Modeling And Analysis of Pressure Vessel by Using FRP Composite Material

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Abstract:

Pressure vessels are crucial components in various industries as they are designed to hold gases or liquids at a pressure substantially different from the ambient pressure. They are commonly used in applications such as chemical processing, power generation, and oil refining, where they ensure the safe and efficient storage and transport of volatile substances. By utilizing FRP composite materials, these vessels can achieve enhanced strength, corrosion resistance, and reduced weight. Modeling pressure vessels using FRP composite material provides several advantages, including enhanced strength-to-weight ratio and corrosion resistance. These materials allow for more efficient designs that can withstand high pressures while reducing overall weight, leading to cost savings in both manufacturing and operation. Additionally, the use of FRP composites can extend the lifespan of the pressure vessel, minimizing maintenance and repair costs. The modeling process involves creating a detailed computer-generated simulation of the pressure vessel using finite element analysis (FEA) software. This simulation allows engineers to input the properties of the FRP composite material, such as its strength and flexibility, to predict how the vessel will behave under various pressure conditions. By analyzing the results, engineers can optimize the design for safety and efficiency before manufacturing the actual vessel. The use of FRP composite materials in pressure vessels has shown significant improvements in both strength and durability. These materials offer excellent resistance to corrosion, reducing maintenance costs and extending the lifespan of the vessels. Additionally, the lightweight nature of FRP composites contributes to easier handling and installation, enhancing overall efficiency.

Keywords: Pressure Vessel, FRP composite, Design, ANSYS, Efficiency.

1. Introduction

As the world is suffering from the scarcity of gas, oil/petroleum in the earth. Most of the vehicles, automotive assemblies, power plants are using these reserve resources termed as fuel which is the main cause of polluting and degrading the quality of air in this atmosphere. At present we are in an alarming zone where we are heading towards the disturbance of ecological sustainability. Since natural gas is one of the cost-effective, eco-friendly fuels as well as reliable for safety for such operation, which can help to reduce the fatal causes. The most effective part for storing the compressed natural gas (CNG) storage is designing of high-pressure cylinders. [1] The pressure vessel is a kind of storage device, reservoirs or a closed container designed for storage of gases or liquids at a pressure which is different from the ambient pressure. It is necessary to keep the compressed natural gas at room temperature, and under the filling high pressure in the pressure vessel or tank. High-pressure storage tank must withstand, and crack at the surface or without leakage as well as maximum pressure like a 20MP i.e. Fatigue load cycle, and burst pressure. It occurs during refilling of storage pressure vessel. It is the most important high-pressure vessel. It should maintain high-pressure tightness with fire safety. Storage pressure for compressed natural gas (CNG) used in various applications such as automobile and aerospace are traditionally produced with help of isotropic material such as Aluminium, steel we are using composite material like carbon fibre, Kevlar fibre etc.

Applications Of Pressure Vessels:

There are numerous applications that require the use of containers for storage or transmission of gasses and fluids under high pressure. Pressure vessels have been used for a long time in various applications in both industry and the private sector. Pressure vessels are probably one of the most widespread equipment within the different industrial sectors. In fact, there is no industrial plant without pressure vessels, steam boilers, tanks, autoclaves, collectors, heat exchangers, pipes, etc. More specifically, pressure vessels represent fundamental components in sectors of paramount industrial importance, such as the nuclear, oil, petrochemical, and chemical sectors and also in the sectors as industrial compressed air receivers and domestic hot water storage tanks Other examples of pressure vessels are diving cylinders, recompression chambers, distillation towers, pressure reactors, autoclaves, and many other vessels in mining operations, oil refineries and petrochemical plants, nuclear reactor vessels, submarine and space ship habitats, pneumatic reservoirs, hydraulic reservoirs under pressure, rail vehicle airbrake reservoirs, road vehicle airbrake reservoirs, and storage vessels for liquefied gases such as ammonia, chlorine, propane, butane and LPG.

2. Literature review

In the base paper [1] a cylindrical pressure vessel, as used to generate steam at low pressure for a boiler drum has been taken, the vessel consists of a cylindrical portion with the two ends closed using hemispherical structure. A nozzle is welded on at the midpoint of the length of the vessel which is supported on two supports. The vessel is constructed using material low alloy steel of type ASME SA516Gr70.[2] In this paper they have discussed on FE analysis of pressure vessel and piping design. The stresses developed in solid layer pressure vessel and multilayer pressure vessels are analysed. The theoretical and ANSYS results are compared. Finally it was concluded that theoretically calculated values are very close to that of the values obtained from ANSYS is suitable for multilayer pressure vessels. Multilayer pressure vessels are superior to the solid layer pressure vessel. [3] In this paper they have discussed on Fatigue analysis of different types of pressure vessel nozzle. He carried out comparison between the two different. methods for the construction of pressure vessel nozzle. He concludes that failure of nozzles was by crack passing through their thickness. Both designs (integral and external reinforcement) give good fatigue life results. [3] In this paper they have discussed on FE analysis of composite high pressure hydrogen storage vessels. Composite pressure vessel is largely used in industrial applications such as softening, filtration and storage. In this design, Unit load method under various internal pressures and analysis was carried out in ABAQUS. The result shows that fatigue lifetime of vessel depends on crack density, stress induced in it and cyclic loading amplitude. BHPV manual on Multilayer Pressure Vessel [4] has investigated There is a percentage saving in material of 26.02% by using multilayered vessels in the place of solid walled vessel. This decreases not only the overall weight of the component but also the cost of the material required to manufacture the pressure vessel. This is one of the main aspects of designer to keep the weight and cost as low as possible. The Stress variation from inner side to outer side of the multilayered pressure vessel is around 12.5%, where as to that of solid wall vessel is 17.35%. [5] In this paper they have discussed on the design and analysis of pressure vessel, the design of pressure vessel depends on its pressure and temperature. In pressure vessel design, the main consideration was safety and the structural integrity of mechanical components of pressure vessel requires fatigue analysis including stress analysis and thermal analysis and the Fatigue analysis also done on modelled in Pv Elite software to improve the life of pressure vessel. [6] has investigated Due to shrink fitting, compressive stresses developed in the layers counter tensile stresses induced due to internal pressure which results in decreased Hoop's stress. It is found that thickness required for shell of Mono Wall. [7] has investigated Fatigue analysis will be carried out for entire equipment for specified regeneration cycles and we will found fatigue life more than required cycles. Accordingly, we conclude that all evaluation points for fatigue are within allowable limits

3.Methodology

The methodology for modeling and analyzing pressure vessels using FRP composite materials involves several key steps to ensure an optimized and reliable design. Initially, a detailed review of the material properties of FRP composites, including their strength, flexibility, and resistance to corrosion, is conducted. These properties are then incorporated into a finite element analysis (FEA) model to simulate the behavior of the pressure vessel under various pressure conditions. The FEA software allows for the creation of a virtual model of the pressure vessel, where the geometry, boundary conditions, and material properties are defined. Various loading conditions, including internal and external pressures, are applied to the model to simulate real-world operational conditions. Sensitivity analyses are performed to assess the vessel’s response to different pressure levels, and the stress distribution across the FRP composite material is examined.

Material Selection and Characterization:

The first step involves selecting an appropriate FRP composite based on the specific requirements of the pressure vessel, such as the type of fluid, operating pressure, and temperature. The FRP composite typically consists of a polymer matrix reinforced with fibers, such as glass fibers or carbon fibers. Material characterization is performed to determine the mechanical properties, including tensile strength (e.g., 1500 MPa for glass fiber composites), compressive strength, and the modulus of elasticity (e.g., 30 GPa for glass fiber composites). These properties are then input into the Finite Element Analysis (FEA) software for accurate modeling.

Modeling the Pressure Vessel:

Using the defined material properties, a 3D model of the pressure vessel is created in FEA software (such as ANSYS or Abaqus). The geometry of the vessel is defined, including the thickness of the FRP composite layers and reinforcement fibers. The software is then used to assign the FRP composite's material properties (such as its strength, modulus, and density) to different regions of the vessel based on the material's fiber orientation and layer distribution.

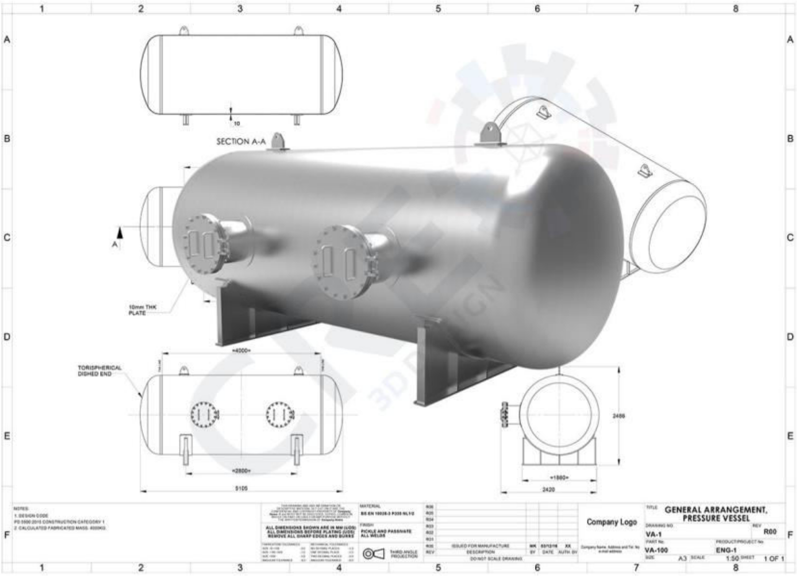

Figure 1: Design model pressure vessel

Finite Element Analysis (FEA):

The FEA simulation is carried out by applying boundary conditions such as internal pressure, external pressure, and temperature variations. The FRP composite's anisotropic nature (different properties in different directions) is modeled by defining the fiber orientations within the composite layers. This allows the simulation to account for the directional strengths and weaknesses of the material. The FEA software computes the stress distribution, displacement, and deformation of the vessel under various loading conditions, helping to predict the vessel's behavior under real-world operating conditions.

4. Thermal Analysis Of Pressure Vessel Using FRP

The results from the thermal load simulation are used to evaluate the thermal stresses within the FRP pressure vessel. The thermal expansion mismatch between the fibers and the matrix may create internal stresses, especially under significant temperature gradients. The analysis also considers the effects of cyclic temperature loading (thermal fatigue) and the potential for delamination between fiber layers.

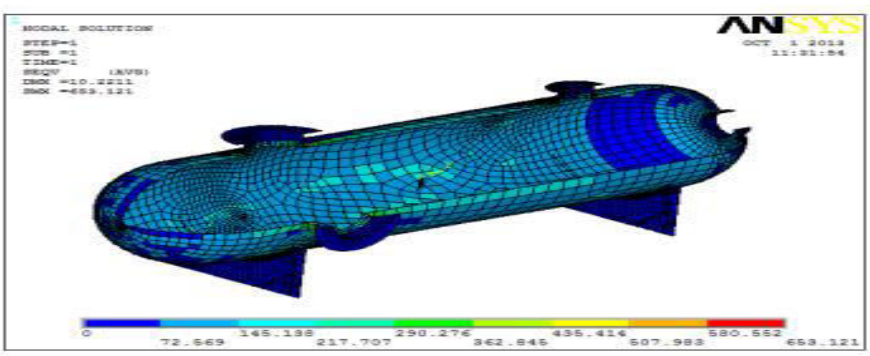

Figure 2: Von-misses stress value 653.121 N/mm²

The Von-Mises stress distribution in a structure analyzed using ANSYS. The highest stress value recorded is 653.121 N/mm², indicating the region of the model where the material experiences the most significant stress. This value suggests that the material in this area may be approaching or exceeding its yield strength, depending on the material properties. It is crucial to ensure that this stress does not surpass the material's tensile strength to prevent failure.

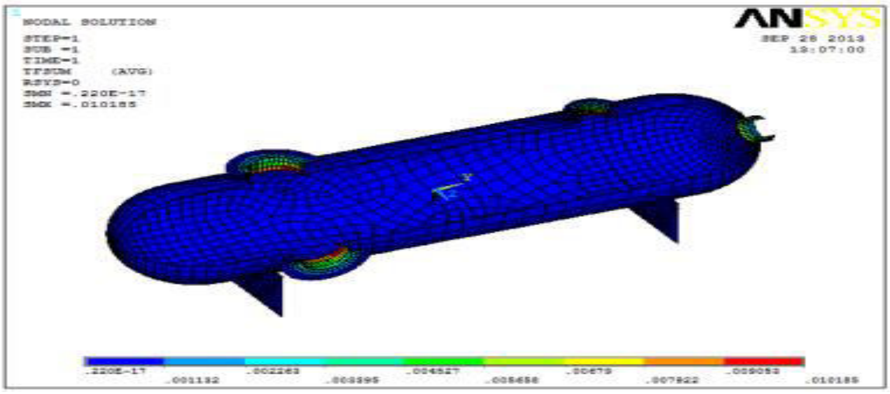

Figure 3: Thermal flux, value is 0.010185 K/mm

The thermal flux distribution in the analyzed structure using ANSYS. The thermal flux value is 0.010185 K/mm, indicating the amount of heat transfer per unit length in the material. The color map shows the variation in thermal flux, with blue representing areas of minimal heat transfer and red showing regions of higher heat flux

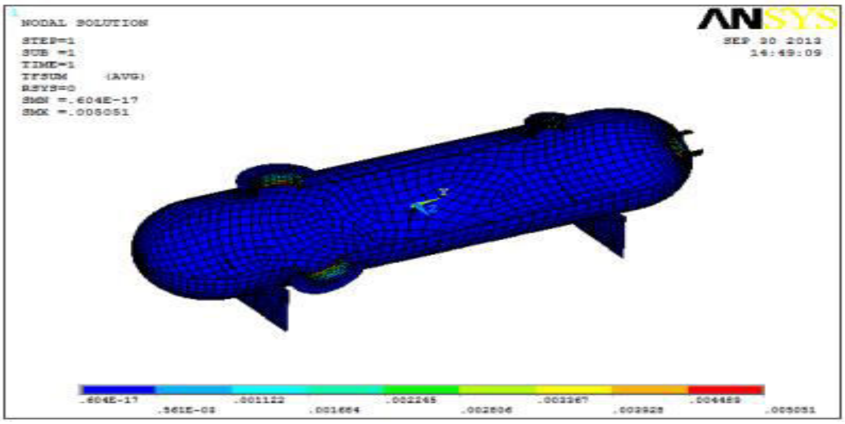

Figure 4: von-misses stress value 1031.84 N/mm2

The Von-Mises stress distribution in the analyzed structure, with the maximum stress value recorded at 1031.84 N/mm². This value indicates the highest concentration of stress within the material, suggesting potential risk areas for failure. The stress levels, represented by the color mapping, indicate that the material in this region is under significant loading, possibly approaching or exceeding the material's yield strength.

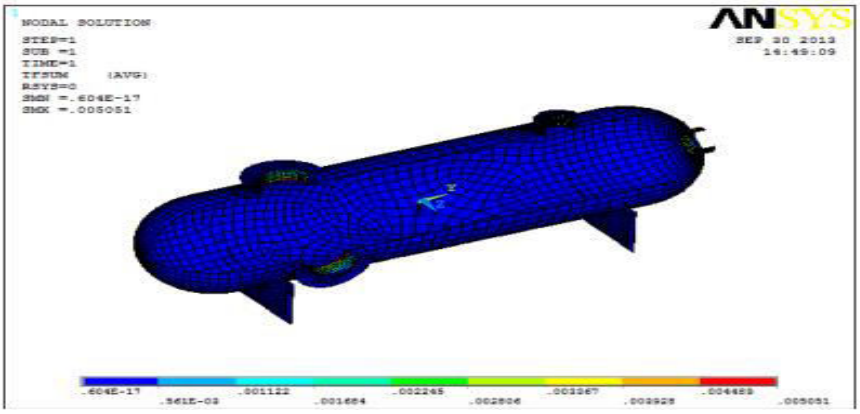

Figure 5: thermal flux, value is 0.010185 K/mm

The image illustrates the thermal flux distribution in the structure, with the recorded thermal flux value being 0.010185 K/mm. The thermal flux, shown through the color mapping, indicates how heat is transferred across the material. Areas in blue represent lower thermal flux, while red areas indicate higher heat transfer. This distribution is critical for assessing the temperature gradients within the structure and ensuring the material can manage the thermal loads without reaching critical temperature limits that could affect its integrity.

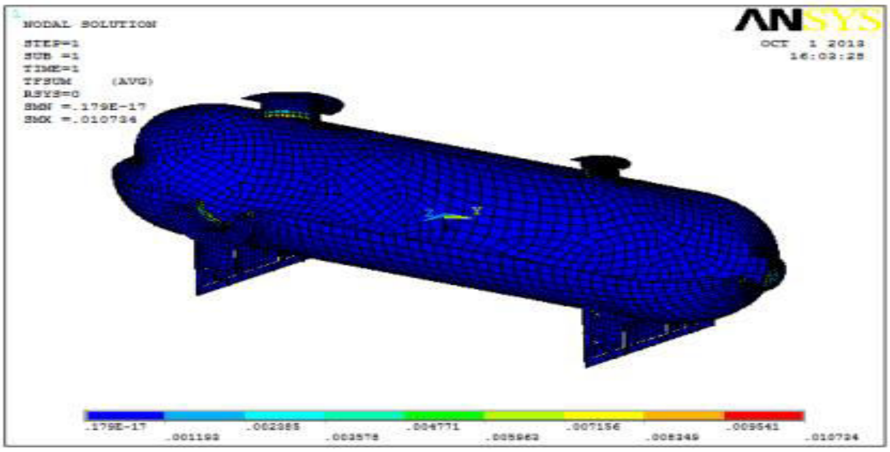

Figure 6: The above image shows von-misses stress value 1031.84 N/mm²

The image shows the Von-Mises stress distribution in the analyzed structure, with the maximum stress value reaching 1031.84 N/mm². This indicates that the material is under significant stress in certain regions, potentially near the yield point. The color mapping highlights areas of higher stress (shown in red) and lower stress (shown in blue). These critical stress areas need to be carefully examined to ensure that the structure can handle the applied loads without risking failure. It is essential to assess the material properties to ensure they can withstand the observed stress values.

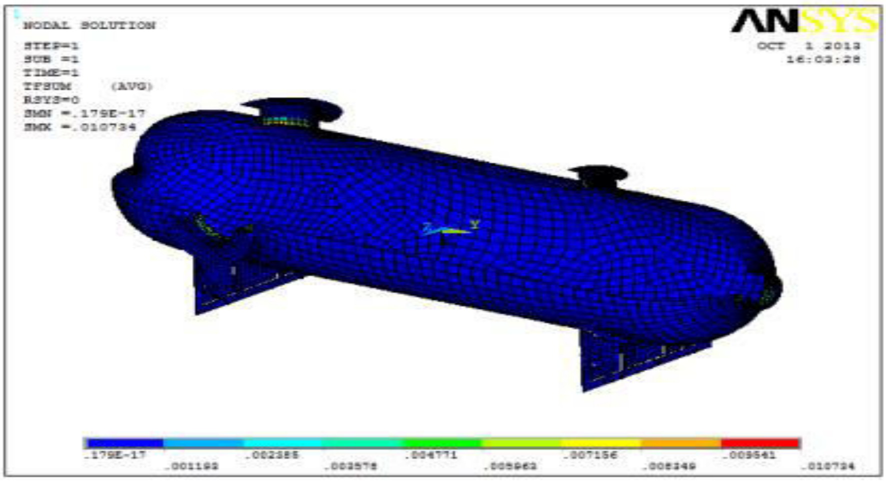

Figure 7: The thermal flux, value is 0.10734 N/mm^2

The image illustrates the thermal flux distribution in the structure, with the recorded thermal flux value being 0.10734 N/mm^2. This value represents the amount of heat transfer across the material. The color map in the image shows varying levels of thermal flux, with areas in blue indicating lower flux and those in red showing higher flux. Monitoring this flux is crucial for evaluating how the material handles thermal stresses, ensuring the system can operate within safe temperature limits without risking structural damage due to excessive heat buildup

Conclusion

In conclusion, the utilization of FRP composite materials in the design and modeling of pressure vessels offers significant advantages in terms of strength, durability, and efficiency. The enhanced strength-to-weight ratio and corrosion resistance of FRP composites enable the creation of pressure vessels that can withstand high pressures while being lighter and more cost-effective than traditional materials. Through the use of finite element analysis (FEA) software, engineers can simulate and optimize designs, ensuring safety and operational efficiency before actual manufacturing. The reduced weight and corrosion resistance of FRP composites not only lead to cost savings in manufacturing but also lower maintenance and repair costs, extending the overall lifespan of pressure vessels. The adoption of these advanced materials results in improved performance, reduced environmental impact, and greater economic efficiency in industries reliant on pressure vessels for storing and transporting volatile substances.

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