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Modelling and Analysis of Hip Implant & Fabrication of Prototype using Fused Deposition Modelling RP Process

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Abstract - It is observed that injury caused by trauma, disease, or accidents results in bone damage which leads to improper functioning (or) permanent destruction of the bone. The damaged bone which is replaced by the implant made up of either ceramic or metal, will function in the human body similar to that of the original bone. The aim of this research work is to compare the finite element analysis results of the designed hip implant and commercial hip implant for different bio-compatible materials under different walking conditions Based on the dimensions of hip joint, it is proposed to design a hip implant in solidworks software. The model is meshed and finite element analysis is performed in ANSYS 16.2 for three different bio-compatible materials (Ti-4Al-6V alloy, SS-316L, Cr-Co-Mo alloy) under different walking conditions. The obtained results are compared with results of commercial hip implant

Key Words: Hip Implant, Analysis, Comparision, 3D Printing.

1.Introduction:

The hip joint is one of the most important joint present in the human body. It bears our body's weight along with the forces acting from the strong muscles of the hip and leg. The hip joint is one of the most flexible joint and allows a greater range of motion compared all other joints present in the human body except the shoulder consisting two main parts which are Femoral Head and Acetabulum as shown in Fig 1.1

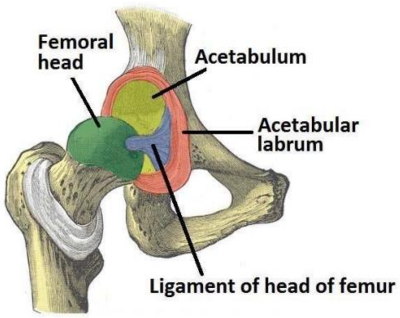


Fig 1.1: Anatomy of Hip Joint

If a hip joint gets damaged in an accident or wears out in old age, a surgeon can replace it with a ball and socket joint made from metal and plastic and engineered in such a way that it will duplicate the motions of a human joint.

Hip Replacement is a surgical procedure in which the diseased parts of the hip joint are removed and replaced with new implant made up of metallic or ceramic part. These artificial parts are called the prosthesis. The goals of hip replacement surgery include increasing mobility, improving the function of the hip joint, and relieving pain. Procedure of hip replacement is shown in fig 1.2.

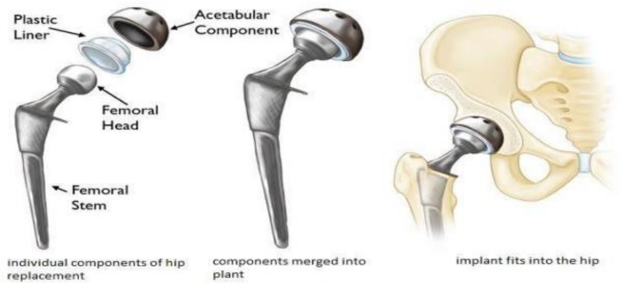


Fig 1.2: General Hip Replacement Procedure

2. Designing of Hip Implant:

CT Scan data of patient pelvis collected from doctor is imported into invesalius 3.0 software from which skin part is separated from bone region by selecting threshold values (lowest value of 662 to highest value of 1792) as shown from figures 2.1 and 2.2

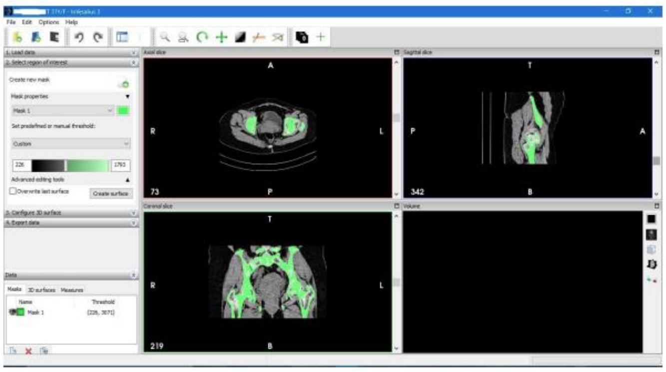


Fig 2.1: CT Scan Data of Patient Plevis

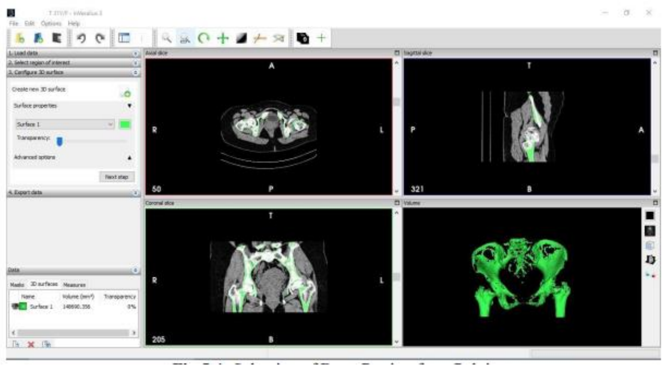


Fig 2.2: Selection of Bone Regioon from Pelvis

After seperating bone region from pelvis it is saved as .stl file format and is imported to meshlab sofware in which hip joint is seperated from entire pelvis bone as shown in fig's 2.3 and 2.4

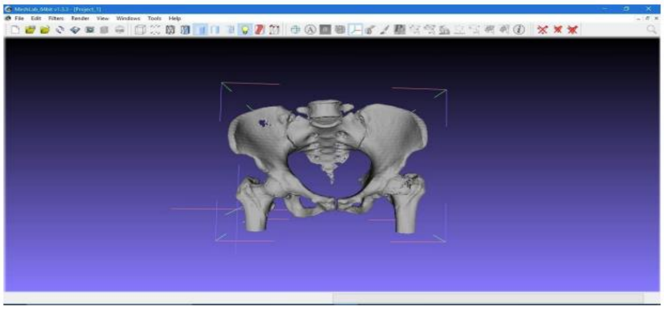


Fig 2.3: Importing of stl file in Meshlab Software

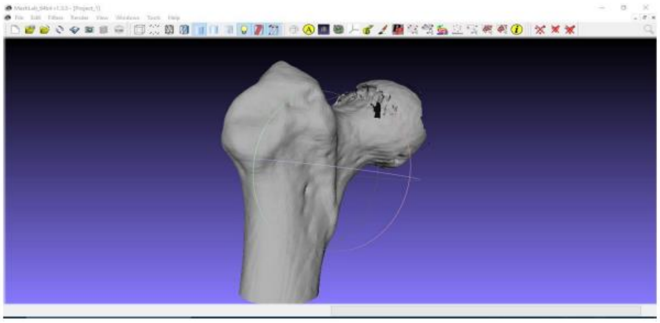


Fig 2.4: Separating Hip Joint from Pelvis Bone

Separated Hip Joint Bone with irregularities is filled in netfabb software as shown in fig 2.5, from which based on dimensions of obtained hip joint hip implant is designed in solidworks software as shown in figures 2.6 and 2.7.

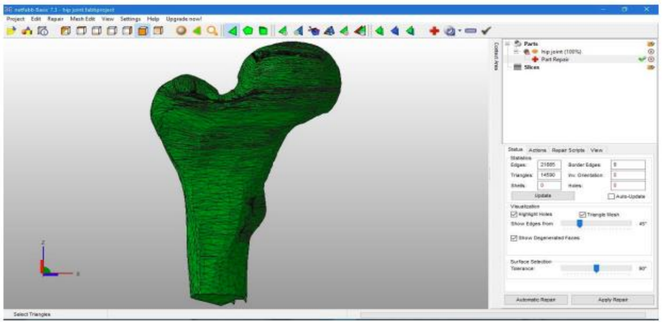


Fig 2.5: Repairing Gaps in Stl File of Hip Joint

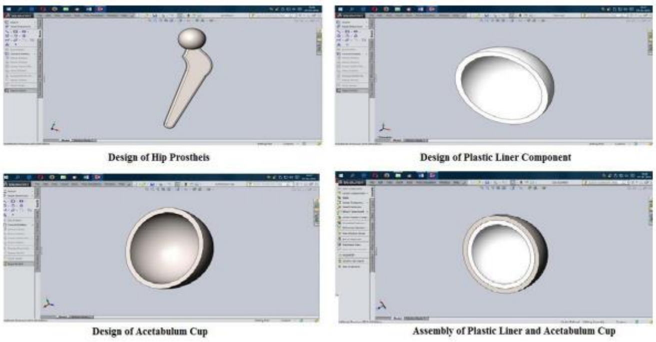


Fig 2.6: Design of Parts of Hip Implant

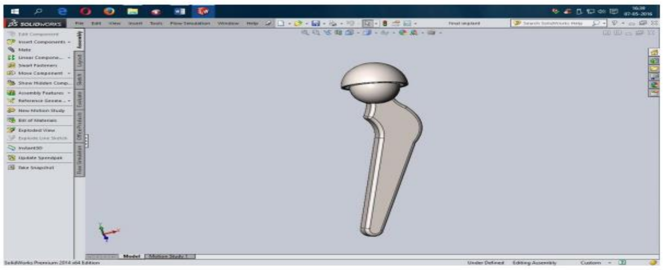


Fig 2.7: Assembly of Plastic Liner, Acetabulum Cup and Prosthesis

2.1: Commercial Hip Implant: which is collected from local doctor is shown in fig 2.8 is 3d scanned by using Hexagon (ROMER) Portable CMM Arm - 2.5 meters 7325 to obtain stl file as shown in fig 2.9 and analyzed to compare the results of designed and commercial hip implants.

Fig 2.8: Commecial Hip Implant Given by Local Doctor,

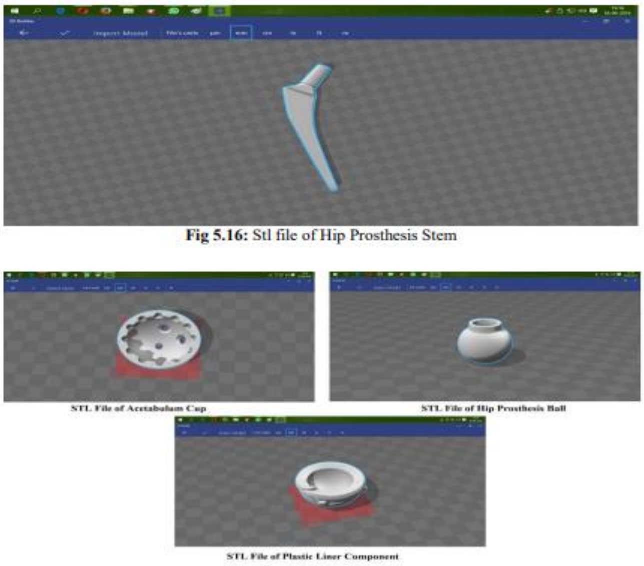


Fig 2.9: Stl Files for parts of Hip Implant

3: Analysis of Hip Implant: Static Structural Analysis is performed in Ansys Workbench Software by assigning following materials which are stainless steel 316, Titanium alloy and Cr-Co-Mo alloy for which properties are mentioned in below table 3.1

Table 3.1: Material Properties:

	Density (Kg/m^3)	Young's Modulus (GPa)	Poisson's Ratio	Yield Strength (GPa)	Ultimate Strength (GPa)
Ti-6Al-4V	4620	96	0.36	0.96	1.07
SS316	7750	193	0.31	0.207	0.586
Cr-Co-Mo	8300	230	0.3	0.612	0.97
Polyethylene	950	1.1	0.42	0.025	0.033

Boundary Conditions: are applied where as by movements by naturally established human bone where bottom part of prosthesis is fixed and forces act on upper part of acetabulum cup as shown in figures 3.1.

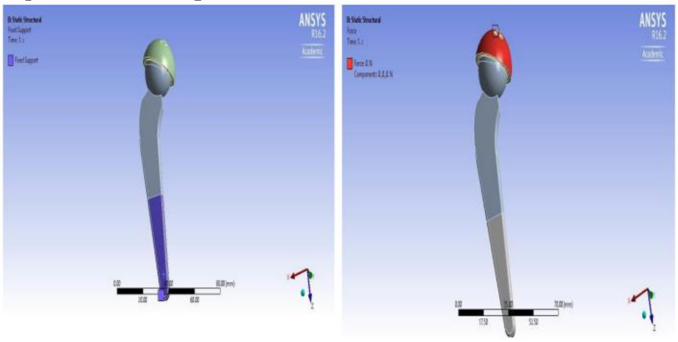
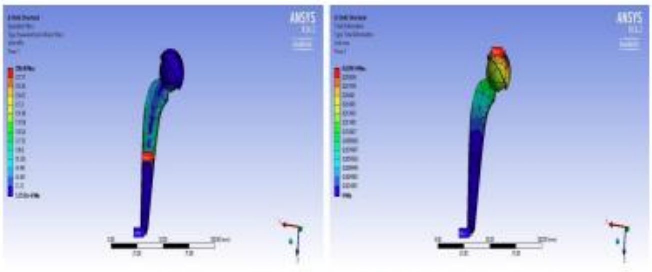


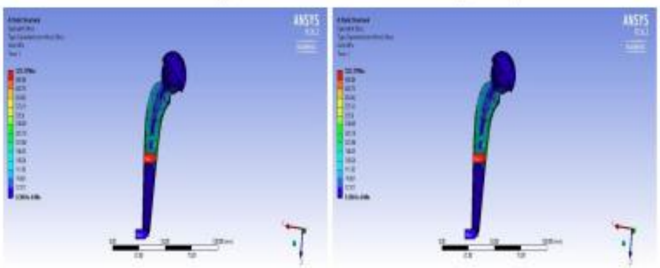
Fig 3.1 Applying Boundary Conditions on Hip Implant

After Applying Boundary Conditions and Applying Fine Mesh, Load is Applied on Designed & Commercial Hip Implant by assuming a three person's having different body weights of 70, 75 & 80 Kg's.

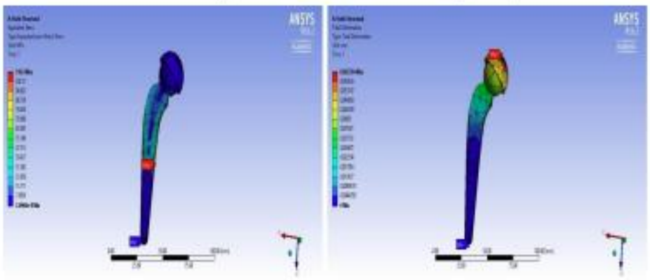
As guman being perform various activities like walking, running, standing, climbing setps etc…. loads are applied in multiples of 2 to 8 times of human body weight as mentioned while performing various activities for three different materials in table 3.1 and figures 3.2 and 3.3. the results of three different materials on designed and commercial hip implant are mentioned in below tables 3.2, 3.3 and 3.4.



Force applied - 3750N for SS316L for designed implant

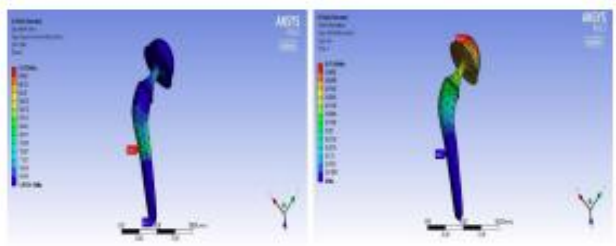


Force applied - 6400N for SS316L for designed implant

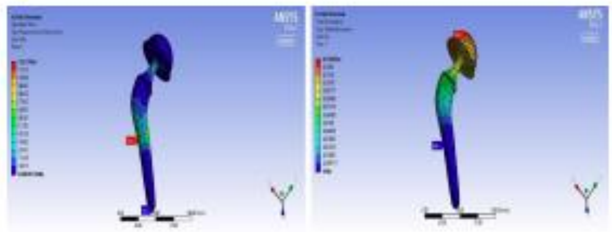


Force applied – 1400N for Cr-Co-Mo for designed Implant

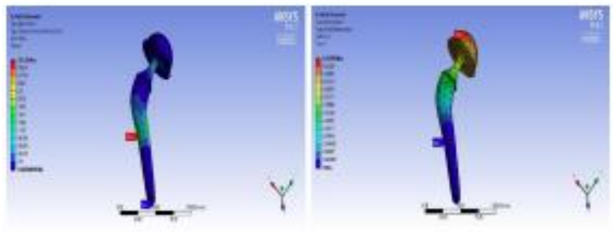
Fig 3.2: Force Applied on Designed Hip Implant



Force applied - 6400N for SS316L for company implant



Force applied - 1400N for Cr-Co-Mo for company implant



Force applied - 3750N for Cr-Co-Mo for company implant

Fig 3.3: Force Applied on Commercial Hip Implant

Table 3.2: Comparison of Equivalent Stress and Total Deformation for Designed and Commercial Hip Implants made of Titanium Alloy

Load Applied	Equivalent Stress (MPa)		Total Deformation (mm)	
(N)	Designed	Commercial	Designed	Commercial
1400	106.16	119.36	0.15	0.31
1500	115.82	127.89	0.16	0.33
1600	135.12	136.41	0.19	0.36
2100	164.07	179.04	0.23	0.47
2250	183.37	191.83	0.25	0.50
2400	202.68	204.62	0.28	0.54
2800	231.63	238.72	0.32	0.63
3000	241.28	255.78	0.33	0.65
3200	270.24	272.83	0.37	0.72
3500	289.54	298.41	0.41	0.78
3750	308.84	319.72	0.43	0.84
4000	328.14	341.04	0.46	0.90
4200	347.45	358.09	0.49	0.94
4500	357.71	383.67	0.50	1.01
4800	403.23	409.24	0.56	1.08
4900	405.35	417.77	0.57	1.10
5250	434.31	447.61	0.61	1.18
5600	463.26	477.45	0.65	1.26
5600	463.26	477.45	0.65	1.26
6000	501.87	511.55	0.70	1.35
6400	540.47	545.66	0.75	1.44

Table 3.3: Comparison of Equivalent Stress and Total Deformation for Designed and Commercial Hip Implants made of SS-316L Alloy

Load Applied (N)	Equivalent Stress (MPa)		Total Deformation (mm)	
	Designed	Commercial	Designed	Commercial
1400	102.60	117.65	0.0072	0.15
1500	111.93	126.06	0.0078	0.16
1600	130.59	134.46	0.009	0.17
2100	158.57	176.48	0.0111	0.23
2250	177.23	189.09	0.0124	0.25
2400	198.88	201.69	0.013	0.26
2800	223.86	235.31	0.0157	0.31
3000	233.19	252.12	0.0163	0.33
3200	261.18	268.92	0.018	0.35
3500	279.83	294.14	0.0196	0.38
3750	298.49	315.15	0.0209	0.41
4000	317.14	336.16	0.022	0.44
4200	335.80	352.96	0.0235	0.46
4500	345.12	378.78	0.0242	0.50
4800	388.43	403.39	0.027	0.53
4900	391.76	411.79	0.0275	0.54
5250	419.75	441.21	0.0297	0.58
5600	447.73	470.62	0.031	0.62
5600	447.73	470.62	0.031	0.62
6000	485.04	504.23	0.0341	0.66
6400	522.35	537.85	0.036	0.71

Table 3.2: Comparison of Equivalent Stress and Total Deformation for Designed and Commercial Hip Implants made of Co-Cr-Mo Alloy

Load Applied (N)	Equivalent Stress (MPa)		Total Deformation (mm)	
	Designed	Commercial	Designed	Commercial
1400	110.40	120.73	0.0627	0.12
1500	120.43	129.36	0.0684	0.13
1600	135.62	137.98	0.0790	0.14
2100	170.61	181.10	0.0969	0.19
2250	190.68	194.04	0.1083	0.20
2400	204.48	206.97	0.119	0.22
2800	240.86	241.47	0.1368	0.25
3000	250.90	258.72	0.1425	0.27
3200	274.23	275.96	0.159	0.29
3500	301.08	301.83	0.1710	0.32
3750	321.15	323.39	0.1824	0.34
4000	342.56	344.95	0.193	0.37
4200	361.29	362.20	0.2052	0.38
4500	371.33	388.07	0.2109	0.41
4800	411.62	413.94	0.239	0.44
4900	421.51	422.57	0.2394	0.45
5250	451.62	452.75	0.2565	0.48
5600	481.73	482.93	0.2736	0.51
5600	481.73	482.93	0.2736	0.51
6000	516.87	517.43	0.2964	0.55
6400	549.49	551.93	0.319	0.59

4. Fabrication of Prototype Using FDM RP Process: Makerbot Replicator 3D Printing Machine is used for making the prototype of designed and commercial hip implant as shown in figures 4.1, 4.2 and .3. Firstly makerbot desktop version 3.9.1 software is used where stl files are imported, allignments are applied and sent to machine for printing purpose.

Printing time for designed implant is 34 Mins and approximately 10.68 gms of material has been consumed. And for commercial hip implant time taken for printing Is 18 mins and approximately 3.39 gms of material has been consumed.

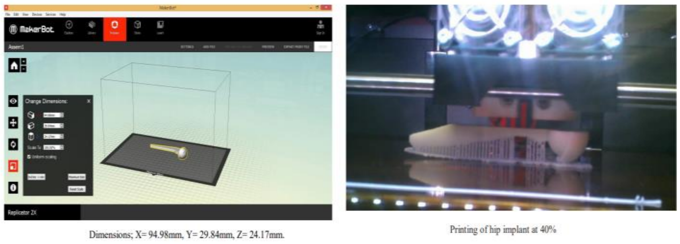


Fig 4.1: Makerbot Software and Printing completed 45% of Designed Implant.

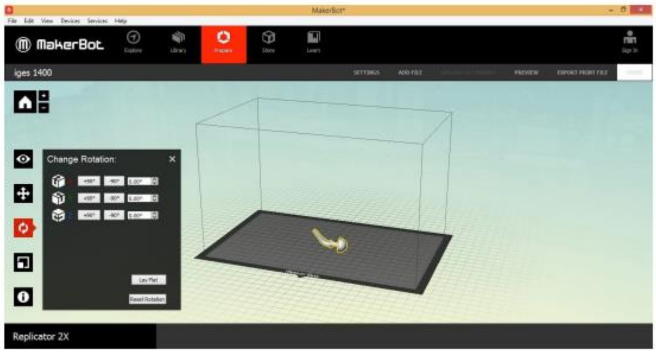


Fig 4.2: Commercial Implant in Makerbot Software

Fig 4.3: Final Printed Prototype of Designed and Commercial Hip Implants

5. Comparison Result of Stress and Total Deformation on Designed and Commercial Hip Implant: Results are shown in figures 5.1, 5.2 and 5.3 for three materials mentioned in table 3.1.

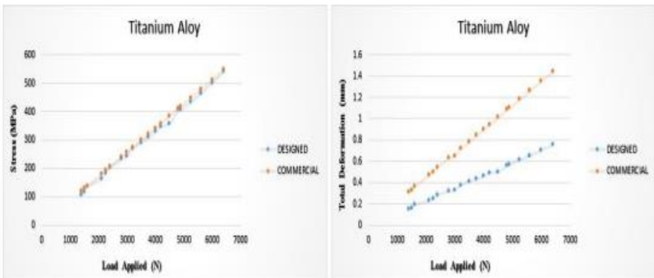


Fig 5.1: Comparison of Equivalent Stress and Total Deformation for Designed and Commercial Hip Implants made of Titanium alloy

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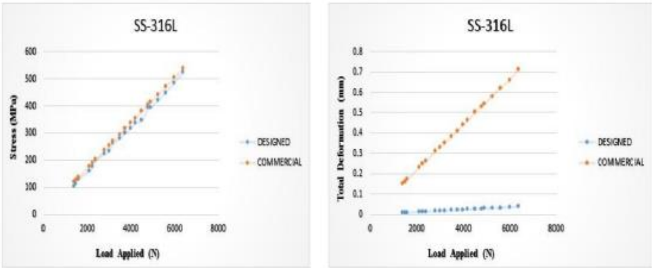

Fig 5.2: Comparison of Equivalent Stress and Total Deformation for Designed and Commercial Hip Implants made of SS-316l Alloy.

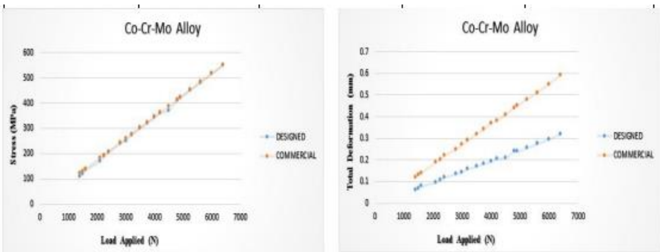

Fig 5.3: Comparison of Equivalent Stress and Total Deformation for Designed and Commercial Hip Implants made of Co-Cr-Mo Alloy.

6. Conclusion:

1. For Proposed Designed hip implant, the von-misses stresses and deformation values obtained for different bio-materials under various loading conditions are as follows:
   - For Ti-4Al46V alloy under running, stairs climbing and running conditions, the maximum von-misses stress and total deformation values obtained are 135.12 MPa, 328.14 MPa, 540.41 MPa and 0.19 mm, 046 mm, 0.75 mm respectively.
   - For SS-316L material under running, stairs climbing and running conditions, the maximum von-misses stress and total deformation values obtained are 130.59 MPa, 317.14 MPa, 522.35 MPa and 0.009 mm, 0.022 mm, 0.036 mm respectively.
   - For Cr-Co-Mo alloy under running, stairs climbing and running conditions, the maximum von-misses stress and total deformation values obtained are 135.62 MPa, 342.56 MPa, 549.49 MPa and 0.167 mm, 0405 mm, 0.668 mm respectively
2. For Commercial hip implant, the von-misses stresses and deformation values obtained for different bio-materials under various loading conditions are as follows:
   - For Ti-4Al46V alloy under running, stairs climbing and running conditions, the maximum von-misses stress and total deformation values obtained are 136.41 MPa, 341.04 MPa, 545.66 MPa and 0.36 mm, 090 mm, 1.44 mm respectively. 65
   - For SS-316L material under running, stairs climbing and running conditions, the maximum von-misses stress and total deformation values obtained are 134.46 MPa, 336.16 MPa, 537.85 MPa and 0.17 mm, 0.44 mm, 0.71 mm respectively.
   - For Cr-Co-Mo alloy under running, stairs climbing and running conditions, the maximum von-misses stress and total deformation values obtained are 137.98 MPa, 344.95 MPa, 551.93 MPa and 0.14 mm, 0.37 mm, 0.59 mm respectively.
3. For all the cases, stress values obtained are safe, compared to the allowable stress of Titanium which is 1034 MPa, SS316L which is 1213 MPa and Cr-Co-Mo which is 841 MPa even when max load of 6400N (i.e. for running condition) is applied.
4. The von-misses stress results obtained for the designed hip implant is less when compared to commercial hip implant, which is due to the modifying the acetabulum cup area in the designed hip implant.
5. For the two designs, which are analysed in this work, Cr-Co-Mo material is best suitable compared to Titanium alloy and SS-316L for hip implant applications.

8. Future Scope: - The present work carried out in this research is that, the modeling and analysis are performed on the two implants, in future, comparison can be made to the experimental and analysis results to find out the fatigue limit of the hip implant.

If possible, loads applied by a patient while performing daily activities can be studied in detail and can be applied while performing dynamic analysis.

Cost analysis, mechanical and bio-mechanical properties can be compared to the conventionally manufactured hip implant to the 3D metal printed hip implant.

9. References:

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