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Modeling and Analysis of Solid Vessel and Multilayered Composite Pressure Vessel

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***Abstract*— A pressure vessel is designed to work under a high internal pressure condition, so the selection of material and the design of the vessel are the most important part.**

In this paper, we are comparing the solid pressure vessel made of a steel s515-gr70 and composite material pressure vessel made of epoxy s-glass, epoxy e-glass and epoxy carbon. The static deformation, von-mises stress and strain energy for a pressure vessel are calculated with multilayered composite material. The main objective of the work is to compare the solid pressure vessel with composite material pressure vessel and multilayered composite pressure and find out the best suitable material and design for the pressure vessel. To reduces the stress on the object here we are designing one more model i.e., multilayer vessel and calculating the deformation and stress and strain energy values from all these values and all other material combinations we conclude which composite is the most suitable and efficient pressure vessel.

Keywords—Design, Analysis, Solid & Multilayer Composite pressure Vessel

I. INTRODUCTION

In Process Industries, like chemical and petroleum, boiler industries there are design restrictions for large volumes of high internal pressures in metallic single-wall cylindrical vessels. As the pressure of the operating fluid rises, an increment in the thickness of the vessel intended to hold that fluid is an automatic choice. The increment in the thickness beyond a certain value will possess fabrication difficulties as well as demands stronger material for the vessel construction. Due to increasing demands from the process industry for higher operating pressures and temperature, new technologies have been developed and underdeveloped to handle the present-day specialized requirements. Multilayer Pressure Vessels have broadened the art of pressure vessel fabrication or construction and introduce the process designer with a genuine piece of equipment useful in a wide range of operating conditions for the problems generated by the storage of hydrogen and hydrogenation processes the term pressure vessel referred to those reservoirs or containers, which are subjected to internal or external pressures.

Pressure vessels find wide applications in thermal and nuclear power plants, process, and chemical industries, in space and ocean depths, and in water, steam, gas and air supply system in industries. The pressure vessel material may be brittle such as cast iron, or ductile such as mild steel. Multilayer composite vessels are built up by wrapping and combining a series of sheets over a core tube to give a unique combination of properties. The construction involves the use of several layers of material, like metals, alloys, plastic co-polymers, minerals, and wood, usually for quality control and optimum properties. Multilayer construction is used for higher pressures. It provides inbuilt safety, high stiffness, and strength-to-weight ratio, long fatigue life, utilizes material economically, no stress relief is required. The finite element method is especially versatile and efficient for the analysis of complex structural behaviour of multilayered composite laminated structures. Using the finite element method, a significant amount of research has been devoted to the analysis of deformation, stress, and strain energy.

II. LITERATURE SURVEY

Zhang et al. [1] derived an analytical solution for determining the stress distribution of a multi-layered composite pressure vessel subjected to internal fluid pressure and a thermal load. The stress distribution of the pressure vessel was computed using the FE method. Ali, Ghosh, and Alam [2] investigated the effect of the auto frottage process in strain hardened thick-walled pressure vessels theoretically by FE modelling. Wang and Ding [3] obtained the thermoelastic dynamic solution of a multilayered orthotropic hollow cylinder in the state of axisymmetric plane strain. Atefi and Mahmoudi [4] offered an analytical solution for obtaining thermal stresses in a pipe caused by periodic time-varying of the temperature of the medium fluid. Jabbari, Sohrabpour, and Eslami [5] developed a general analysis of one-dimensional steady-state thermal stresses in a hollow thick cylinder made of functionally graded material. Shao, Wang, and Ang [6] carried out a thermomechanical analysis of functionally graded hollow cylinder subjected to axisymmetric mechanical and transient thermal loads. Thick-walled cylinders subjected to internal heat flow are used in many engineering applications. Typical examples are nuclear engineering structures, nozzle sections of rockets, gun tubes, and dies of hot forming tools. The study of thick-walled cylinders subjected to internal heat flow and/or internal pressure is a problem of great practical interest. Industrial demands for such applications have focused the attention of the investigators on this point of research. However, most investigators have only dealt with the analysis of thermal stresses of thick-walled cylinders under steady-state conditions [7]. conductivity as a function of temperature. They concluded that the effect of thermal conductivity on the temperature and stresses is slight for small values of internal heat flow. However, for large heat flow, the difference in temperature and stresses between temperature-dependent and -independent thermal conductivity can be as much as 20%.

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Vollbrecht [8] has analyzed the stresses in both cylindrical and spherical walls subjected to internal pressure and stationary heat flow.

III. PROBLEMS DEFINITION

This paper is mainly carried out to compare the solid pressure vessel and multilayered pressure vessel and find out the best suitable material and design for pressure vessel. It is modelled using CREO and analysis is carried out into Ansys software using the structural analysis method. The von-mises stress, deformation and strain energy are found for various pressure vessel materials.

The pressure vessel material taken for analysis is M.S. steel and composite material such as glass epoxy fiber and epoxy carbon.

IV. METHODOLOGY

Modelling of the pressure vessel:

A virtual model of solid pressure vessel and the composite pressure vessel is created using CREO software and then the model was imported to ANSYS for analysis and the results of deformation, stress and strain analysis of different materials are compared with each other.

The line diagram of the pressure vessel is shown in Fig. 1. The 3D model of the pressure vessel created in CREO is shown in Fig. 2.

V. GEOMETRY AND BOUNDRY CONDITION

1. Geometry of reference model for creating an object:

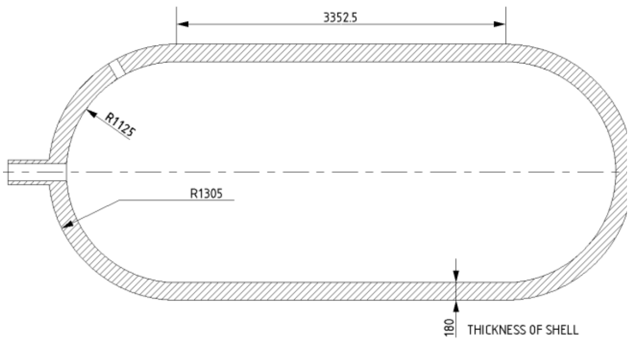

Fig. 1. Line Diagram of the Pressure Vessel

2. 3D Model

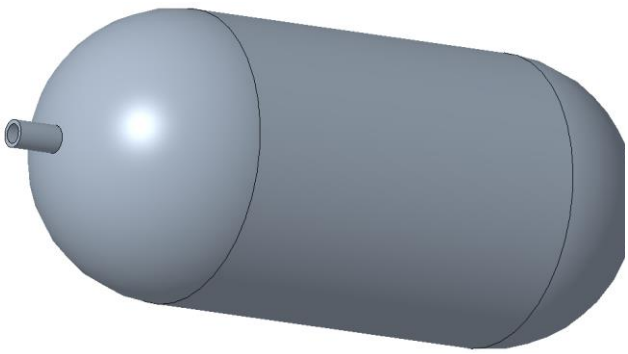

Fig. 2. 3-D CAD model of the Pressure Vessel

3. Meshing (FE Modelling)

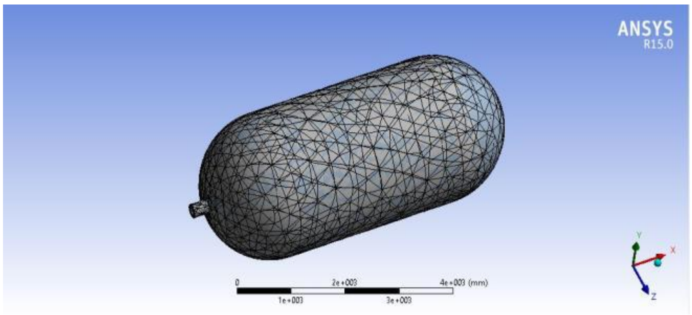

Fig. 3. FE Tetra-Mesh of Pressure Vessel in Ansys Workbench

4. Boundary Conditions

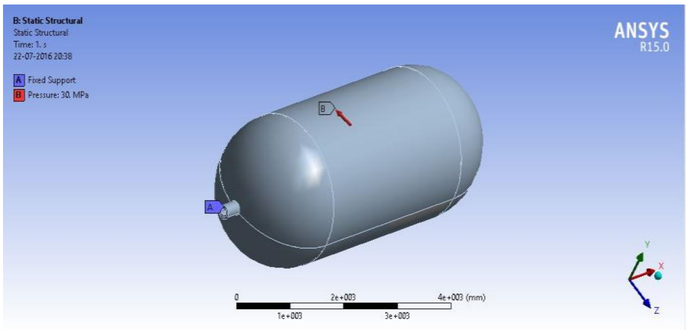

Fig. 4. Boundary Conditions of the Pressure Vessel

VI. STATIC STRUCTURAL ANALYSIS RESULT

The goal of this paper is to determine the static analysis of the pressure vessels like deformation, stress, and strain energy. Effects of the different materials of steel and different composite materials as well as multilayered composite material on static deformation, stress and strain energy are investigated, including comparison with results using Creo and Ansys.

The material properties of various materials with which the pressure vessel is made are:

Mild Steel:
Young's modulus -205 x 10^9 Pa, Poisson's ratio - 0.29, Density - 7850 Kg/m^3.

Epoxy e-glass:
Density - 2000 kg/m^3, Young's modulus in x-direction: 45x 10^9 Pa, Young's modulus in y-direction: 10x10^9 Pa, Young's modulus in z-direction: 10x10^9 Pa, Poisson's ratio in xy- 0.3, Poisson's ratio in yz- 0.4, Poisson's ratio in zx- 0.3.

Epoxy s-glass:
Density - 2000 kg/m^3, Young's modulus in x-direction – 50 x 10^9 Pa, Young's modulus in y-direction – 8 x10^9 Pa, Young's modulus in z-direction - 8 x10^9 Pa, Poisson's ratio in xy - 0.3, Poisson's ratio in yz - 0.4, Poisson's ratio in zx - 0.3.

Epoxy carbon:
Density - 1480 kg/m^3, Young's modulus in x-direction -

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91.820 x 10^9 Pa, Young's modulus in y-direction - 91.820 x 10^9 Pa, Young's modulus in z-direction – 9 x10^9 Pa, Poisson's ratio in xy - 0.05, Poisson's ratio in yz - 0.3, Poisson's ratio in zx - 0.3.

A. Analysis of Solid Pressure Vessel

(Existing material (steel s515-gr70))

1. Deformation

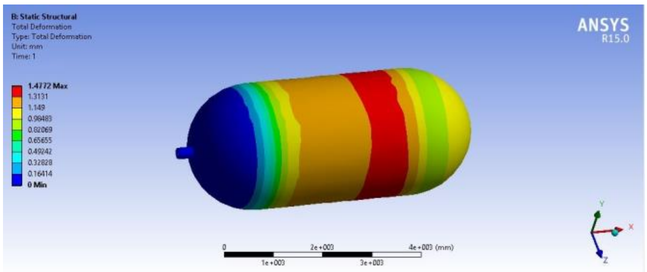

Fig. 5. Static Structural Deformation of Steels515-gr70

2. Stress

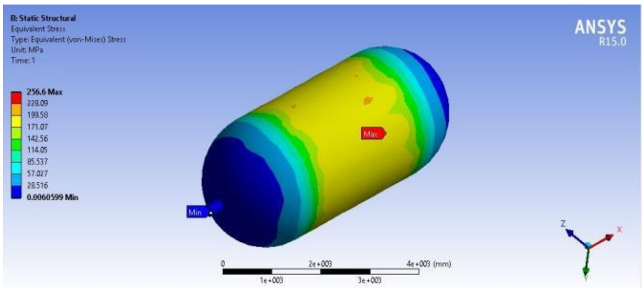

Fig. 6. Static Structural Von-Mises stress of Steels515-gr70

3. Strain Energy

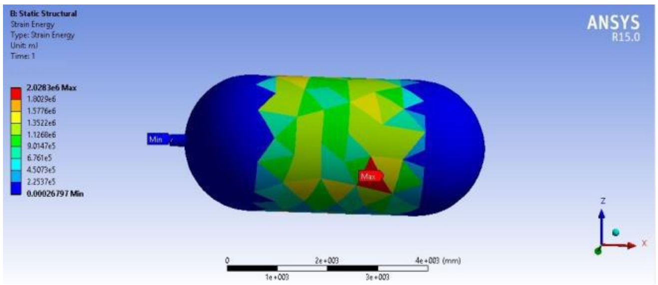

Fig. 7. Static Structural Strain Energy of Steels515-gr70

When we applied 30Mpa pressure on the vessel it produces nearly 256Mpa stress to reduces the stress on the body here we are changing material. We have chosen 3 composite materials now we are going to analyze these 3 materials with the same boundary conditions.

B. Analysis of Composite Material

I. Epoxy s-glass

1. Deformation

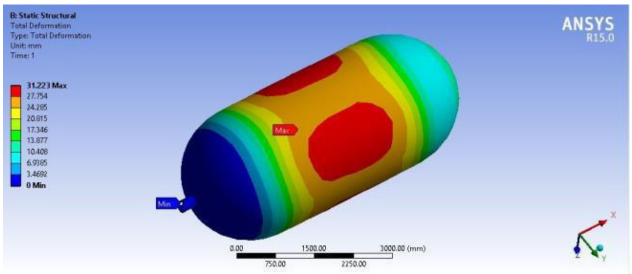

Fig. 8. Static Structural Deformation of Epoxy s-Glass

2. Stress

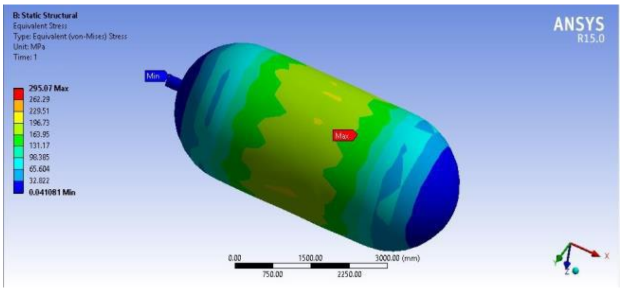

Fig. 9. Static Structural Von-Mises stress of Epoxy s-Glass

3. Strain Energy

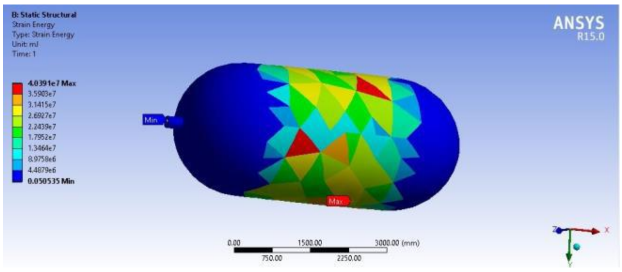

Fig. 10. Static Structural Strain Energy of Epoxy s-Glass

II. Epoxy e-glass

1. Deformation

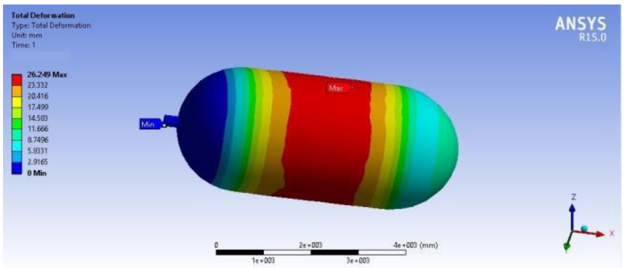

Fig. 11. Static Structural Deformation of Epoxy e-Glass

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2. Stress

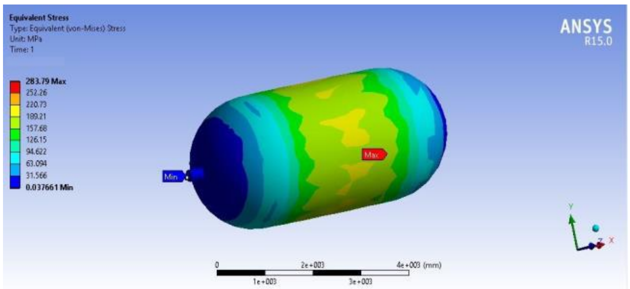

Fig. 12. Static Structural Von-Mises stress of Epoxy e-Glass

2. Strain Energy

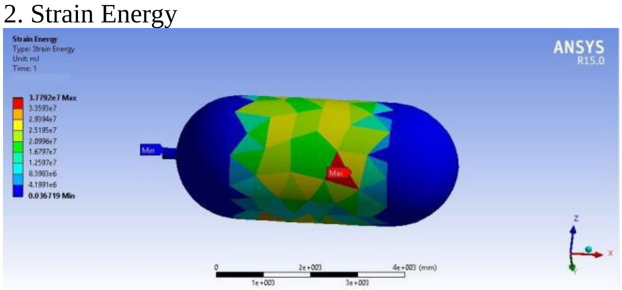

Fig. 13. Static Structural Strain Energy of Epoxy e-Glass

III. Epoxy Carbon

1. Deformation

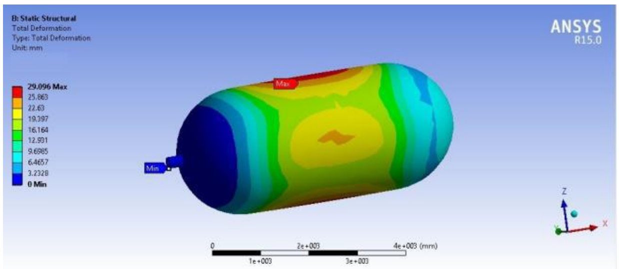

Fig. 14. Static Structural Deformation of Epoxy Carbon

2. Stress

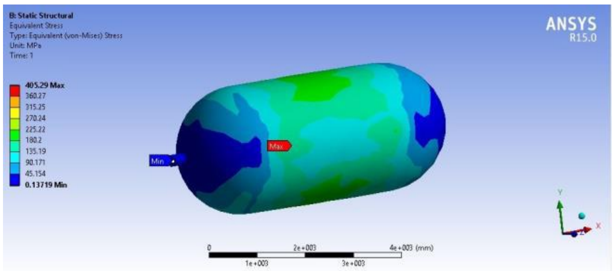

Fig. 15. Static Structural Von-Mises stress of Epoxy Carbon

3. Strain Energy

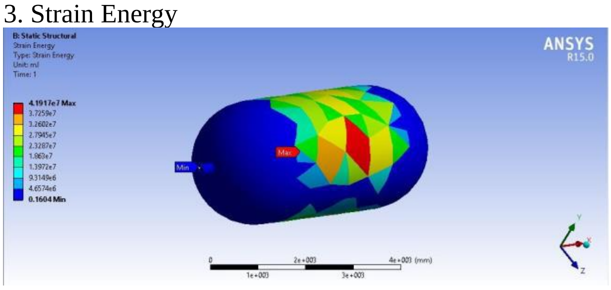

Fig. 16. Static Structural Strain Energy of Epoxy Carbon

TABLE I. RESULT OF SOLID AND COMPOSITE MATERIAL VESSEL

Material	*Deformation (mm)*	*Stress (Mpa)*	*Strain energy (mJ)*
Steel-s515-gr70	1.6143	264.48	9.3644e5
Epoxy s-glass	31.223	295.07	4.0391e7
Epoxy e-glass	26.249	283.79	3.7792e7
Epoxy-carbon	29.096	405.29	4.1917e7

We can say that the deformation values are low for steel-s515-gr70 and high for epoxy e-glass. The stress has been increasing for all materials and in this steel-s515-gr-70 have fewer stress values and epoxy carbon has high-stress values.

From the above solid vessel (162mm thickness) results when we change material from ss515-gr70 to composite materials no other material gave fewer stress values. By these changes, the stress has been increased so we cannot use complete composite material for a vessel and here we follow another concept i.e., multilayer vessel in this process we have created the original model with the same dimensions but here we created two layers for a vessel which are those 162mm and 18mm respectively and here we are applying the outer layer as same steel-s515-gr70 but inner material we are adding composite materials.

VII. STEEL-S515-GR70 AND EPOXY-CARBON COMPOSITE MATERIAL

1. Geometry Modification of model for creating the object:

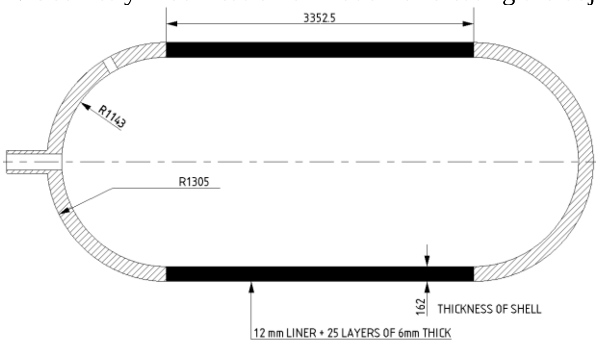

Fig. 17. Line Diagram of the Multi-layered Composite Pressure Vessel

We are going to create one newer model of multilayer composite pressure vessel. The line diagram of the multilayer composite pressure vessel is shown in Fig. 17.

The construction of the multilayer composite pressure vessel is:

Total No. of layers: 26, (25 shell layers +1Liner)

Total Thickness: 162 mm

Liner thickness: 12 mm &

Each Shell layers Thickness, t: 6 mm.

1. Deformation

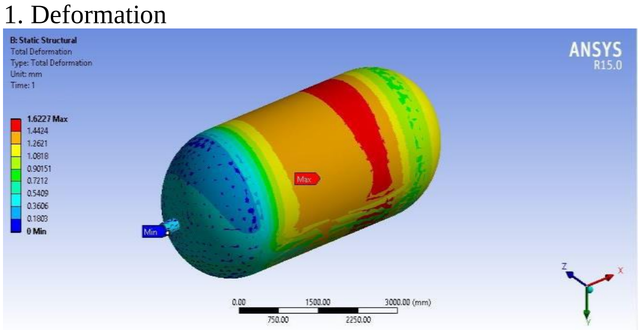

Fig. 17. Static Structural Deformation of Steel-s515-gr70 and Epoxy Carbon

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2. Stress

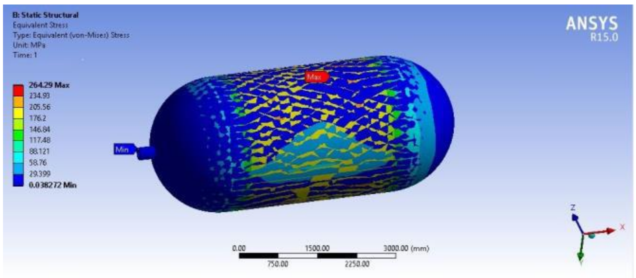

Fig. 18. Static Structural Von-Mises stress of Steel-s515-gr70 and Epoxy Carbon

3. Strain Energy

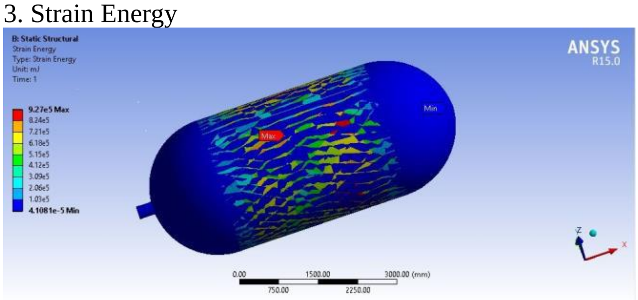

Fig. 19. Static Structural Strain Energy of Steel-s515-gr70 and Epoxy Carbon

TABLE II. RESULT OF STEEL-S515-GR70 AND EPOXY MATERIAL

Material	*Deformation (mm)*	*Stress (Mpa)*	*Strain energy (mJ)*
Steel-s515-gr70 & epoxy-s-glass	1.6152	264.49	9.3705e5
Steel-s515-gr70 & epoxy-e-glass	1.4772	256.6	2.0283e6
Steel-s515-gr70 & epoxy-carbon	2.1842	230.25	9.27e5

Deformation- values for all multi-layer models and in this steel-s5155 epoxy e-glass has produced less deformation among all and steel-s515-gr70 epoxy carbon-producing high deformation.

Stress- For steel-s515-gr70 producing high deformation but in this stress values it has exceptionally low stresses among all other materials.

Strain Energy- From all results here steel-s515-gr70 epoxy e-glass having high energy compares to others. But it also has high-stress values which are not safe for a model.

VIII. CONCLUSION

In this project, we have analyzed one solid vessel (180mm thickness) of existing material steel-s515-gr70 and applied 30Mpa pressure on it. We got nearly 256Mpa stress on the whole body to reduce these stress values we completely use composite materials which are epoxy carbon and epoxy e-glass and epoxy s-glass, respectively. But these changes will not satisfy our condition. These composite materials have incredibly good strength compare with existing material, but it also produces remarkably high stress on the body.

To avoid these stresses on the model we have done one more model which is called multi-layer vessel (162mm thick & 18mm thick) with steel-s515-gr70 and composite material respectively and analyses with the same boundary conditions and calculated results for all combinations.

From all combination results steel-s515-gr70 with epoxy carbon produces fewer stress values 230Mpa only compared to a solid vessel by this change we have been reduced 35Mpa stresses on the body and composite materials are lightweight, so we reduce component weight in this case.

Finally, we conclude that multi-layer vessel with (steel-s515-gr70&epoxy carbon) gave fewer stress values compare to solid vessel with steel-s515-gr70 materials.

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