International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 04 | Apr 2021 www.irjet.net p-ISSN: 2395-0072

Design & Analysis of an Artificial Ankle Joint Under Various Loading Conditions

KONDETI SRAVANTH[1], BADATALA OOHA[2], PUTTI VENKATA SIVA TEJA[3]

[1]HCL Technologies, CAE, Technical Member Chennai
[2,3]Department of Mechanical Engineering. Dhanekula Institute of Engineering and Technology, Ganguru, Vijayawada, India

---

Abstract: *The total ankle replacement is a procedure in which an injured ankle joint is replaced with a biological implant of composite material. The alloys like SS316L, Co-Cr-Mo, Ti-6Al-4V are being used as implant material in ankle replacement surgery. The objective of this work is to develop a model & assign the materials in such a way that the density of the artificial ankle joint is minimum & the young's modulus of the artificial ankle joint is close to the young's modulus of the bone. So that the developed joint provides good biological fixation through bone tissue ingrowth into the porous network potential and preventing stress shielding effect. This is obtained by using alloys like β-type titanium alloys Ti–13Nb–13Zr (TNZ). These alloys possess excellent mechanical, physical, and biological properties. As low modulus β-type Ti-based alloys are developed with Young's modulus close to that of cortical bone. These alloys are composed of non-toxic and allergy-free elements, which are best suited for biomaterial implants. A finite element model of the implant is to be developed in CATIA V5 software. The analysis is performed on the developed model using ANSYS software for various loading conditions. The Von-Mises Stress, Deformation, Natural frequencies, and Contact stresses of the developed artificial joint are determined. From the obtained values the best-suited material for a biological implant (Artificial Ankle Joint) is determined in this paper.*

Keywords: Biological Implant, Artificial Ankle Joint, Stress Shielding Effect, β-type titanium alloys, Von-Mises Stress, Natural Frequency, Contact Stresses

1.Introduction: The human body is a series of many bones, joints, and muscles. At the time of birth human body has about 350 bones, by the time of adulthood some of the bones will be fused to a total of 206 bones in our body. The adult skeleton consists of 206 bones in which 28 skull bones (8 cranial, 14 facials, and 6 ear bones) The horseshoe-shaped hyoid bone of the neck, 26 vertebrae, 24 ribs & the sternums. The shoulder girdle, the pelvic girdle & 30 bones in arms and legs. There are also a few partial bones, ranging from 8-18 in number, which is related to joints.

1.1Biomechanics of ankle joint: The ankle joint is also called a mortise joint, a gliding joint between the distal ends of the tibia and fibula and the proximal end of the talus. The ankle is a complex mechanism. The ankle is made up of two joints: the subtalar joint, and the true ankle joint. The true ankle joint consists of 3 bones. They are tibia, fibula & talus. The motion of the foot (up & down) is caused due to ankle joint. The tibia is located on the medial side of the leg and has a greater cross-section than the second-long bone of the leg, the fibula. The tibia is in a direct line between the femur and the talus and carries most of the load.

1.2Range of motion of the ankle: Due to various geographical & cultural differences of humans in their daily activities the Ankle Range of Motion (ROM) varies. All movements of an ankle at normal gait (dorsiflexion, plantar flexion, supination, and pronation), occurs at different levels which involve various hindfoot and midfoot joints. The motions of plantar flexion and dorsiflexion are the major contributors to overall ankle motion that are of particular importance during clinical evaluation. The average plantar flexion and dorsiflexion of the ankle have been measured at 40°-56° and 13°-33°, respectively.

1.3Current implants and failures: The total number of Total Ankle Replacements (including revision) was approximately 7000 procedures in 2005 and is estimated to increase to 11,000 in 2012 for an increase of 6-8% a year (Below graph). Similarly, these procedures generated $285 million in revenue and are expected to increase to $476 million in 2012 industry-wide.

2.Problem Identification: The conventional materials used for ankle replacement are heavier in density and improper which fails within a prescribed period. Steel has low corrosion resistance and high density. Co-Cr-Mo alloy good corrosion resistance and low cost but heavier than steel. Ti-6Al-4V alloy is superior to those of other metallic materials but the use of vanadium produces toxicity. To remove toxic elements, to improve tissue and blood compatibility & to miniaturize medical devices a low Young's modulus Metallic biomaterials are required. In which Young's modulus of the metallic biomaterials must be close to that of bone (10–30 GPa).

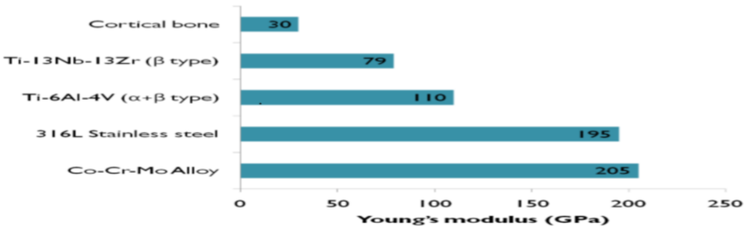

Figure 1:Young's modulus comparison of different materials

3.Methodology

Modelling, Defining material properties, Meshing	Pre-Processor
Boundary conditions & Defining loads	Solver
Solution / Results	Post-Processor

4.1 Design of Tibial component, Mobile bearing component & Talar component

Specifications of a Tibial Component
Tibial plate thickness =2.5mm
Tibial plate length= 35mm
Anterior view = 32mm
Posterior view= 28mm
Parallel cylindrical barrels length =19mm
Diameter= 2.5mm

Specifications of a Bearing Component
Length of bearing component = 30mm
Width of bearing component= 20mm
Height of bearing component= 8mm
Width of the groove running to posterior=2mm
Length of groove running to posterior=20mm

Specifications of a Talar Component
The width of the talar dome surface was averaged as 29.9 ± 2.6mm at the anterior.
27.9 ± 3.0mm at middle and
25.2 ± 3.7mm at the posterior portions.
The radius of the surface contour on the midsagittal section was 20.7_+2.6mm.

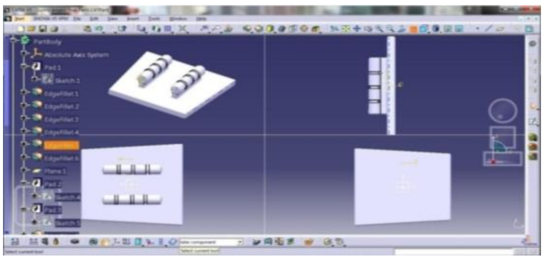

Figure 2. Design of Tibial component

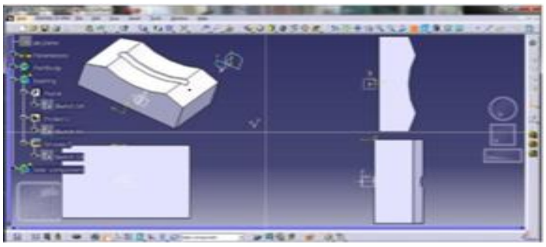

Figure 3. Design of bearing component

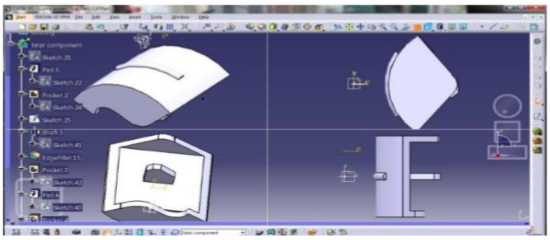

Figure 4. Design of Talar component

4.2Artificial Ankle Joint

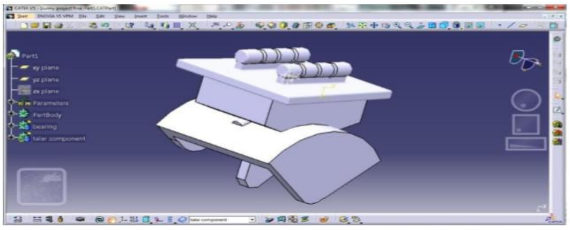

Figure 5. Artificial ankle joint

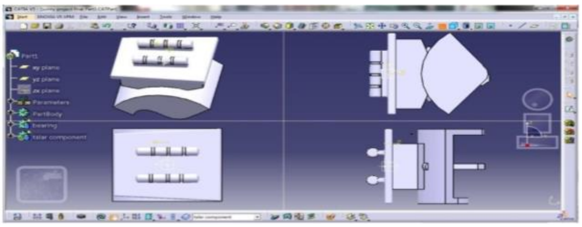

Fig 6. Different Views

4.3 Meshing & Boundary conditions

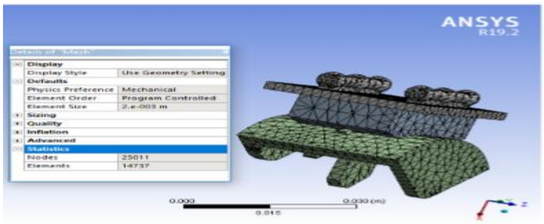

Figure 7. Meshing (25011 Nodes 14737 Elements)

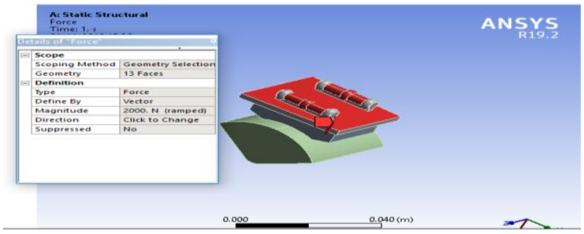

Figure 8. Boundary conditions (Talar component fixed & applied different forces on Tibial component)

4.4 Material Properties

PROPERTIES OF MATERIALS	CO-CR-MO ALLOY	TI-6AL-4V ALLOY	TI-13NB-13ZR ALLOY	UHMWPE
Density (Kg/M^3)	8300	4430	4920	930
Poisson's Ratio	0.32	0.31	0.32	0.46
Young's Modulus (Gpa)	205	110	79-84	0.894
Yield Strength (Mpa)	660	880	836-908	21.4
Ultimate Tensile Strength (Mpa)	1100	950	973-1037	38.6

Table no: 1 property

5 Results

5.1 Static Analysis (Ti-13Nb-13Zr alloy) ; When 3500N Load Applied

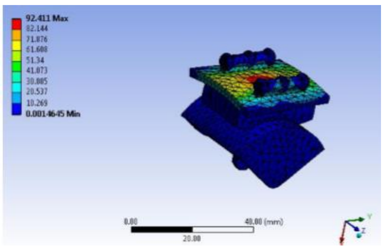

Fig 9. Von-mises stress at 3500N

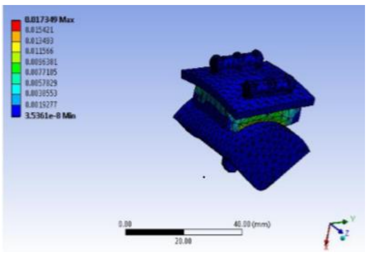

Fig 10. Equivalent strain at 3500N

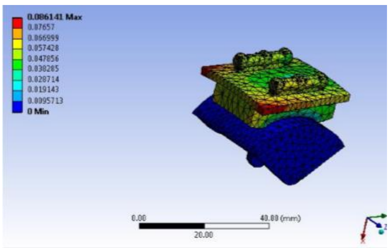

Fig 11. Total deformation at 3500N

5.2 Static Analysis (Ti-6Al-4V alloy) ; When 3500N Load Applied

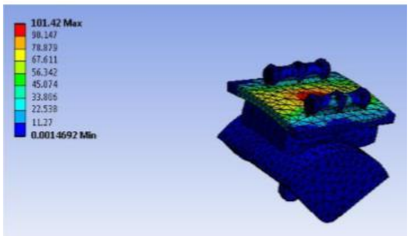

Fig 12. Von-mises stress at 3500N

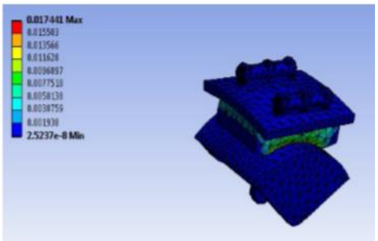

Fig 13. Equivalent strain at 3500N

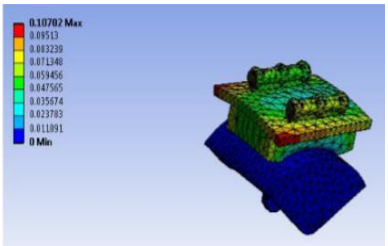

Fig 14. Total deformation at 3500N

5.3 Static Analysis (Co-Cr-Mo alloy) ; When 3500N Load Applied

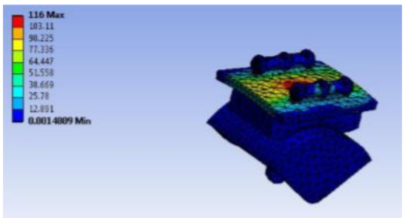

Fig 15. Von-mises stress at 3500N

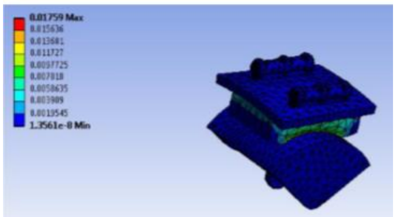

Fig 16. Equivalent strain at 3500N

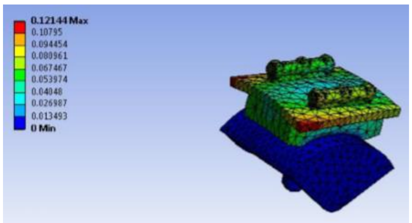

Fig 17. Total deformation at 3500N

Load (N)	Co-Cr-Mo alloy	Ti-6Al-4V alloy	Ti-13Nb-13Zr alloy
2000	**66.287**	**57.952**	**52.807**
2500	**82.859**	**72.439**	**66.008**
3000	**99.431**	**86.927**	**79.21**
3500	**116.1**	**101.42**	**92.411**

Table 2: Static Analysis Von-Mises Stress (MPa)

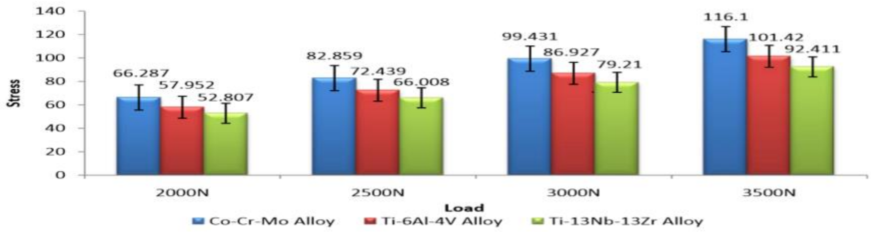

Fig 18. Von-Mises stress [MPa] Vs Load

Load (N)	Co-Cr-Mo alloy	Ti-6Al-4V alloy	Ti-13Nb-13Zr alloy
2000	0.01005	0.00996	0.00991
2500	0.01252	0.01245	0.0123
3000	0.015	0.01495	0.0148
3500	0.01759	0.01744	0.01734

Table 3. Static Analysis of Equivalent strains

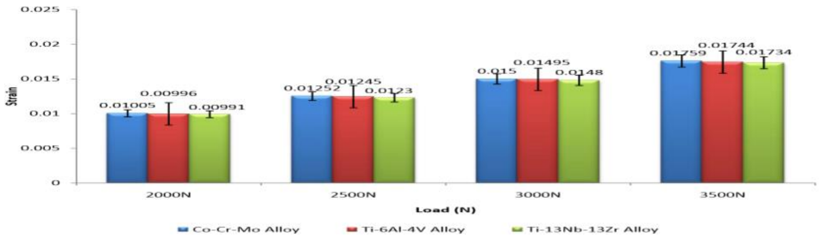

Figure 19. Equivalent strains

Load (N)	Co-Cr-Mo alloy	Ti-6Al-4V alloy	Ti-13Nb-13Zr alloy
2000	**0.069**	**0.06115**	**0.0492**
2500	**0.086**	**0.07644**	**0.0615**
3000	**0.104**	**0.091**	**0.0738**
3500	**0.121**	**0.107**	**0.0861**

Table 4. Static Analysis Total Deformation (mm)

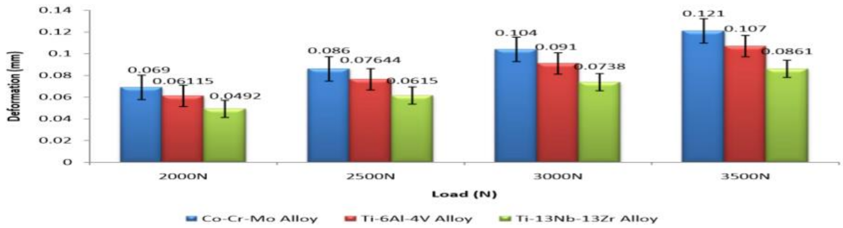

Figure 20. Total Deformation (mm)

5.4 Modal Analysis

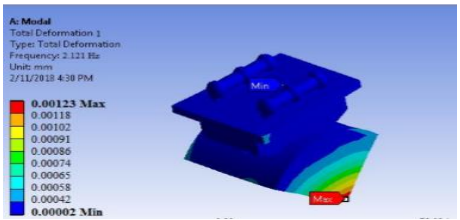

Fig 21. Ti-13Nb-13Zr 1st Mode

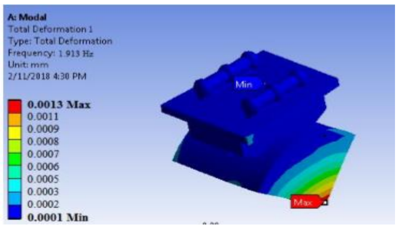

Fig 22 Ti-6Al-4V 1st Mode

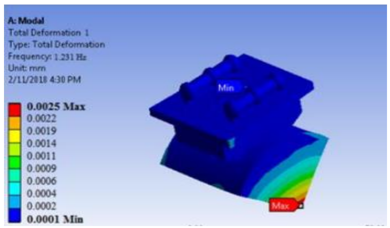

Fig 23. Co-Cr-Mo 1st Mode

Table 5. Modal Analysis Frequencies & Deformation (Ti-13Nb-13Zr alloy)

Mode	Frequency (Hz)	Total Deformation (mm)
1	2.12	0.0010
2	11.132	1.106
3	30.183	2.131
4	57.262	5.231
5	113.307	9.732
6	180.262	15.73

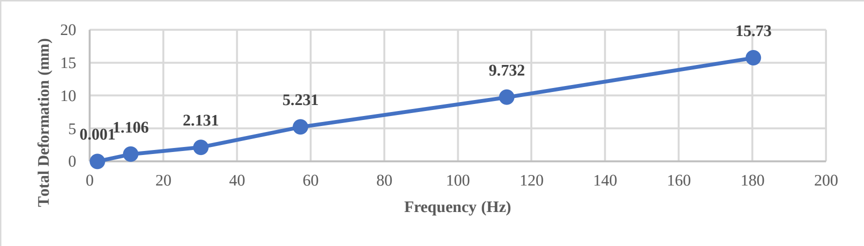

Figure 24. Frequency Vs Total Deformation

Table 6. Modal Analysis Frequencies & Deformation (Ti-6Al-4V alloy)

Mode	Frequency (Hz)	Total Deformation (mm)
1	1.231	0.0025
2	12.142	1.752
3	28.314	3.216
4	56.12	6.823
5	110.14	9.242
6	171.22	17.14

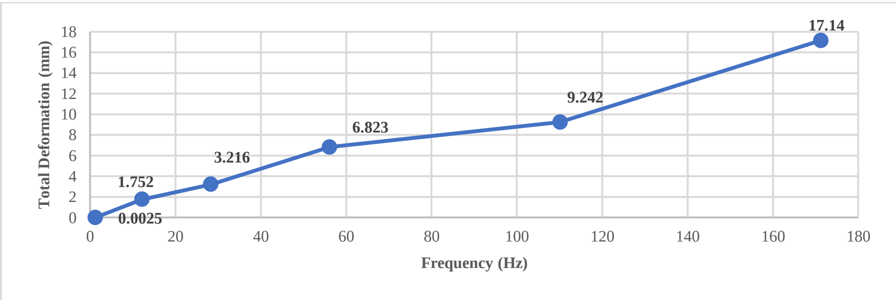

Figure 25. Frequency Vs Total Deformation

Table 7. Modal Analysis Frequencies & Deformation (Co-Cr-Mo alloy)

Mode	Frequency (Hz)	Total Deformation (mm)
1	1.913	0.0013
2	9.132	1.101
3	25.31	2.155
4	53.76	4.661
5	111.33	12.136
6	159.83	17.25

5.5 CONTACT Analysis

Table 8. Modal Analysis Frequencies & Deformation (Co-Cr-Mo alloy)

Load (N)	Contact Pressure (MPa)		
	Co-Cr-Mo alloy	Ti-6Al-4V alloy	Ti-13Nb-13Zr alloy
3500	17.291	17.315	17.341

6 **Conclusion:** The static structural analysis of the ankle joint has great significance. In this thesis, the modeling of the three-component mobile-bearing artificial ankle joint was done using CATIA V5 R20 software and the analysis work was supported by ANSYS 19.2. The Static structural analysis, Modal

analysis, and Contact analysis were performed on three different alloy materials mainly Co-Cr-Mo alloy, Ti-13Nb-13Zr alloy, and Ti-6Al-4V alloy. At maximum loading conditions in structural analysis, Ti-13Nb-13Zr alloy yields low-stress values and less deformation compared to other materials. From the Modal analysis, we obtained Natural frequencies and corresponding mode shapes were plotted. From contact analysis, the contact pressures of the three models are within the permissible limits. By incorporating Ti-13Nb-13Zr alloy, we can also avoid both toxic and stress shielding effect. Finally, I conclude that Ti-13Nb-13Zr alloy gives better performance at maximum loading conditions when compared to the other two materials and it is most suitable for artificial ankle joint implants.

7 References

[1] Oonishi, H., Hamaguchi, T., Okabe, N., Nabeshima, T., Hasegawa, T., Kitamura, Y.: Cementless alumina ceramic artificial ankle joint. In Biomaterials and Biomechanics 1983. Ducheyne, P. , et al (eds.), Amsterdam, Elsevier Science Publishers B. V., 1984, pp. 85–90.

[2] Lewis, G. and G.E. Austin, A Finite Element Analysis Study of Static Stresses in a Biomaterial Implant. Innovations and Technology in Biology and Medicine, 1994. 15(5): p. 634-644.

[3] Genda, E., et al. Three-Dimensional Stress Analysis of Ankle and Foot Joints. in 45th Annual Meeting, Orthopedic Research Society. February, 1999. Anaheim, California. p. 390.

[4] Ledoux, W.R., et al., Finite Element Foot Modelling, http://www.truegrid.com/gallery/show_foot.html.

[5] Valderrabano, V., et al., Gait analysis in ankle osteoarthritis and total ankle replacement. Clinical Biomechanics, 2007. 22(8): p. 894-904

[6] Vickerstaff, J.A., A.W. Miles, and J.L. Cunningham, A brief history of total ankle replacement and a review of the current status. Medical Engineering and Physics, 2007. 29(10): p. 1056-1064.

[7] Espinosa, N. and G. Klammer, Treatment of ankle osteoarthritis: arthrodesis versus total ankle replacement. European Journal of Trauma and Emergency Surgery, 2010. 36(6): p. 525-535

[8] Bauer, G., et al., Total ankle replacement. Review and critical analysis of the current status. Foot and Ankle Surgery, 1996. 2(2): p. 119-126

[9] Abdul Kadir, M.R., N. Kamsah, and H. Sabudin, Stability of Talus Component in Total Ankle Arthroplasty. 2008, Springer Berlin Heidelberg: Berlin, Heidelberg. p. 453-456

[10] Reggiani, B., et al., Finite element analysis of a total ankle replacement during the stance phase of gait. Journal of Biomechanics, 2006. 39(8): p. 1435-1443.

Author's Biography

	**KONDETI SRAVANTH,** HCL Technologies, CAE, Technical Member, Chennai.
	**BADATALA OOHA,** Assistant Professor Department of Mechanical Engineering, Dhanekula Institute of Engineering & Technology.

PUTTI VENKATA SIVA TEJA, Assistant Professor
Department of Mechanical Engineering,
Dhanekula Institute of Engineering & Technology.