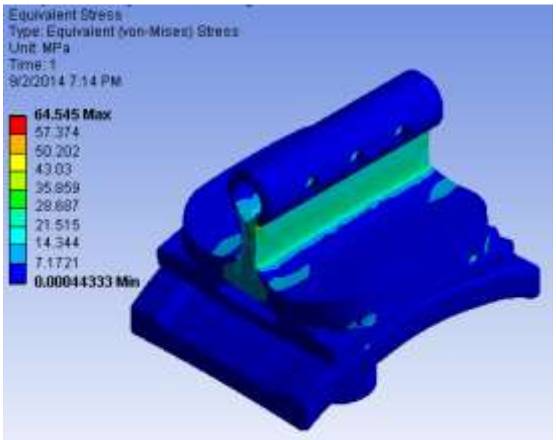


C. Results of analysis of SS316L under impact loading

1. DISPLACEMENT

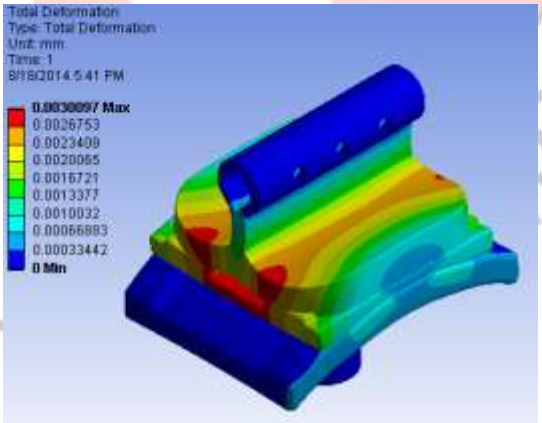


2. VON-MISES STRESS

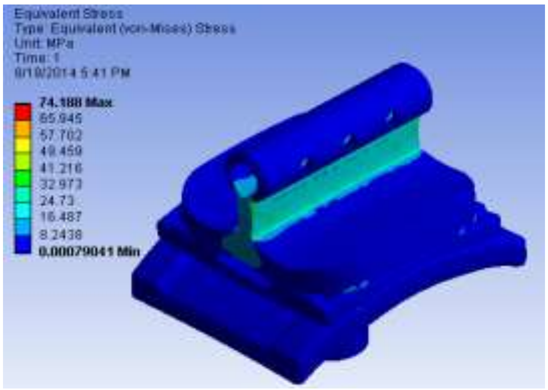


D. Results of analysis of Ti-6Al-4V under impact loading

1. DISPLACEMENT



2. VON-MISES STRESS



IV. RESULTS SUMMERY

E. Results summery of SS316L under normal walking

Patient weight (kg)	Maximum Load(N)	Displacement (max) mm	Von misses stress(max) N/mm^2
50	2000	2.25e-04	6.456
60	2400	2.70e-04	7.747
70	2800	3.15e-04	9.038
80	3200	3.60e-04	10.33
90	3600	4.05 e-04	11.621

F. Results summery of Ti-6Al-4V under normal walking

Patient weight (kg)	Maximum Load(N)	Displacement (max) mm	Von misses stress(max) N/mm^2
50	2000	3.00 e-04	7.4173
60	2400	3.61 e-04	8.9008
70	2800	4.21 e-04	10.384
80	3200	4.81 e-04	11.868
90	3600	5.41 e-04	13.351

G. Results summery of SS316L under impact loading

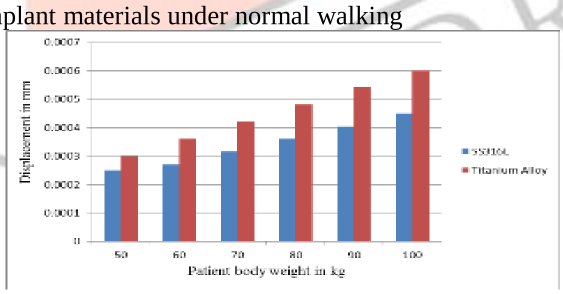
Patient weight (kg)	Maximum Load(N)	Displacement (max) mm	Von misses stress(max) N/mm^2
50	10000	1.125e-03	32.278
60	12000	1.35e-03	38.732
70	14000	1.57e-03	45.186
80	16000	1.80e-03	51.64
90	18000	2.02 e-03	58.093
100	20000	2.25 e-03	64.5460

H. Results summery of Ti-6Al-4V under impact loading

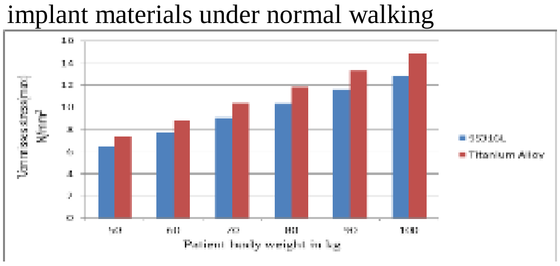
Patient weight (kg)	Maximum Load(N)	Displacement (max) mm	Von misses stress(max) N/mm^2
50	10000	1.506 e-03	37.07
60	12000	1.180 e-03	44.509
70	14000	2.10 e-03	51.928
80	16000	2.40 e-03	59.347
90	18000	2.70 e-03	66.767
100	20000	3.007 e-03	74.188

I. Analysis of ankle joint replacement implant materials under different dynamic loading condition are shown in bar chart in terms of displacement, von-misses stresses

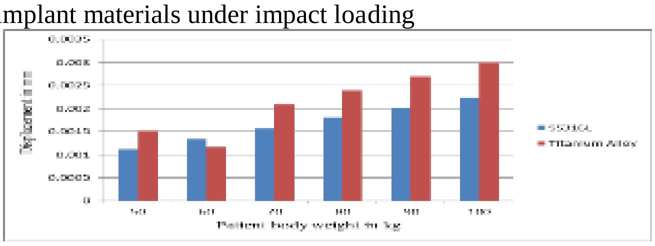
1. Displacement bar chart for implant materials under normal walking



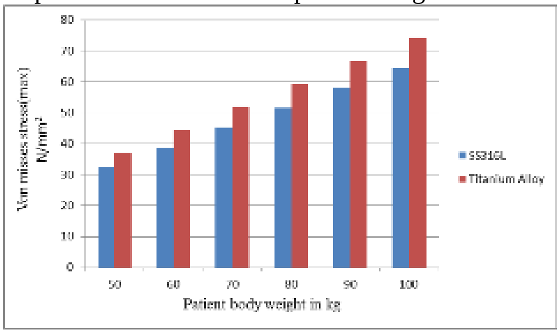
2. Von-mises stress bar chart for implant materials under normal walking



3. Displacement bar chart for implant materials under impact loading



4. Von-mises stress bar chart for implant materials under impact loading



V. Conclusion

- Among the considered materials Stainless steel exhibited the maximum stress of 12.912 N/mm^2 and maximum displacement 4.5e-04mm for the patient body weight 100kg. The stresses produced are within the yield stress hence material is safe.
- Titanium alloys exhibited the maximum stress of 14.835 N/mm^2 and maximum displacement 6.01e-04 for the patient body weight 100kg under normal walking condition .The stresses produced are within the yield stress
- Stainless steel exhibited the maximum stress of 64.6 N/mm^2 and maximum displacement 2.25e-03 mm for the patient body weight 100kg
- Titanium alloys exhibited the maximum stress of 74.188 N/mm^2 and maximum displacement 3.009e-03 for the patient body weight 100kg under impact loading condition. The stresses produced are within the yield stress

VI. References

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