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Design and Analysis of Artificial Heart Model by Using Finite Element Analysis

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Abstract

The human heart is a cardiac muscular organ which pumps blood through blood vessels to various tissues and organs for their function and also carries oxygen and other nutrients to tissues. The heart geometry is very complex and function of heart also plays major role in all kinds of animals for survival and carryout all kinds of functions. Investigating the biomechanical behaviour of a soft artificial heart model is a hard task as such things are very complicated in terms of both material properties and geometry. This work is focused on modelling of soft material heart model and study of static and dynamic behaviour with easily operable, full-size. Theatrical heart model was designed using Creo Parametric 5.0 software. The developed model was further analyzed by the boundary condition such as Total Deformation, Principal stress, Maximum principle stresses and Elastic strain for five different case studies for various pressures at ventricle chamber and Expansion Chamber. The developed model can be used for further numerical simulation and investigation of the artificial heart were implemented using Creo Parametric 5.0 and ANSYS, with different Bio-Compatible materials such as Silicon Elastomers, Teflon (PTFE), Polyethylene, Graphene, Carbon fiber. The biomechanical modelling and analysis of the soft artificial heart were implemented using the finite element modelling in ANSYS.

Keywords: *Artificial Heart model, Soft artificial heart, Creo Parametric 5.0, ANSYS, Static and Dynamic Analysis, Silicon Elastomers, Teflon (PTFE), Polyethylene, Graphene and Carbon Fiber.*

1.0 Introduction

The human heart is a muscular cardiac organ that pumps blood through blood vessels to various tissues and organs for their functions, as well as carrying oxygen and other nutrients to tissues. The heart geometry is extremely complicated, and the heart's function is critical for all species' survival and ability to perform a variety of tasks. Investigating the biomechanical behaviour of a soft artificial heart model is a difficult endeavour since the material properties and shape are so complex.

The goal of this project is to construct a soft material heart model and analyze static behaviour with a full-size, easily operable model. Catia V5 modelling software was used to create the artificial heart model. For five separate case studies at varied pressures in the ventricle chamber and expansion chamber, the created model was further examined using boundary conditions such as Total Deformation, Principal Stress, Maximum Principle Stresses, and Elastic Strain. The generated model can be utilized for further numerical simulation and analysis of the artificial heart using different Bio-Compatible materials such as Silicon Elastomers, Teflon (PTFE), Polyethylene, Graphene, and Carbon fiber utilizing Catia V5 and ANSYS. The soft artificial heart's biomechanical modelling and analysis were done in ANSYS utilizing finite element modelling.

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The human heart beats 75 times per minute, 100,000 times per day, 30 million times per year, and 2.5 billion times over the course of a lifetime. It is thus capable of pumping 70ml per contraction, 7,000 liters per day, or 2.5 million liters per year, and 200 million liters throughout the course of a person's life. The average human body has a total blood volume of 5 to 6.5 liters. As a result of this constant blood circulation within the human body, the cardiovascular system is a complicated structure, and cardiovascular disease, which includes heart failure, is the leading cause of death globally.

According to the World Health Organization (WHO), around 300 million people worldwide suffer from some type of cardiovascular disease, and approximately one million people die each year as a result of cardiovascular disease. About 50 million people in India suffer from various types of cardiovascular disorders. Cardiogenic shock, congenital heart disease, infection, and myocardial infarction are among these. The human heart is a muscular organ that circulates blood throughout the body. The left and right atria (receiving chambers), as well as the left and right ventricles, make up the heart (the pumping chambers). Blood from the left ventricle (left heart) travels through the body via the aorta, whereas blood from the right ventricle (right heart) travels to the lungs via the pulmonary artery.

The heart works as a pump in the circulatory system, ensuring that blood flows freely throughout the body. The systemic circulation to and from the body, as well as the pulmonary circulation to and from the lungs, make up this circulation. Through the act of breathing, blood in the pulmonary circulation exchanges carbon dioxide for oxygen in the lungs. The systemic circulation then delivers oxygen to the body while returning carbon dioxide and deoxygenated blood to the heart for delivery to the lungs.

The pulmonary veins return oxygenated blood to the left atrium in the left heart. It is then pushed through the mitral

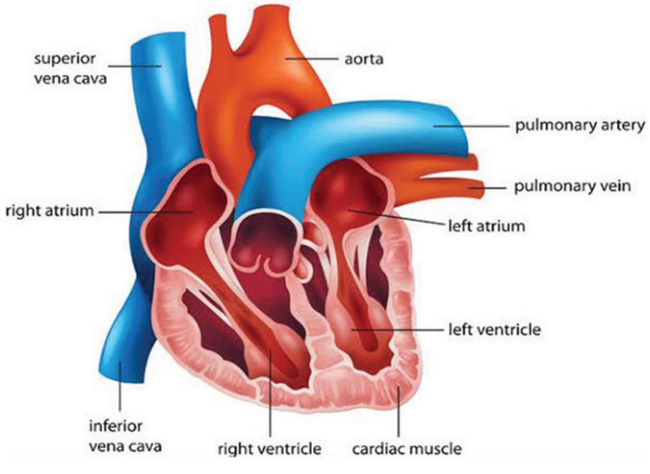

Figure 1: Anatomic Model of The Human Heart

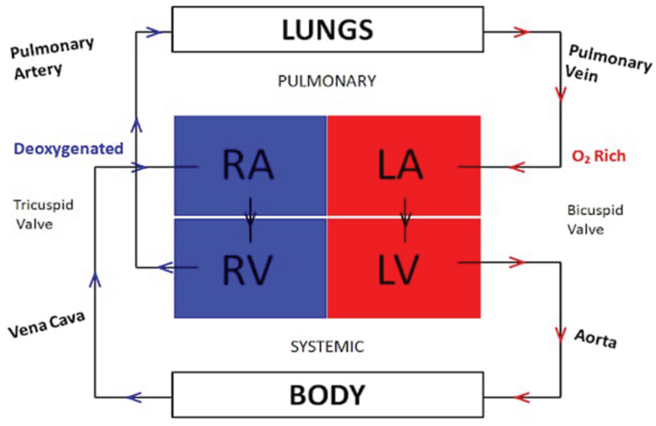

Figure 2: Block Diagram of Heart

valve into the left ventricle and the aortic valve into the aorta for systemic circulation. The aorta is a big artery that divides into several smaller arteries, arterioles, and capillaries. Oxygen and nutrients from the blood are delivered to body cells via capillaries, where they are exchanged for carbon dioxide and waste products. Deoxygenated capillary blood moves into venules and veins, eventually collecting in the superior and inner vena cava, as well as the right heart.

2. Objectives

The main objectives of present works are:

- Modelling of soft Artificial Human Heart model using CATIA V5.
- Meshing and Static Analysis of designed Artificial Heart model using ANSYS.
- Clinical use for studies in medical science.
- Experimental use for studies in the field of circulatory physiology using the analysis results.
- For Manufacturing Prototype of Total Artificial Heart using bio compatible material as a permanent replacement.

3.0 Material and Methodology

The initial stage in modelling a soft artificial heart is to obtain modelling dimensions from a plastic replica of an adult heart, with the assumption that the model is isotropic and homogeneous. The soft artificial heart model's shape, sketch, measurements, and numerous viewpoints. The soft artificial heart is not intended to serve as a bridge to a new heart; rather, it is intended for use as a true heart replacement, with few side effects, unlike hard material total artificial heart implants, which can cause blood clots as the immune system becomes hostile to the foreign object. Metal and plastic devices can be difficult to integrate with tissue, and their abnormal movements can harm the blood, which includes careful modelling of Artificial Heart in solid works. 3D modelling software can be used to predict correct meshing utilizing element sizes of 1mm, 2mm, 5mm, and 10mm, and then a mesh convergence criteria can be determined. Then, after comprehensive meshing, the required restrictions are applied at required points, and the two to three bio materials with appropriate material qualities are assigned to the Total Artificial Heart. Then perform a structural analysis to determine the maximum stress position, maximum and minimum deformation positions, Von Misses stress, internal stress distribution, and unidirectional stresses of the model for various biomaterials.

Design tool used

CATIA stands for Computer Aided Three-Dimensional Interactive Application. It is much more than a CAD (Computer Aided Design) software package. It is a full software suit which incorporates CAD, CAE and CAM.

Analysis tool used

- After the modelling in CATIA V5 software it can be further transfer to Ansys Work bench for static and dynamic analysis.
- In Ansys Work bench initially assigns the materials and later it can be thoroughly meshed by giving proper element size like 1mm, 2mm, 5mm, 10mm etc.
- Based on the complexity of the model and also importance of required output data for the application
- Then by applying suitable boundary conditions we have to analyse the total deformation, Material strength, Stress, Strain, fatigue load, Pressure handled contour area of the designed surface.

For thorough Static Analysis there is need for boundary Conditions Such as:

- Pressure Flow
- Contracting and Expansion pressure
- Effect of Gravity or self-weight
- Fatigue load

Material properties

In this project for analysing we choose five different materials with different grades of polymer materials. For each pressure variables of three different case we have to choose the individual material

4.0 Results and Discussion

The artificial heart model's geometry, sketch, dimensions, and various view points are displayed here.

The artificial heart model is designed with dimensions of 100 mm*110 mm *90 mm, it can be modelled using boundary surface method and having entire 7mm wall thickness. Inside the wall there are two ventricle chamber are maintained one is left ventricle chamber and similarly one right ventricle chamber and also similarly surrounding of ventricle chamber the expansion chamber is designed

To Design the Artificial Heart will be having three chambers as shown in the figure,

Chamber 1: compressed air chamber

Chamber 2: Right ventricle

Chamber 3: Left ventricle

Approximate operating pressure in the chamber 1 is 250 KPa,

Approximate operating pressure in ventricles i.e. chamber 2 and chamber 3 is 50 KPa,

The wall thickness is maintained all round 7mm.

The figures below represents the various valves

Table 1: Material Properties

	Properties	Polyethylene	Teflon	Carbon Fiber	Graphene	Silicon
1	Density	940kg/	2175 kg/	2270 kg/	1100 kg/	2000 kg/
2	Poisonous ratio	0.3	0.46	0.2	0.33	0.10
3	Youngs modulus	1000 GPa	575 MPa	1000 GPa	0.05 GPa	500 GPa
4	Tensile yield strength	20 MPa	20 MPa	130000 MPa	40 MPa	2500 MPa
5	Tensile ultimate strength	30 MPa	30.5 MPa	N/A	55 MPa	4000 MPa
6	Brinell Hardness	40 BHN	N/A	N/A	N/A	N/A
7	Tharmal conductivity	0.5 w/mk	N/A	N/A	N/A	100 w/mk
8	Shear strength	N/A	5 Mpa	N/A	6.05 MPa	N/A
9	Compressive yield strength	N/A	12.5MPa	N/A	N/A	N/A

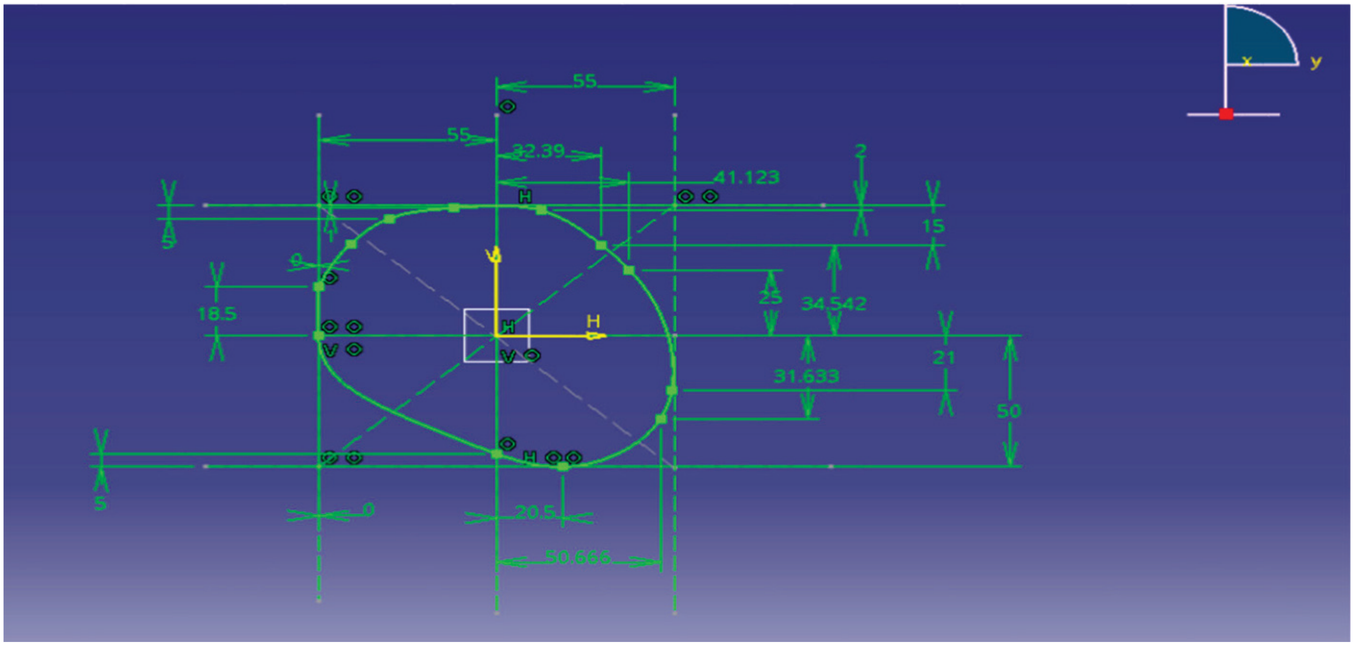

Figure 3: Sketch of Heart With Dimensions

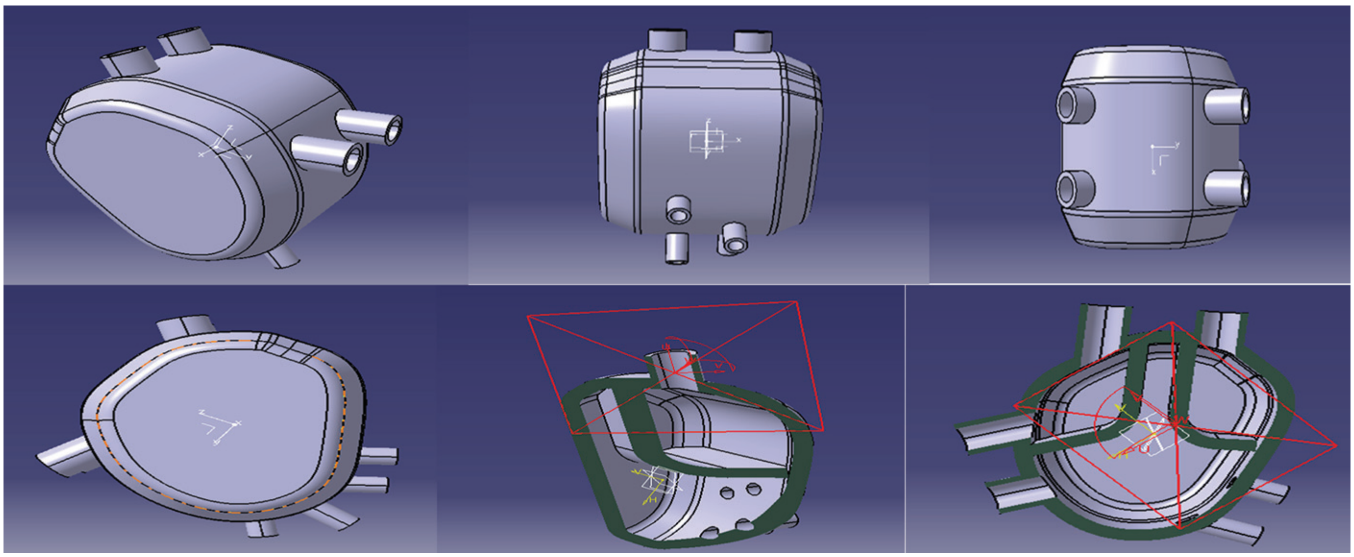

Figure 4: Various Views of Artificial Heart Model

(a) Shows Aortic valve and pipe connects to Aorta i.e. oxygenised blood pump to the body.

(b) Shows Pulmonary valve and pipe connects pulmonary artery, i.e. blood contains carbon dioxide pumps to pulmonary veins(lungs).

(c) Shows Tricuspid Valve and tube connects to vena cava, through this blood with carbon dioxide enters into heart

(d) Shows Mitral valve and tube connects pulmonary veins. i.e. Blood enters ventricle from lungs.

Figure 6 shows the inlet and outlet of compressed air respectively

The Inlet (1 & 4) and Outlet (2 & 3) valve of compressed air respectively, the compressed air is responsible for actuation of the ventricle chamber walls. The maximum operating air pressure inside the chamber which helps

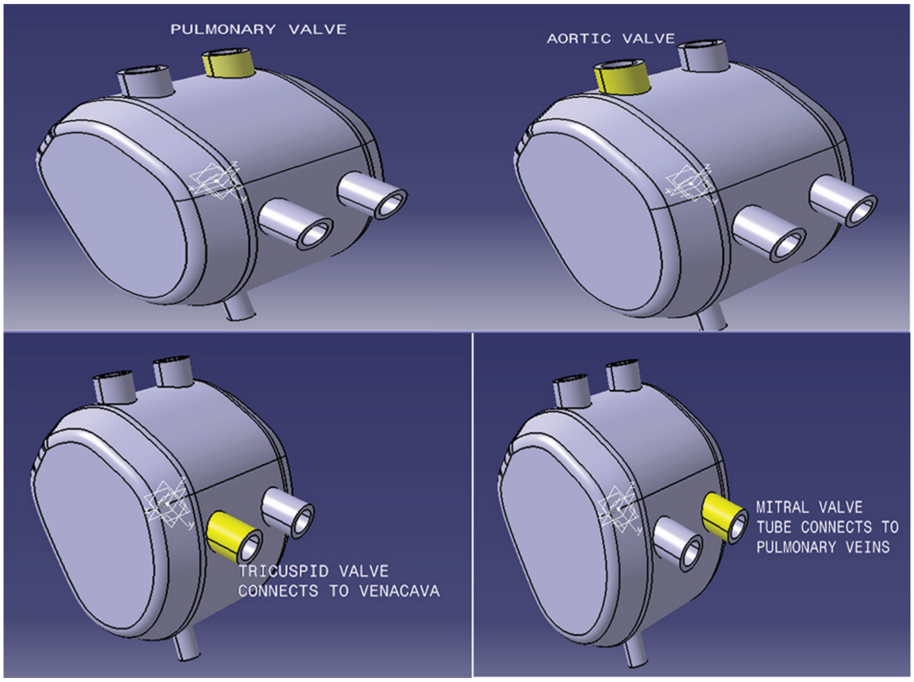

Figure 5: Valves of Artificial Heart

ventricle wall to push the blood which entered into ventricles is approximately 250 kilo pascals. When pressure raised to maximum compression of ventricle wall takes places i.e. push the wall forward, when pressure reduced ventricle walls comes back to original position.

The compressed air supplied to the chamber from externally mounted pump, and pump operated by electric motor together mounted along with pump. power supply to motor and pump is from battery which is rechargeable.

Meshing of the Artificial Heart Model

In Finite Element Analysis (FEA) the goal is to simulate some physical phenomena using a numerical technique called the Finite Element Method (FEM). To quantify the results of solutions the meshing role is very important so here the meshing is done with tetrahedral method with fine meshing and the size of the element is 1mm. For complex geometry meshing the tetrahedron method of meshing gives more precise values as compared to Hexa-method.

Boundary Condition

The artificial heart model was constrained with fixed support all circular veins like structure such as Aorta, Pulmonary Vein, Tricuspid valve outlet, Mitral valve outlet and all Gas Exchange Veins. Because we can fix these round circular objects with fixed rigid supports to the body.

Again varying the pressure for different conditions of activities like during the normal walking, jogging, running and other activities.

The static analysis of Total Deformation, Equivalent elastic strain, Minimum principal stress, Strain energy, Equivalent stress for different cases of varying pressures on ventricle chambers as 0.2 MPa, 0.3 MPa, and 0.4 MPa. Similarly 0.3 MPa, 0.5 MPa and 0.7 MPa on expansion chambers. Here the fixed supports are Aortic Vein, Pulmonary vein, Tricuspid valve Mitral Valve and also Gaseous Exchange veins with rigid support.

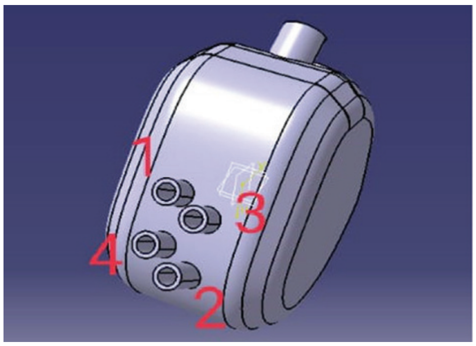

Figure 6: Various Compressed Air Inlet and Outlet

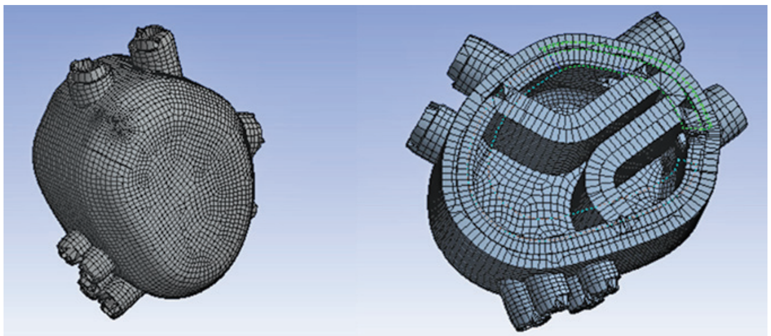

Figure 7: Meshing of Artificial Heart

Table 2: Output Results of Static Analysis of Total Deformation

Types of cases	Pressure in MPa	Silicon	Polyethynene	Graphene	Teflon (PTFE)	Carbon Fiber
Case 1	0.2 0.3	11.272mm	575.93mm	0.0006066mm	0.8361mm	0.00124mm
Case 2	0.3 0.5	22.376mm	1143.3mm	0.00120mm	1.66mm	0.00247mm
Case 3	0.4 0.7	33.482mm	1710.7mm	0.00180mm	2.1839mm	0.00370mm

Table 3: Output Results of Minimum Principal Stress

Types of cases	Pressure in MPa	Silicon	Polyethynene	Graphene	Teflon (PTFE)	Carbon Fiber
Case 1	0.2 0.3	1.6029MPa	1.569MPa	1.387MPa	2.042MPa	1.1755MPa
Case 2	0.3 0.5	3.022MPa	2.853MPa	2.363MPa	3.366MPa	2.0246MPa
Case 3	0.4 0.7	4.4406MPa	4.105MPa	30338MPa	4.964MPa	2.890MPa

Table 4: Output Results Equivalent Elastic Strain

Types of cases	Pressure in MPa	Silicon	Polyethynene	Graphene	Teflon (PTFE)	Carbon Fiber
Case 1	0.2 0.3	0.1035	5.1706	5.1187×10^{-6}	0.00942	8.992×10^{-6}
Case 2	0.3 0.5	0.1743	8.6079	8.993×10^{-6}	0.01477	1.9449×10^{-5}
Case 3	0.4 0.7	0.2464	12.497	1.332×10^{-5}	0.0218	2.878×10^{-5}

Table 5: Output Results Maximum Principal Stress

Types of cases	Pressure in MPa	Silicon	Polyethylnene	Graphene	Teflon (PTFE)	Carbon Fiber
Case 1	0.2 0.3	5.5405 MPa	5.4595 MPa	5.1914MPa	5.843MPa	5.0371MPa
Case 2	0.3 0.5	8.7447MPa	8.7121MPa	8.5679MPa	8.887MPa	8.3825MPa
Case 3	0.4 0.7	12.236MPa	12.19MPa	11.988MPa	12.44MPa	11.728MPa

Table 6: Output Results Strain Energy

Types of cases	Pressure in MPa	Silicon	Polyethylnene	Graphene	Teflon (PTFE)	Carbon Fiber
Case 1	0.2 0.3	27.175mJ	1371.2mJ	0.00128mJ	2.151mJ	0.00273mJ
Case 2	0.3 0.5	62.68mJ	3163mJ	0.00319mJ	4.9631mJ	0.00631mJ
Case 3	0.4 0.7	112.82mJ	5693.1mJ	0.00576mJ	8.9335mJ	0.01138mJ

Table 7: Output Resultsanalysis of Equivalent Stress

Types of cases	Pressure in MPa	Silicon	Polyethylnene	Graphene	Teflon (PTFE)	Carbon Fiber
Case 1	0.2 0.3	5.1181MPa	5.1076MPa	5.0492MPa	5.417MPa	5.0199MPa
Case 2	0.3 0.5	8.5206MPa	9.6438MPa	8.9329MPa	8.414MPa	9.6438MPa
Case 3	0.4 0.7	12.05MPa	12.255MPa	13.228MPa	12.55MPa	14.27MPa

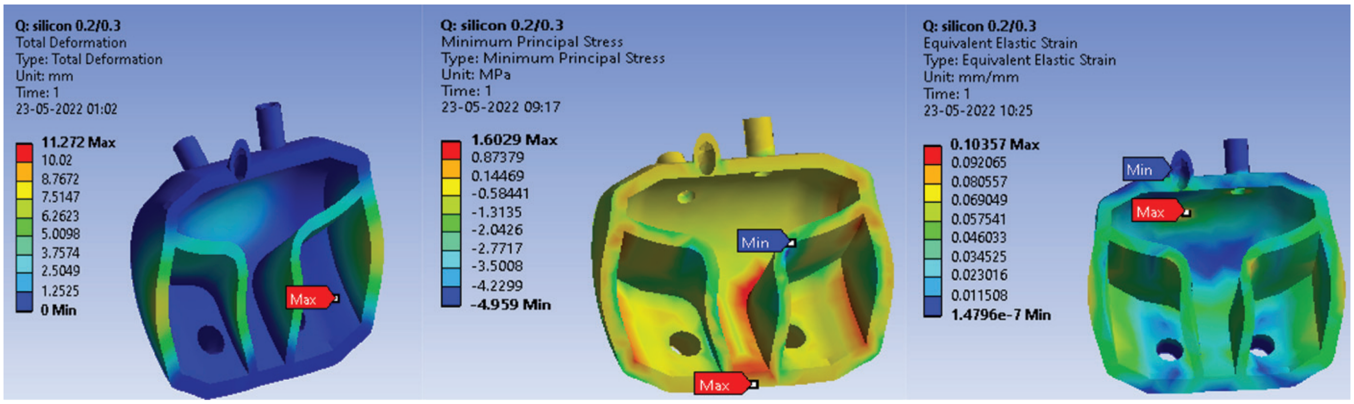

Figure 8: Pictures of Various Results obtained from Analysis

5.0 Conclussions

The above analysis was concluded the results of total deformation, maximum principal stress, equivalent elastic strain for all case 1, case 2 and case 3 with different materials such as Silicon, Graphene, Carbon fiber, Polyethylene and Teflon (PTFE). Here the model is meshed with Tetrahedron method like the element is tetrahedron with element size is 1mm as per mesh convergence. The meshed model was solved with structural static analysis different variables with different engineering material data.

For different pressure inputs across left ventricle chamber, right ventricle chamber and expansion chamber we made the separate cases for each pressure inputs. As the aneten working conditions like normal in rest, walking, jogging, running and some little mild work can create different pressures in ventricles and expansion chamber. These change in pressure causes the different stresses and strains.

(1) The Total deformation of model is maximum in Polyethylene material as compared to Silicon, Graphene, Carbon fiber and Teflon (PTFE) materials.

- The Graphene shows lesser deformation among all the five materials

- Maximum in Polyethylene
- Minimum in Graphene

(2) The Minimum principal stress of model is maximum in Teflon (PTFE) material as compared to Silicon, Graphene, Carbon fiber and Polyethylene materials.

- The Carbon fiber shows lesser deformation among all the five materials
- Maximum in Teflon (PTFE)
- Minimum in Carbon fiber

(3) The equivalent elastic strain of model is maximum in Polyethylene material as compared to Silicon, Graphene, Carbon fiber and Teflon (PTFE) materials.

- The Graphene shows lesser deformation among all the five materials
- Maximum in Polyethylene
- Minimum in Graphene

(4) The Maximum principle stress has very less variations among the materials. These slight differences shows maximum in Teflon (PTFE) material as compared to Silicon, Graphene, Carbon fiber and Polyethylene materials.

- The Carbon fiber shows lesser deformation among all the five materials.
- Maximum in Teflon (PTFE)
- Minimum in Carbon fiber

(5) The Strain Energy of model is maximum in Polyethylene material as compared to Silicon, Graphene, Carbon fiber and Teflon (PTFE) materials.

- The Graphene shows lesser deformation among all the five materials
- Maximum in Carbon fiber
- Minimum in Graphene

(6) The equivalent stress of model is maximum in Carbon fiber material as compared to Silicon, Graphene, Polyethylene and Teflon (PTFE) materials.

- All the materials shows an average minimum value among these materials.
- Maximum in Polyethylene

Among all five different material with three different pressure input cases with considered all outlet veins as rigid fixed support the Polyethylene material exhibits higher in Total deformation, Equivalent elastic strain and Equivalent stress and Graphene shows grater sustainability as compared to other two materials.

Graphene material is having greater sustainability in all three cases of pressures. It has lesser Total deformation, Equivalent elastic strain, Strain energy and Equivalent stress. And even Carbon fiber material also shows lesser Minimum Principle stress and Maximum Principle stress.

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