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Structural Analysis of Solid and Multilayered Composite Pressure Vessels

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Abstract **- A solid wall vessel also called as Mono Block pressure vessel consists of a single cylindrical shell with closed ends. Multilayer vessels are built up by wrapping a series of sheets over a core tube. In this work a solid vessel is to be created using CAD tool (creo-2) and then it is to be analyzed with analysis tool ANSYS. The analysis is to be carried out for two materials of pressure vessel, one with existing material steel S515-gr70 and another with composite material. In order to reduce the stress on the object multi layer vessel is also to be modeled. The efficient pressure vessel is to be selected based on the obtained values of deflection, stress and strain energy.**

Keywords - Pressure vessel; wrapping; composite; strain energy.

I. INTRODUCTION

The construction pressure vessel involves the use of several layers of material, usually for the purpose of quality control and optimum properties. Multilayer pressure vessel construction is used for withstanding of higher pressures. The benefits of multilayer pressure vessel are inbuilt safety, utilizes material economically, no stress relief is required. For corrosive applications the inner liner is made of special material and is not considered for strength criteria. The outer load bearing shells can be made of high tensile low carbon alloys. Zhang et al. [1] derived an analytical solution for determining the stress distribution of a multilayered composite pressure vessel subjected to an internal fluid pressure and a thermal load. They computed the stress distribution of the pressure vessel using FE method. Ali et al [2] investigated the effect of auto frottage process in strain hardened thick-walled pressure vessels theoretically by FE modeling. Wang and Ding [3] obtained the thermo elastic 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 temperature of medium fluid. Jabbari et al [5] developed a general analysis of one-dimensional steady-state thermal stresses in a hollow thick cylinder made of functionally graded material. Shao et al [6] carried out thermo mechanical 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. S. T. Stasynk et al [7] found the thermal stresses of thick-walled cylinders under steady-state conditions with 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. From results they observed that for large heat flow, the difference in temperature and stresses between temperature-dependent and independent thermal conductivity can be as much as 20%. Vollbrecht [8] analyzed the stresses in both cylindrical and spherical walls subjected to internal pressure and stationary heat flow. Kandil [9] studied the effect of steady-state temperature and pressure gradient on compound cylinders fitted together by shrink fit. Sinha [10] used finite element method for analyzing the thermal stresses and temperature distribution in a hollow thick cylinder subjected to a steady-state heat load in the radial direction. Naga [11] presented the stress analysis and the optimization of both thick-walled impermeable and permeable cylinders under the combined effect of steady-state temperature and pressure gradient. Zukhova and Pimshtein [12] studied the one dimensional, steady-state thermal problem for a laminated cylinder consisting of concentric layers and subjected to internal pressure and external heating. From their calculations they showed that the radial compressive stress due to the internal pressure can permit external heating without layer separation. From results they found that the distribution of temperatures and stresses depends on the manner of stress application and heating. In this paper, thermo mechanical stresses was computed in a two layered composite hollow thick cylindrical pressure vessel taking into the effect of centrifugal and centripetal heat flow by using finite element approach. The proposed finite element solution may be used to design multilayered composite pressure vessel under steady state condition.

II. MODELING OF PRESSURE VESSEL

The modeling of pressure vessel is to be done in CAD tool CREO. CREO is a suite of programs that are used in the design, analysis, and manufacturing of a virtually unlimited range of product. CREO is a parametric, feature-based solid modeling system. Feature based means that creating a part and assembly by defining feature like pad, rib, slots, holes, rounds, and soon, instead of specifying low-level geometry like lines, arcs, and circle & features are specifying by setting values and attributes of element such as reference planes or surfaces direction of creation, pattern parameters, shape, dimensions and others. 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.

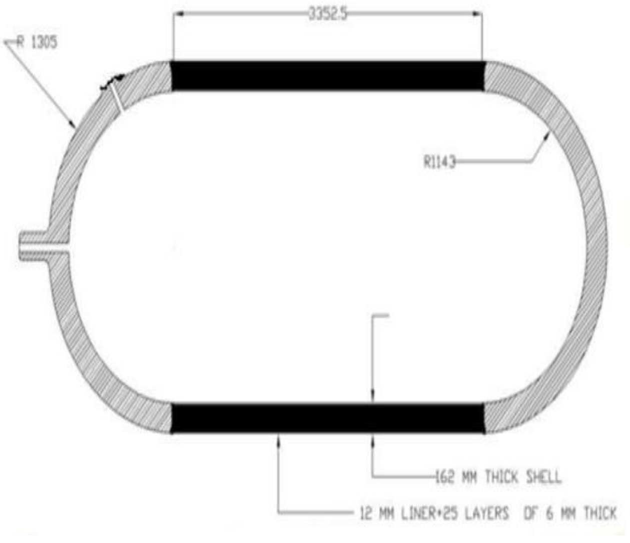

Fig. 1. Sketch of pressure vessel

Fig. 2. 3D model of pressure vessel

III. STRUCTURAL ANALYSIS OF PRESSURE VESSEL

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

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

Epoxy e-glass:
Density - 2000 kg/m^3, Young’s modulus in x-direction – 45 x 10^9 Pa, Young’s modulus in y-direction – 10 x 10^9 Pa, Young’s modulus in z-direction – 10 x 10^9 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 - 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 x10^0 Pa, Poisson’s ratio in xy - 0.05, Poisson’s ratio in yz - 0.3, Poisson’s ratio in zx - 0.3.

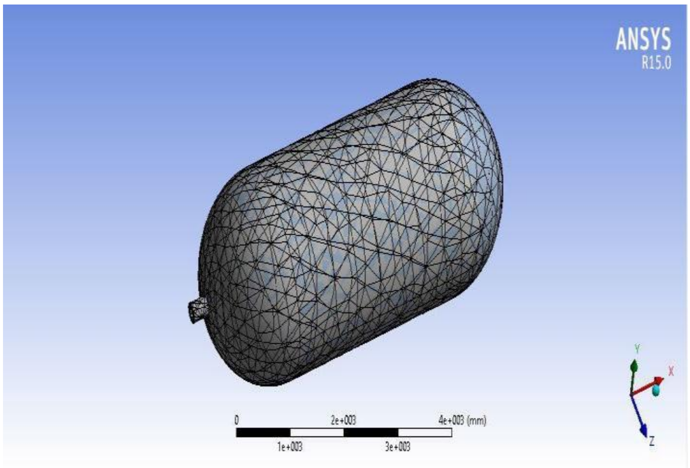

Fig. 3. Meshed model of pressure vessel

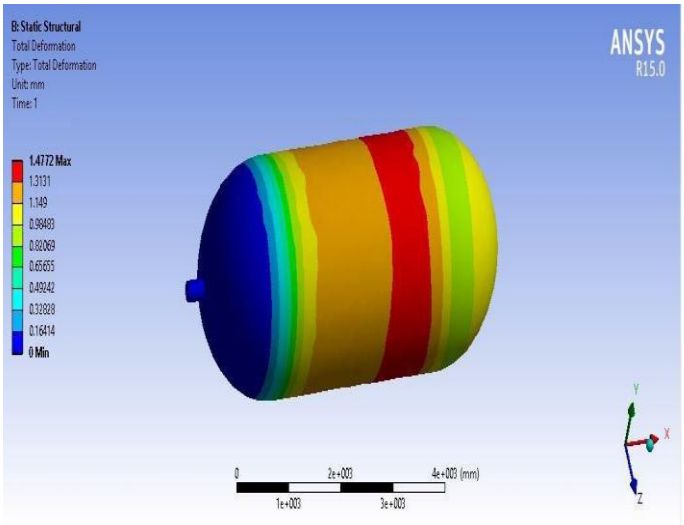

Fig. 4. Deformation of pressure vessel made of steel s515-gr70

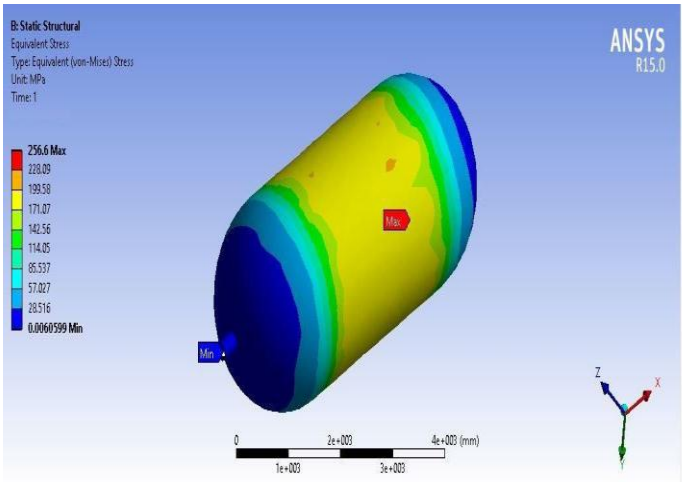

Fig. 5. Von–Mises Stress of pressure vessel made of steel s515-gr70

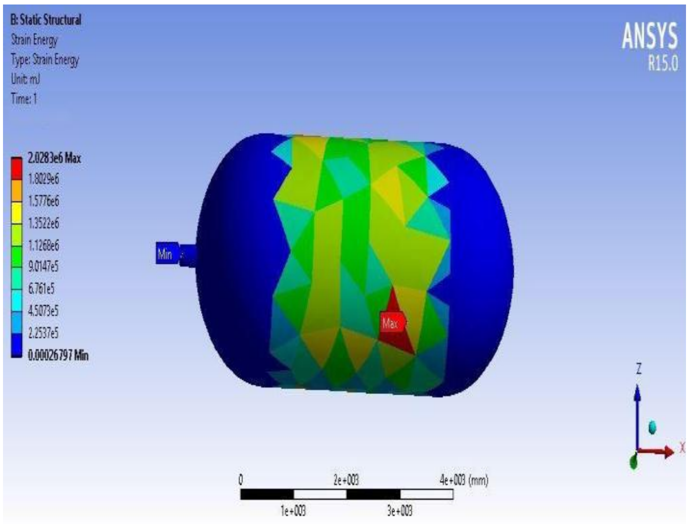

Fig. 6. Strain energy of pressure vessel made of steel s515-gr70

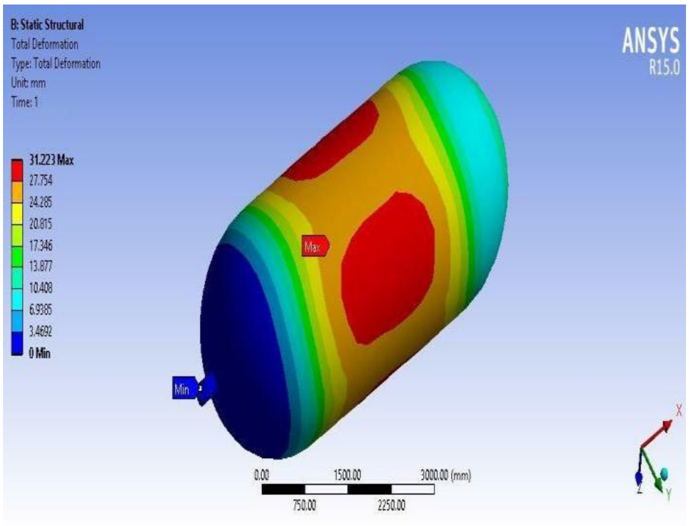

Fig. 7. Deformation of pressure vessel made of Epoxy s-glass

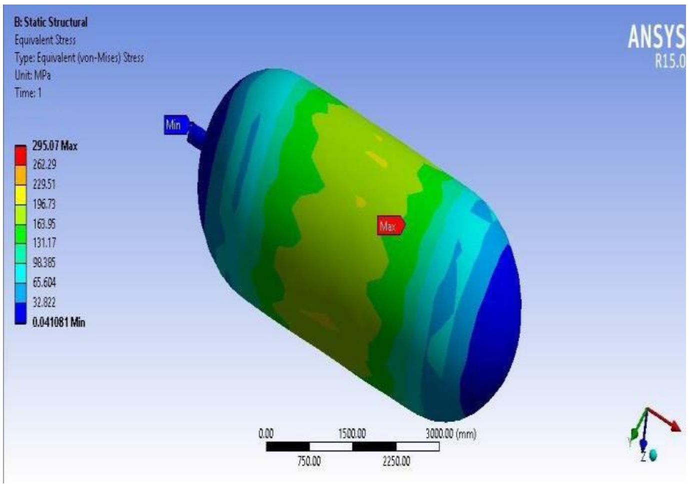

Fig. 8. Von-Mises stress of pressure vessel made of Epoxy s-glass

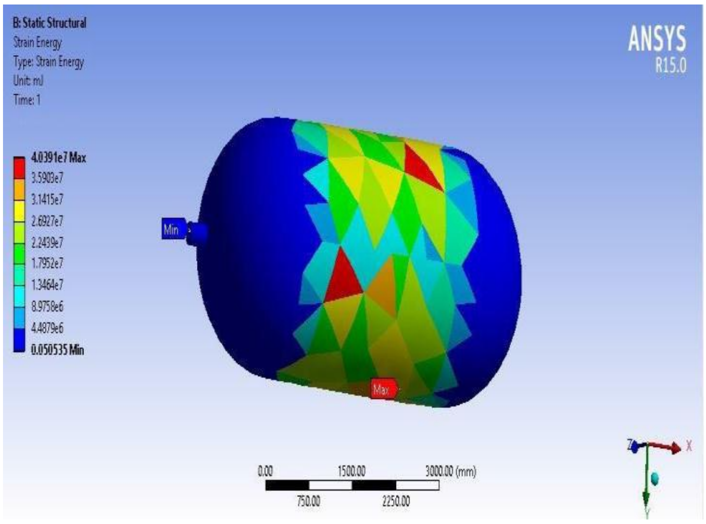

Fig. 9. Strain energy of pressure vessel made of Epoxy s-glass

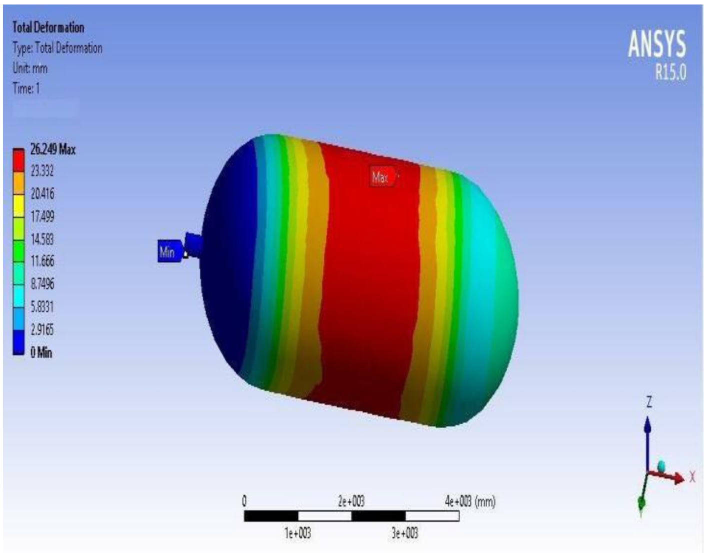

Fig. 10. Deformation of pressure vessel made of Epoxy e-glass

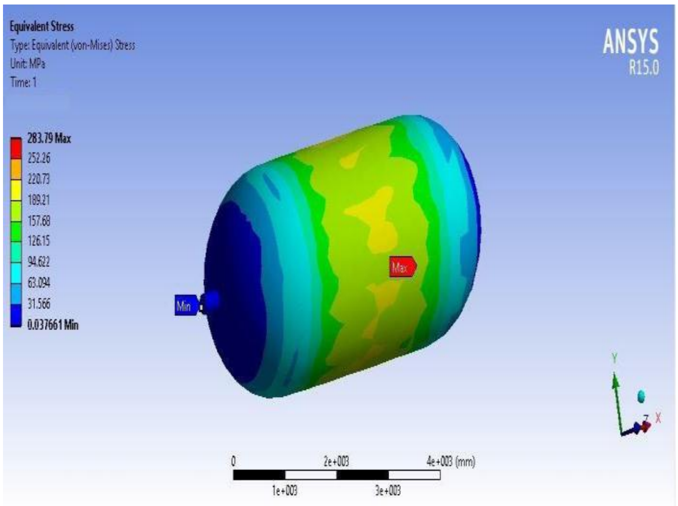

Fig. 11. Von-Mises stress of pressure vessel made of Epoxy e-glass

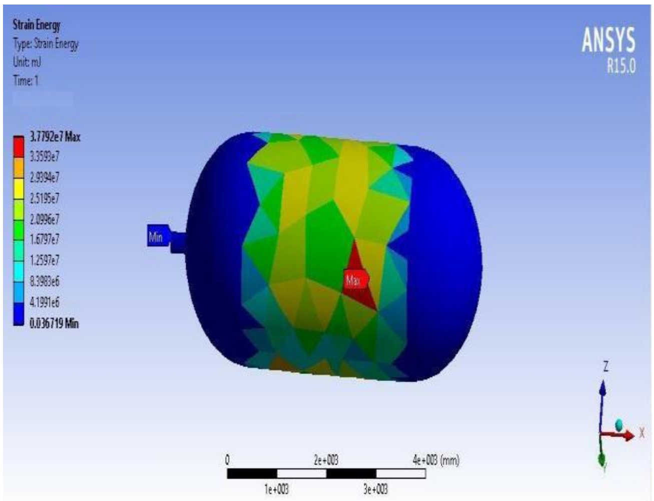

Fig. 12. Strain energy of pressure vessel made of Epoxy e-glass

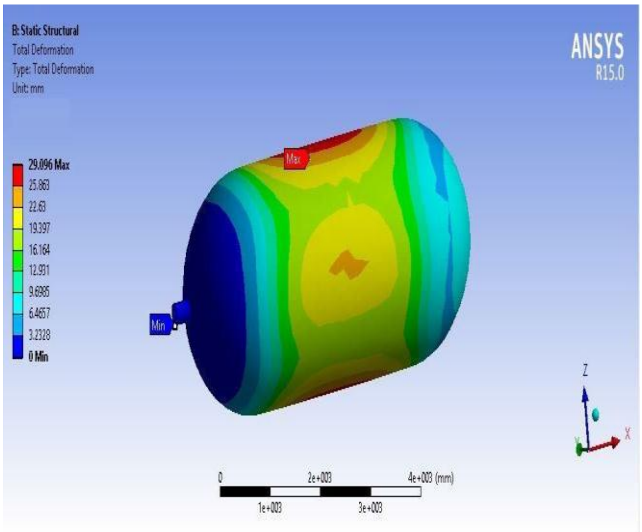

Fig. 13. Deformation of pressure vessel made of Epoxy carbon

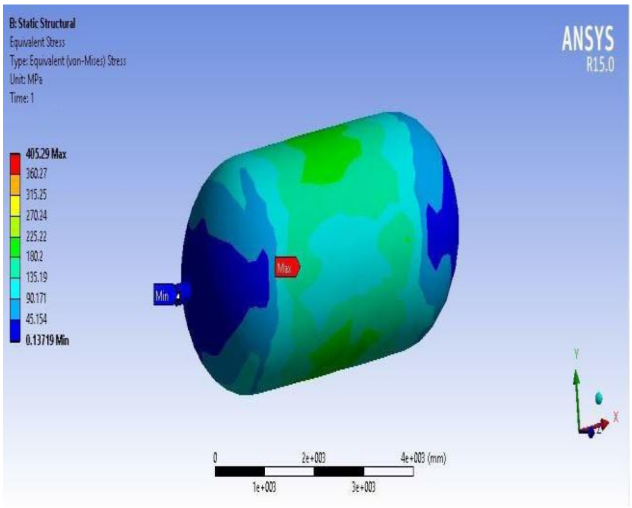

Fig. 14. Von-Mises stress of pressure vessel made of Epoxy carbon

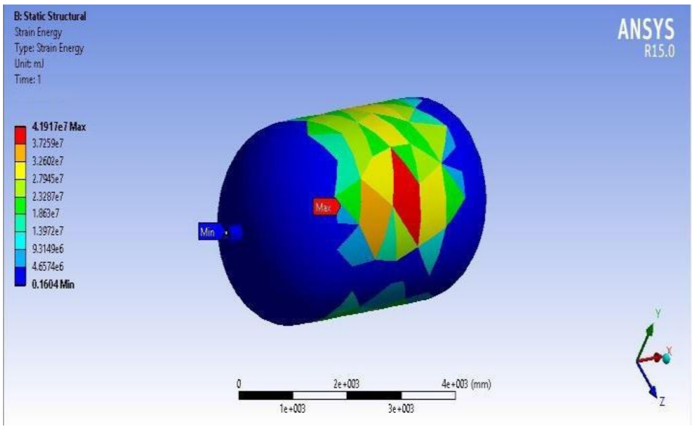

Fig. 15. Strain energy of pressure vessel made of Epoxy carbon

The 3D meshed model of pressure vessel is shown in Fig. 3. The deformation, stress and strain energies obtained for various materials of pressure vessel are shown from Fig. 4 to Fig. 15. The results obtained for single layer pressure vessel are tabulated in Table 1. From results it is observed that the strain energy obtained for pressure vessel made of composite materials is 4.1917e7 MJ where as for steel it is 9.3644e5 MJ. Table 2 gives the data of multi layered pressure vessel. From the analysis of multi layered pressure vessel the strain energy obtained for pressure vessel made of steel-s515-gr70 & epoxy-e-glass is 2.0283e6 MJ where as for Steel-s515-gr70 & epoxy-carbon it is 9.27 e5 MJ. The deflection obtained for multi layered pressure vessel is much less than the pressure vessel made of single layer.

Table 1: Deformation, stress and strain energy of pressure vessel made of different materials

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

Table 2: Deformation, stress and strain energy of multi layered pressure vessel made of different materials

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

IV. CONCLUSION

In this work a solid vessel is created using CAD tool creo-2 and then it is analyzed in ANSYS with existing material steel-s515-gr70 and an applied pressure of 30Mpa on it. Then the pressure vessel made of composite materials with epoxy carbon and epoxy e-glass and epoxy s-glass respectively is analyzed with same pressure. From results it is found that composite materials have very good strength compare with existing material but it also produces very high stress on the body. In order to reduce these stresses a multi layer pressure vessel made of steel-s515-gr70 as well as composite material are analyzed with same boundary conditions. From all combination results a multi layered pressure vessel made of steel-s515-gr70 with epoxy carbon produces less stress values i.e., 230Mpa when compared to solid vessel of same material which is 265 MPa.

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