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Computational Fluid Dynamic Analysis and Mechanical Strength Evaluation of Additive Manufactured Customized Bone Scaffolds

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Abstract - *The effectiveness of fabricated bone scaffolds to mimic exact bone tissue can be evaluated based on the mechanical strength and fluid dynamic behaviour. The mechanical properties of the scaffolds is analysed through static structural analysis and fluid behaviour is analysed through fluent analysis. Paper presents the manufacturing of the customized porous bone scaffold and its compressive property evaluation employing FEM. Additive manufacturing processes manufacture end-use elements from CAD models by supplemental material layer by layer. The fluid dynamic characteristics in a porous scaffold plays a vital role for cell viability and tissue generation. To overcome the constraints of those typical techniques, automatic computer-controlled fabrication techniques, like Additive manufacturing (AM), are being explored. Pre-production stage Finite element analysis (FEA) was carried out on designed cobalt chrome scaffold for evaluating the mechanical properties .The failure of implant is maximum by wearing, corrosion and improper material selection. Fluent analysis is carried out to determine the fluid behaviour of the implant scaffolds in the environment of synovial fluid. From the results of analysis of static loading condition and material comparison, the implant can left in the human body for a long term*

***Key Words*: Scaffold, Finite element analysis, Additive manufacturing**

1. INTRODUCTION

Various types of metallic implants have been used in the form of screws, bone plates and compression plates to achieve rigid internal fixation in our body. Various factors are to be taken into consideration while selecting an implant material. These include physical and chemical properties, the nature of host tissue, the interface reaction between the bone and implant, cost effectiveness, availability, and choice of the operator. Two different types of bio materials are commonly used in clinical practice, namely titanium and stainless steel. The titanium bone plates are imported from different countries. These bone plates are not only expensive but also require complicated instrument system. At present the stainless steel bone plates are manufactured indigenously. These bone plates are not only economical but also easily available.

Design of scaffolds

For this study structural can developed by CAD software, the design data exported to fabrication through SLM technology. In this study a twisted design of crossing struts had treated. Two different designs in varying dimensional parameters in width (a), depth (b) and height (c) strut diameter (d) are used and the designed properties of the structural composition are investigated.

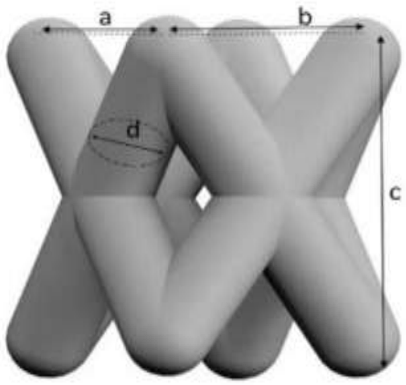

Fig 1.1.1 : twisted design of crossing struts

Fig 1.1.2Crossectional strut strcuture

2. Analysis

Static structural analysis

Static structural analysis is used to find out the stresses and deformations in bone scaffolds when force applied on it. Three dimensional cobalt chrome model is performed in solid modeling software, The model exported by ANSYS and subdivided into nodes and elements. Collection of elements is called mesh and it is make mesh optimization to getmore accuracy results Materials used for static structural analysis

1 Titanium

2 Cobalt chromium

Properties of titanium

Table 2.1.1

Materials	Density	Young,s modulus	Poisson,s ratio
Titanium	4430	895	.342

Procedure for static structural analysis

The 3d model of bone scaffold is prepared with different orientations and angles in ANSYS modelling software. From the ANSYS main window select static structural analysis option. Then set the unit in software as standard unit .Assign the material as cobalt chromium from the engineering data option in the static structure window and add the properties corresponding to the material select the model option from the static structural window .Then mesh the model in accurate relevance and divide it into nodes and elements. Collection of elements is called mesh and it is make mesh optimization to getmore accuracy results. Mesh optimization is occurred until the FEA results and analytical solutions are similar to each other. After meshing applying boundary conditions from the setup option in the static structural window corresponding to the scaffolds .Boundary conditions are the limits upon which a material can gone. After the determination of mesh model, apply boundary conditions, initial conditions, and load stress are applied on the designed model. The scaffold and intact bone segment was analysed using ANSYS. The maximum stress and displacement of scaffold were studied. . Scaffold bottom plate side is fixed and the upper side scaffold with pressure plate is applied on the 1000 N force on upper plate surface. Fix the direction downwards. Select the solution option from the static structural window tree and select the required parameters such as total deformation and equivalent stress. Click the solve option from the window, and all the tabulated results were displayed on the window.

Results after analysis of titanium scaffolds

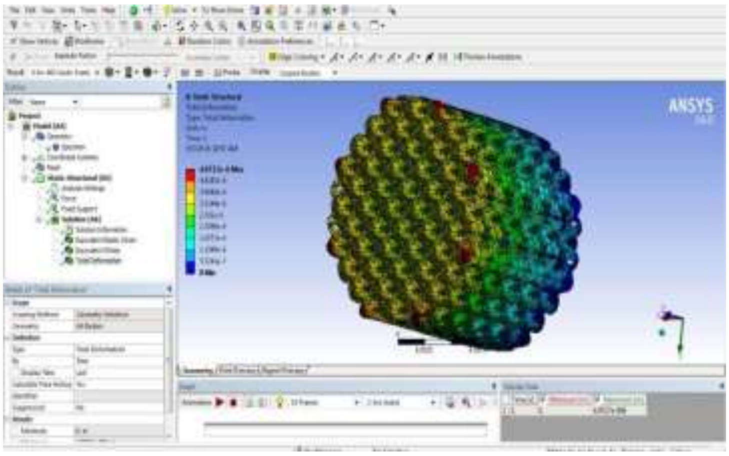

Fig 2.1.1 Total deformation

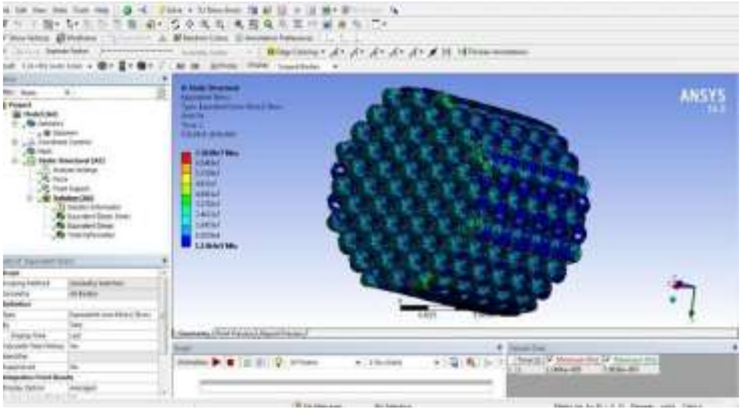

Fig 2.1.2 Equivalent stress

Properties of cobalt chromium

Table 2.1.2

Material	Density	Young,s modulus	Poisson,s ratio
Cobalt chromium	1010	220	.29

rocedure

Three dimensional cobalt chrome model is performed in solid modeling software, The model exported by ANSYS and subdivided into nodes and elements. Collection of elements is called mesh and it is make mesh optimization to get more accuracy results. Mesh optimization is occurred until the FEA results and analytical solutions are similar to each other. After the determination of mesh model, apply boundary conditions, initial conditions, and load stress are applied on the designed model. Scaffold bottom plate (A) side is fixed and the upper side scaffold with pressure plate is applied on the 1000 N force on upper plate surface. Then FEA analysis of six models is performed and results are compared with the each other. It is aimed to determine the total von-mises stress and the elongation

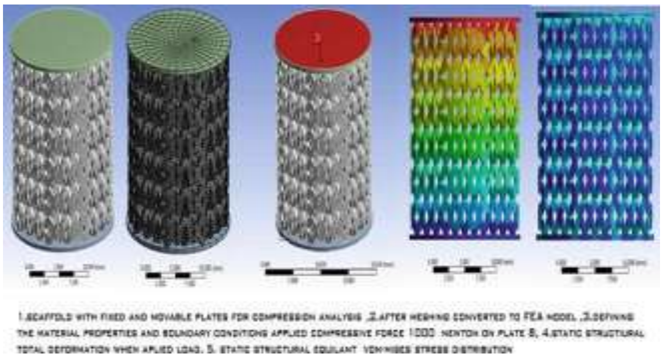

Fig 2.1.3 Results after analysis of cobalt chromium

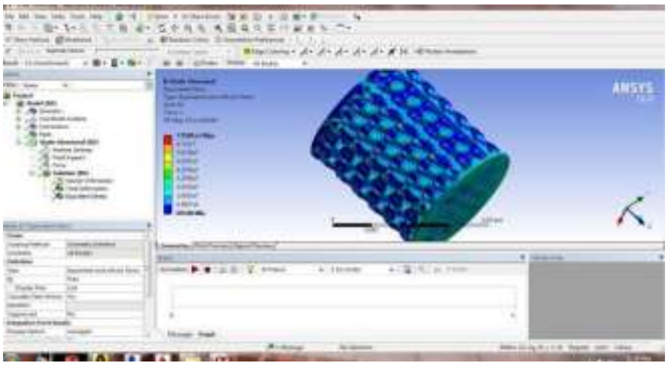

Fig 2.1.5 Equivalent stress

Fluent analysis of scaffolds structure

Computational Fluid Dynamics (CFD) is the science of predicting fluid flow, heat and mass transfer, chemical reactions, and related phenomena by solving numerically the set of go-verning mathematical equations

– Conservation of mass
– Conservation of momentum
– Conservation of energy
– Conservation of species
– Effects of body forces

CFD analysis complements testing and experimentation by reducing total Acquisition effort and cost required for experimentation and data acquisition. ANSYS CFD solvers are based on the finite volume method Domainis discretised into a finite set of control volumes In order to study the fluid behaviour of scaffold structure ,fluent analysis should be carried out Because of complex structure of bone scaffold ,it is very difficult to mesh So removing the unnecessary structures in geometry that would complicate the structure For the application of boundary conditions or domains we need to split the model Define the material properties and prescribe the operating conditions .

Provide the initial values of operating conditions such as
1 - synovial fluid pressure(0 to 5mmHg)
2-normal body temperature of human(98.6 farenheat)
3- normal mass flow rate of fluid through

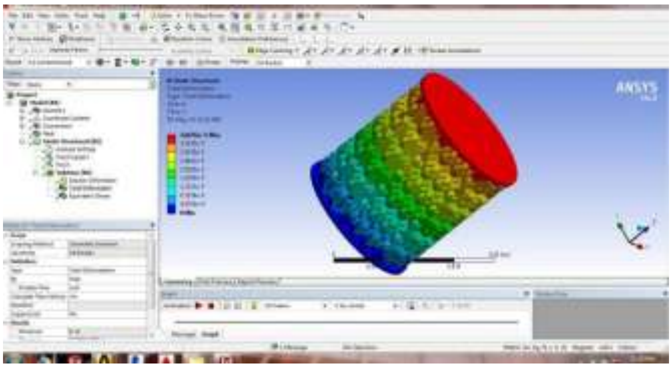

Fig 2.1.4 Total deformation

Pores Compute the solution The meshed conservation equations are solved iteratively until converges . Display the contours of static pressure and velocity variation inside the porous scaffold structure. Computational fluid dynamics (CFDs) has been applied to simulate the microfluid dynamics through interconnected pores. However, the same flow rate through different pore architectures of scaffolds can bring about different wall shear stress (WSS) on the cells. The scaffold architecture also determines the level of fluid shear stress to which the cells are exposed to as a result of perfusion flow.

Procedure for fluent analysis

In order to study the fluid behaviour of scaffold structure ,fluent analysis should be carried out .Select the geometry option from the main window Because of complex structure of bone scaffold ,it is very difficult to mesh So removing the unnecessary structures in geometry that would complicate the structure .For the application of boundary conditions or domains we need to split the model cut the model into symmetry structure to reduce the complexity of the scaffolds structure .In order to get the fluid path ways we need to remove the entire solid structure we only need the outline shape of the structure.. Enclose the whole structure to a cylinder shape. Scaffold is named as inlet, outlet, body, symmetry in co ordinate geometry option. Then mesh the model to relevant size. Select the fluent flow option from the main tree. Import the meshed file to fluent main window. Then check the mesh. Enable energy equation from the model option from the tree.. Check the given initial parameters. Take the material option from the side tree and edit it as fluid. Add fluid properties such as density, specific heat thermal conductivity, viscosity. Then select cell zone conditions and edit operating conditions and set the initial pressure. Selecting boundry conditions from the tree and select inlet option from there apply momentum and thermal conditions. Then select the solution methods, change the scheme from simple to coupled. Select hybrid initialization from the solution initialization and click initialize. Then check the case. Set the number of iterations as 1000.Click the calculate icon to compute the results and display the results by clicking graphics and animations option .from the fluent analysis results we get the streamline velocity variation of different scaffolds structure and contours of pressure variation when synovial fluid flows through it.

Results after fluent analysis of porous scaffolds

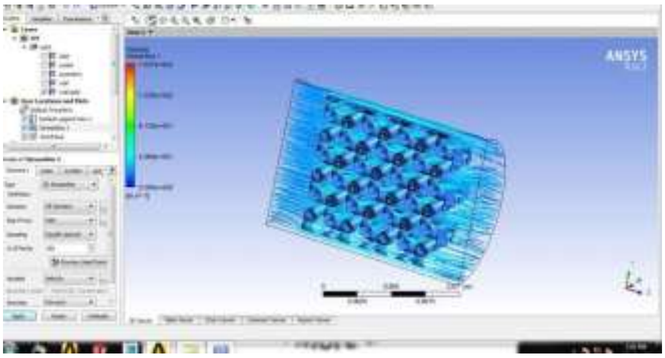

Fig 2.2.1 Stream line velocity variation

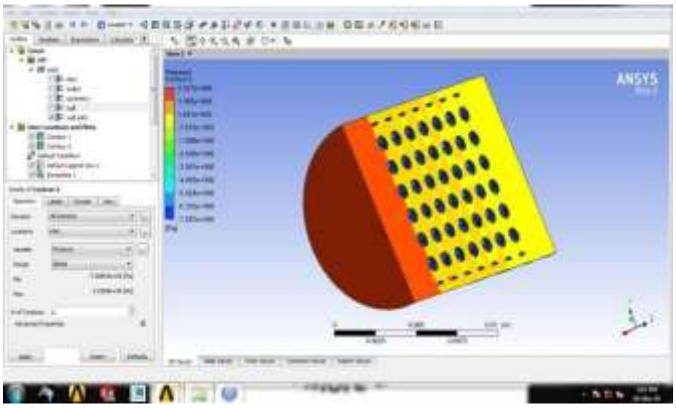

Fig 2.2.2 Pressure contour variation

3. RESULTS AND DISCUSSION

Table 3.1 Static structural results of titanium

Model	Structure1	Structure2	Structure3	Structure4	Structure5
Max deformation in mm	.0044192	.0114042	.030012	.14764	.031152
MAX equivalent von-mises stress in MPa	65.469	130.54	528.35	427.15	335.19

Table 3.2 Static structural results of cobalt chromium

Model	Structure1	Structure2	Structure3	Structure4	Structure5
Max deformation in mm	.03692	.093846	.12019	.15981	.2746
MAX equivalent von-mises stress in MPa	75.501	427.14	256.2	429.47	171.35

Static structural results

Analysis results are classified according to the different pore sized scaffold models. Structural analysis of 2 different materials were performed TI and COBALT-CHROMIUM Compare the results of 2 materials with each other by taking equivalent stress and deformation. Among them cobalt- chromium shows less deformation and better bio- compatibility characteristics. From the results obtained by comparing the static structural analysis the equivalent stress produced in the pores of scaffold model plays an important role in selection of material for the material for the scaffolds. During the action of sudden pressure on the scaffolds the maximum equivalent stress will determine how long an implant scaffold can sustain in our human body

Fluent analysis results

From the fluent analysis results we get the streamline velocity variation of different scaffolds structure and contours of pressure variation when synovial fluid flows through it. The scaffolds structures shows variations that are similar to exact bone will remain in our body for a long term. The existence of human bone in our body in presence of synovial fluid has some standard conditional parameters. The made up scaffolds should exhibit or mimics characteristics of normal human bone in our body

3. CONCLUSION

From the static structural analysis. Metallic material of cobalt chromium found to have low deformation when load acts on the scaffolds structure . Besides good biocompatibility and non allergic tissue response, cobalt chrome has an elastic modulus lesser than of that of titanium.In order to investigate the alternative materials for human Orthopedic Implants which is Bio-Compatible. Cobalt chromium implants are expected to be Bio-Compatible & they should not cause inflammation or rejection. Since Ti material cost more,and have low biocompatibility with synovial fluid.

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