

Analysis of hip femur joint for material polycaprolactone

S.K. Ramkumar Raja ¹, G. Mageshwaran ²

Lecturer, Dept. of Mechanical Engineering, Sathyabama University, Chennai-119.

*Corresponding author: mageshwaran.mechanical@gmail.com; +91 7708007184

ABSTRACT

Various works are carried out in development of implants. Using the concept of reverse engineering modeling and analysis of human hip femur joint using Polycaprolactone material is carried out. This enlarges the possibility of development in the field of implants. The output can be readily linked to a rapid prototyping machine and prototypes can be made in a single step for further study before manufacturing the implants. A case of the patient named Thulasidass aged 48 is taken; using these images in MIMICS software a 3D model is generated from where the hip femur joint is alone extracted and using modeling software 3D model is corrected from which the analysis for the suggested material is carried out using ANSYS software.

Keywords: bio materials, analysis, implants, modeling.

INTRODUCTION

The fractured pelvis of the patient named Thulasidass aged 48, is scanned using X-ray CT system to get fifty four, two dimensional slices or cross sectional images in DICOM, JPEG or Bitmap file format. The fifty four slices of two dimensional cross sectional images of the fractured pelvis of the patient named Thulasidass in Bitmap (.BMP) format are shown in Figures 1,2,3.

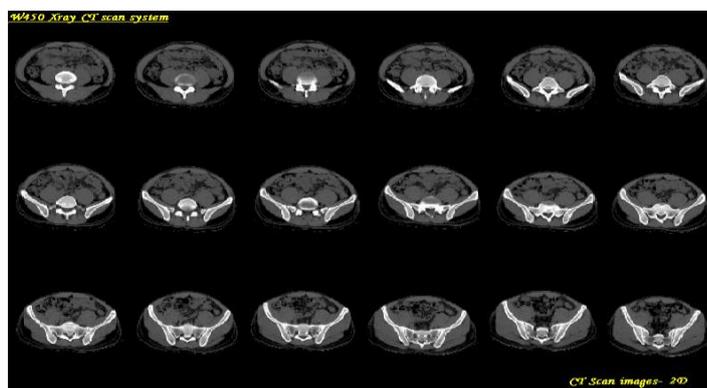


Figure.1.

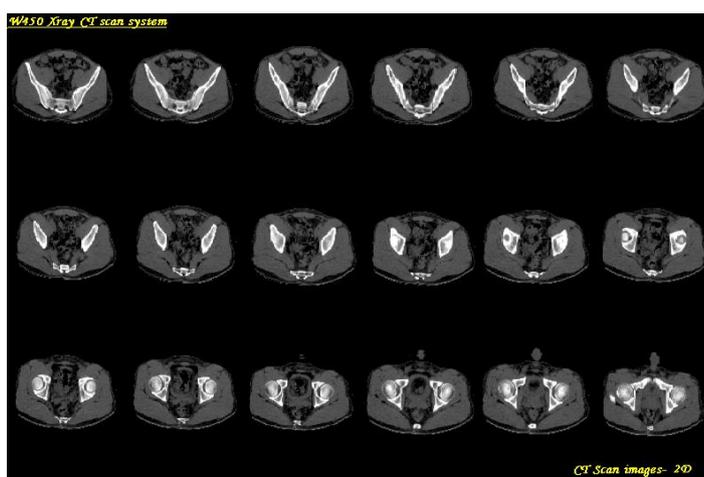


Figure.2.

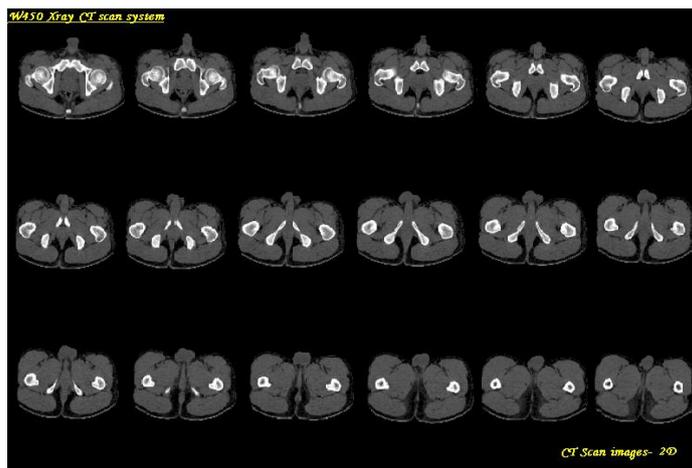


Figure.3

The various three dimensional images of the fractured pelvis of the patient named Thulasidass are shown in Figure.4a, Figure.4b.

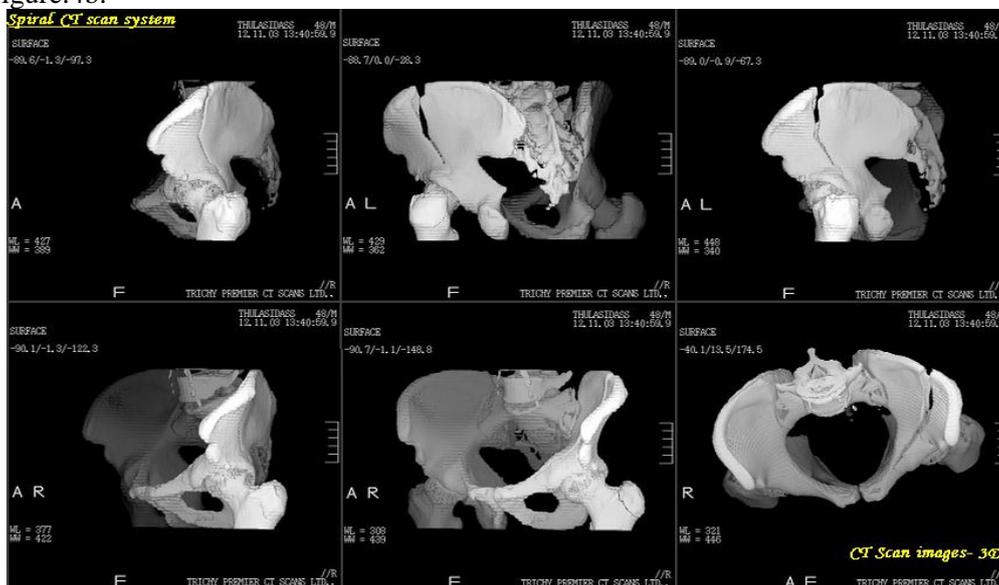


Figure.4a



Figure-4b

Generation of 3D model:

Compilation of CT scan images using MIMICS: The fifty four, two dimensional slices or cross sectional images of the patient are ordered in proper means. These images in JPEG file format are imported after stacking them in proper order. A range of segmentation tools allows selecting the region of interest especially the bone parts of the pelvis. Within a few clicks the part under consideration is transformed into a three dimensional virtual model on which a real time rotation, pan, zoom, transparency functions can be applied. The output of the Mimics software is STL (Standard Triangulation Language) file format. The virtual model with STL file format is imported in file conversion software Rapid form XOR2-Redesign to convert the file into DXF (Drawing Exchangeable File format).

The various views of the virtual modeling using MIMICS-9 are shown in the Figure.5a

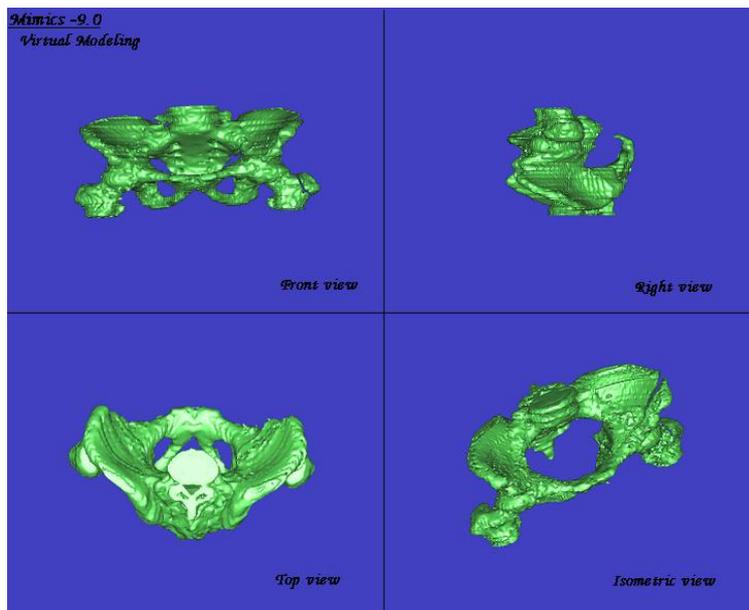


Figure.5a

In Figure.5b, the various views like coronal view, axial view, sagittal view and isometric view are shown. A-Anterior side; B- Bottom side; L- Left side; P-Posterior side;R-Right side

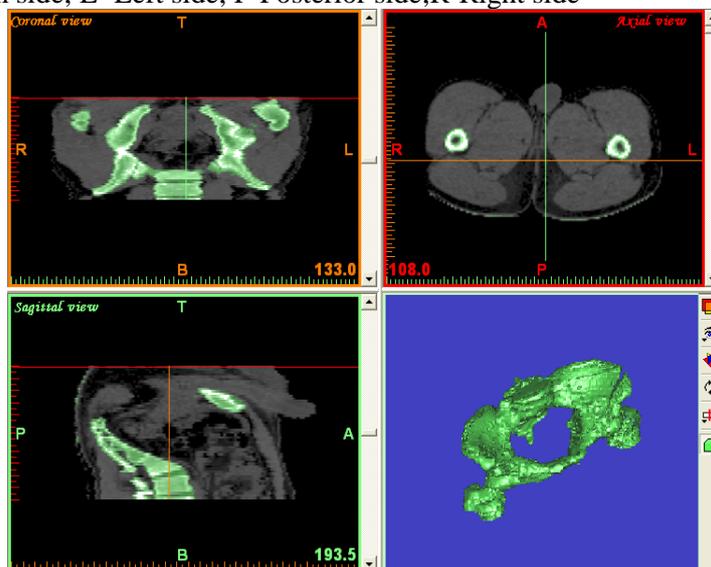


Figure.5b

Extracting Hip femur joint: The fractured pelvis with DXF file format is imported in Mechanical Desktop-6. It is made up of triangulated facets of wire meshes. In the pelvis, the part which is fractured is left end of the hip femur joint. Therefore, the right end of the hip femur joint is isolated from the other parts by just selecting and deleting the other parts. Then right end of the femur hip joint is mirrored to get left end of the femur hip joint. Since there is no parent-child relationship, the deletion of the right end of the hip femur joint can be done to get the required left end of the femur hip joint. The various views of the triangular meshed left end of hip femur joint of the fractured pelvis like front view, top view, side view and isometric view are shown in Figure.6.

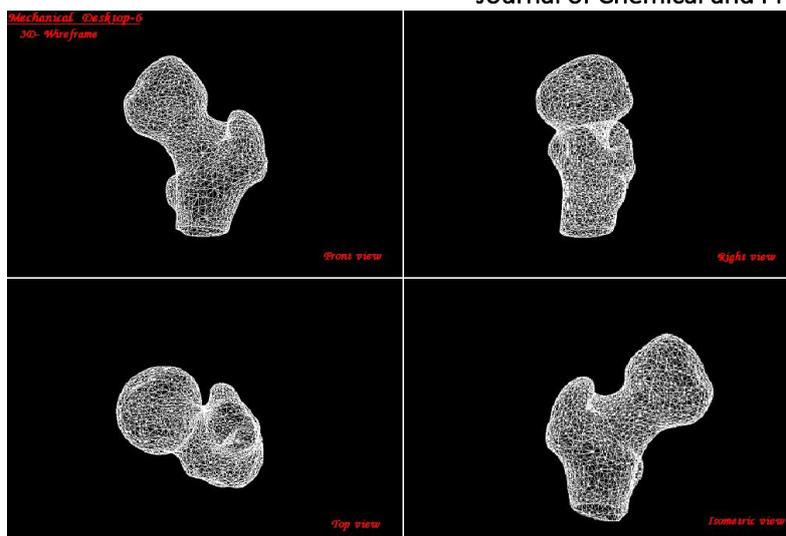


Figure.6.

Generating spline curves using MECHANICAL DESKTOP-6: After extracting the left end of the femur hip joint, the bone is cross sectioned at various sections using various work planes at various offset angles. At each work plane, the triangulated facets of the wire mesh are joined using splines to get the out sketch cross sectional profile. Then these out sketch cross sectional profiles are traced out with various geometries and the dimensioning is carried out using automatic dimensioning.

Modeling & Detailing using PRO/E WILDFIRE-2: The work planes in PRO/E WILDFIRE-2 are off seted at various angles as such the offset angles made in Mechanical Desktop-6. Then at each work plane, the curves for the left end of the femur hip joint are drawn at proper positions. Using these curves drawn at various planes, the protrusion (material addition) is carried out by sweeping through these curves using the option variable section sweep, to get the complete surface model of left end of the femur hip joint. Then in detailing module, the various views like front view, top view, and side view of the left end of the femur hip joint can be obtained. Then, surface to solid conversion of the model is carried out by just exporting the model of the left end of the femur hip joint in IGES (Initial Graphics Exchange Specification) file format.

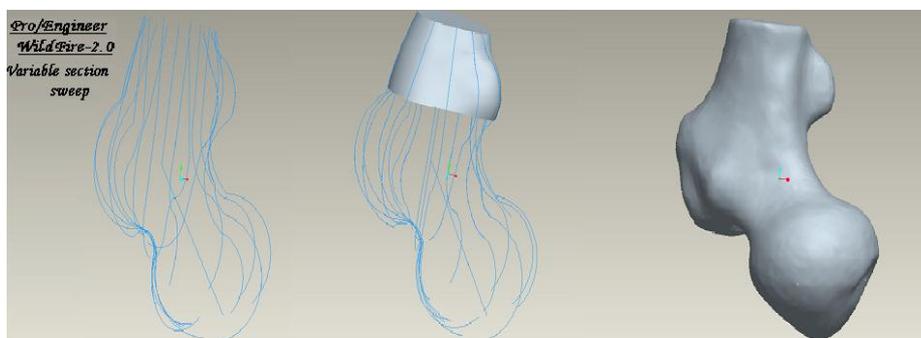


Figure.7.

The various stages of modeling of left end of femur hip joint, through the option of variable section sweep are shown in the Figure.7. The left end of femur hip joint of the fractured pelvis is modeled in PRO/E WILDFIRE-2 and the various views of the modeled left end of femur hip joint like front view, top view, side view and isometric view are shown in the Figure.8.

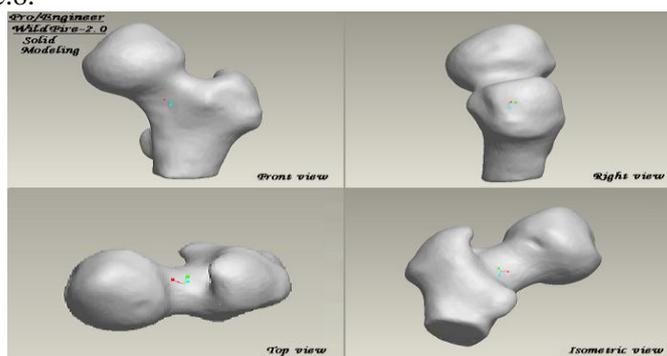


Figure.8.

The left end of femur hip joint of the fractured pelvis is detailed in PRO/E WILDFIRE-2 and the various views of the detailed left end of femur hip joint like front view, top view, side view and isometric view are shown in the Figure.9.

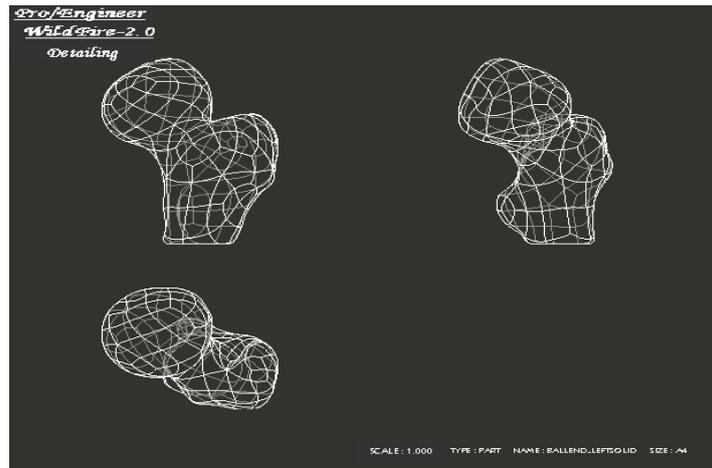


Figure.9

RESULTS & DISCUSSION

Analyzing the bone using ANSYS-10: The model of left end of the femur hip joint is analyzed by introducing Polycaprolactone (PCL). The analysis is started with preferences for Graphics User Interface to select a discipline type, structural and discipline option, h-method. Then in the preprocessor step, the element type is decided as 10 node 92 and material properties for this material model as isotropic, elastic, linear like young's modulus (30 MPa) and poisson ratio (0.05) are given. In the meshing step, the meshing is done with coarse mesh size 6 to mesh all the volume of the model. After giving loads, and constraints, the model is solved (41,133 equations) with the given loads and constraints to get the various stress distributions along with deformation. By trial and error, it is known that 0.5 MPa is the max pressure should be given, to prevent from its failure. The left end of the femur hip joint is analyzed using ANSYS-10 and the nodal solution for the given pressure of 0.5 MPa is shown as contour plot in the Figure-10.

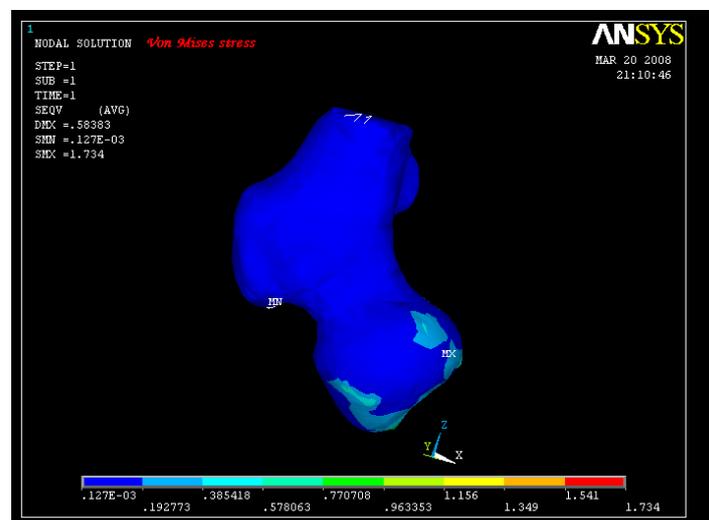


Figure.10

Theories of failure:

1. **Maximum stress theory (Rankine theory):** S_1 or S_2 or S_3 (whichever is maximum) $\leq S_y$
2. **Maximum shear theory (Guest's or Coulomb's theory):** $(S_1 - S_2)$ or $(S_2 - S_3)$ or $(S_3 - S_1)$ (whichever is maximum) $\leq S_y$
3. **Maximum strain theory (St.Venant's theory):** $S_1 - p(S_2 + S_3)$ or $S_2 - p(S_3 + S_1)$ or $S_3 - p(S_1 + S_2)$ (whichever is maximum) $\leq S_y$
4. **Maximum strain energy theory:** $S_1^2 + S_2^2 + S_3^2 - 2p(S_1 S_2 + S_2 S_3 + S_3 S_1) \leq S_y^2$
5. **Octahedral or Distortion energy theory (Von-Mises Hencky's theory):** $S_1^2 + S_2^2 + S_3^2 - (S_1 S_2 + S_2 S_3 + S_3 S_1) \leq S_y^2$

Substituting all the results of the analysis in the above theories of equations, the obtained results should be less than or equal to the yield strength of the material.

For Femur hip joint:

First principal stress, $S_1 = 1.9370$ MPa

Second principal stress, $S_2 = 0.37786$ MPa

Third principal stress, $S_3 = 0.069753$ MPa

Von-Mises stress, $S_{von} = 1.734$ MPa

Checking for failure of Femur hip joint using theories of failure:

1. Maximum stress theory (Rankine theory):

$$S_1 = 1.9370 \text{ MPa} = S_{max}$$

$$S_2 = 0.37786 \text{ MPa}$$

$$S_3 = 0.069753 \text{ MPa}$$

$$S_{max} = 1.9370 \text{ MPa} \leq 2.3 \text{ MPa}$$

2. Maximum shear theory (Guest's or Coulomb's theory):

$$S_1 - S_2 = 1.56014 \text{ MPa} = S_{max}$$

$$S_2 - S_3 = -0.30847 \text{ MPa}$$

$$S_3 - S_1 = -1.86692 \text{ MPa}$$

$$S_{max} = 1.56014 \text{ MPa} \leq 2.3 \text{ MPa}$$

3. Maximum strain theory (St. Venant's theory):

$$S_1 - p(S_2 + S_3) = 1.821257 \text{ MPa} = S_{max}$$

$$S_2 - p(S_3 + S_1) = -0.35548 \text{ MPa}$$

$$S_3 - p(S_1 + S_2) = -0.03058 \text{ MPa}$$

$$S_{max} = 1.821257 \text{ MPa} \leq 2.3 \text{ MPa}$$

4. Maximum strain energy theory:

$$S_1 * S_1 + S_2 * S_2 + S_3 * S_3 - 2p(S_1 * S_2 + S_2 * S_3 + S_3 * S_1) = 3.8103 \text{ MPa} \leq 5.29 \text{ MPa}$$

5. Octahedral or Distortion energy theory (Von-Mises Hencky's theory):

$$S_1 * S_1 + S_2 * S_2 + S_3 * S_3 - (S_1 * S_2 + S_2 * S_3 + S_3 * S_1) = 3.00623 \text{ MPa} \leq 5.29 \text{ MPa}$$

Substituting all the results of the analysis in the above theories of equations, the obtained results are less than or equal to the yield strength of the material at the given pressure of 0.5 MPa.

CONCLUSION

The different structures of cortical bone and trabecular bone result in different mechanical properties. Bone mechanical properties are highly variable according to species, age, anatomical site, liquid content, etc.

| Property | Age (years) | | | | | | |
|-------------------------|-------------|---------|---------|---------|---------|---------|---------|
| | 10 - 20 | 20 - 30 | 30 - 40 | 40 - 50 | 50 - 60 | 60 - 70 | 70 - 80 |
| Ultimate strength (MPa) | | | | | | | |
| Tension | 114 | 123 | 120 | 112 | 93 | 86 | 86 |
| Compression | - | 167 | 167 | 161 | 155 | 145 | - |
| Bending | 151 | 173 | 173 | 162 | 154 | 139 | 139 |
| Torsion | - | 57 | 57 | 52 | 52 | 49 | 49 |
| Ultimate strain (%) | | | | | | | |
| Tension | 1.5 | 1.4 | 1.4 | 1.3 | 1.3 | 1.3 | 1.3 |
| Compression | - | 1.9 | 1.8 | 1.8 | 1.8 | 1.8 | - |
| Torsion | - | 2.8 | 2.8 | 2.5 | 2.5 | 2.7 | 2.7 |

Ultimate strength (MPa) and ultimate strain (%) of cortical bone from the human femur as a function of age. Biomimetic materials are not made by living organisms but have compositions and properties similar to those made by living organisms. The calcium hydroxyapatite coating found on many artificial hips is used as a bone replacement that allows for easier attachment of the implant to the living bone. Surface functionalization may provide a way to transform a bio-inert material into a biomimetic or even bioactive material by coupling of protein layers to the surface, or coating the surface with self-assembling peptide scaffolds to lend bioactivity and/or cell attachment 3-D matrix. Different approaches to functionalization of biomaterials exist. Plasma processing has been successfully applied to chemically inert materials like polymers or silicon to graft various functional groups to the surface of the implant. Polyanhydrides are polymers successfully used as drug delivery materials.

The computer modeling concept integrates the surgeon, implant design engineer together. Therefore studying the issues and abnormal conditions in the bone are clearly seen. This analysis is used to identify the sources of possible errors for using Polycaprolactone. Now it is possible for a surgeon to carry a rehearsal on the bone models of the patient and plan for surgery with reduced risk of the patient by using RP methods. The accuracy of bone models helps surgeons to rehearse the re-alignment of bones or fitting of implants on the RP model prior to the operating procedure. The analysis helps in validating the selected bio compatible material's suitability in the specific

application. This concept of CT images to CAD model followed with analysis helps to identify abnormal issues and planning surgical implants effectively.

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