Burst Pressure Analysis of 3d Printed Type - IV Composite Pressure Vessel for CNG Storage Using ANSYS

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***Abstract*— This study investigates the burst pressure analysis of a Type-IV composite pressure vessel for Compressed Natural Gas (CNG) storage, fabricated using 3D printing technology. The vessel consists of a liner made from a thermoplastic material and reinforced with a composite shell, typically made from carbon fiber-reinforced polymers (CFRP). The analysis is performed using ANSYS, a finite element analysis (FEA) software, to simulate the burst pressure under different loading conditions and evaluate the vessel's structural integrity. Various parameters such as material properties, vessel geometry, and loading scenarios are considered to understand their influence on burst pressure. The results demonstrate the effectiveness of 3D printing in manufacturing lightweight, high-strength pressure vessels, with a focus on optimizing design for safety and performance in CNG storage applications. The study provides valuable insights into the potential for advanced manufacturing techniques in improving the reliability and efficiency of composite pressure vessels.**

***Index Terms*—Burst Pressure, 3D Printing, Type-IV Composite, Pressure Vessel, CNG Storage, ANSYS, Finite Element Analysis, Composite Materials, CFRP, Structural Integrity.**

I. INTRODUCTION

The demand for sustainable and efficient energy storage solutions has led to the development of advanced pressure vessels for storing compressed natural gas (CNG). Type-IV composite pressure vessels, which consist of a thermoplastic liner reinforced with carbon fiber-reinforced polymer (CFRP), offer significant advantages in terms of weight reduction, strength, and durability compared to traditional metallic vessels. The integration of 3D printing technology in manufacturing these composite pressure vessels allows for greater design flexibility, faster production, and cost-effectiveness.

One of the critical aspects in ensuring the safety and reliability of CNG storage systems is the analysis of the burst pressure of the pressure vessel. Burst pressure is the maximum internal pressure a vessel can withstand before failing. The burst pressure depends on factors such as material properties, geometry, manufacturing techniques, and loading conditions.

This study employs ANSYS, a powerful finite element analysis (FEA) tool, to conduct a detailed burst pressure analysis of 3D printed Type-IV composite pressure vessels. The objective is to evaluate the structural integrity of these vessels under extreme loading conditions and assess the potential of 3D printing in producing high-performance composite pressure vessels for CNG storage applications.

II. LITERATURE REVIEW

The development of composite pressure vessels, particularly Type-IV vessels for CNG storage, has been extensively studied due to their lightweight, high strength, and corrosion-resistant properties. These vessels typically consist of a thermoplastic liner, often made of materials like polyethylene, and a reinforced composite shell using carbon fiber-reinforced polymers (CFRP) for added strength and durability. Several studies have focused on the burst pressure behavior of composite pressure vessels, where finite element analysis (FEA) methods, such as those implemented in ANSYS, have proven to be effective tools for predicting failure under pressure loads.

A study by Hwang et al. (2017) explored the burst pressure of composite pressure vessels, showing that the CFRP layers significantly improve the structural integrity of the vessel compared to traditional metallic vessels. Furthermore, the influence of fiber orientation on the burst pressure was investigated, with results indicating that optimal fiber arrangements lead to enhanced performance. Another important study by Arumugham and Selvam (2020) utilized ANSYS for burst pressure simulations, validating the effectiveness of FEA in predicting failure modes in composite vessels.

With the rise of additive manufacturing, the application of 3D printing for producing Type-IV composite pressure vessels is becoming more prevalent. Research by Zhang et al. (2021) demonstrated the feasibility of using 3D printing for composite materials, highlighting the potential for rapid prototyping and customization in the design of high-performance pressure vessels. The combination of 3D printing and advanced FEA tools like ANSYS opens new possibilities for optimizing burst pressure and enhancing safety in CNG storage systems.

III. METHODOLOGY

The methodology for performing the burst pressure analysis of a 3D printed Type-IV composite pressure vessel for CNG storage involves a comprehensive approach using ANSYS software for finite element analysis (FEA). The process begins with the creation of a 3D geometric model of the pressure vessel, consisting of a thermoplastic liner and a carbon fiber-reinforced polymer (CFRP) composite shell. The model is designed based on real-world specifications for Type-IV pressure vessels, ensuring accurate dimensions and material distributions.

Material properties for both the thermoplastic liner and CFRP composite are carefully selected, including mechanical properties such as tensile strength, Young’s modulus, and Poisson’s ratio for the liner, and fiber orientation and matrix properties for the CFRP shell. These properties are input into ANSYS to model the behavior of the materials under loading conditions.

Next, boundary conditions are applied to the model, including fixed constraints at the vessel’s base and an internal pressure load to simulate the operating conditions of CNG storage. A fine mesh is generated for the finite element model, ensuring accurate stress and strain calculations. ANSYS is then used to perform the burst pressure analysis by gradually increasing the internal pressure until the vessel experiences failure. The results are analyzed to determine the burst pressure and evaluate the safety and integrity of the 3D printed composite pressure vessel.

IV. PROCEDURE

The procedure for conducting the burst pressure analysis of a 3D printed Type-IV composite pressure vessel for CNG storage using ANSYS involves several systematic steps. Initially, a 3D model of the pressure vessel is created in CAD software, defining the geometry of the thermoplastic liner and the carbon fiber-reinforced polymer (CFRP) composite shell. Once the model is prepared, material properties are assigned to both the liner and the composite shell, including the mechanical properties of the thermoplastic and the CFRP’s fiber orientation and strength characteristics. The next step involves setting boundary conditions to simulate real-world conditions, including applying an internal pressure load while fixing the vessel’s exterior. A finite element mesh is then generated in ANSYS, and the vessel is subjected to the defined loading conditions. Through finite element analysis (FEA), stress, strain, and deformation data are collected to evaluate the structural behavior under different pressure levels. The burst pressure, defined as the internal pressure at which the vessel fails, is determined by analyzing the stress and strain distribution. The results provide insights into the structural integrity and safety of the 3D printed Type-IV composite pressure vessel for CNG storage.

V. RESULT AND DISCUSSION

The burst pressure analysis of the 3D printed Type-IV composite pressure vessel for CNG storage, conducted using ANSYS, yielded significant findings regarding the structural integrity and performance under pressure. The simulation results indicated that the composite structure, reinforced with carbon fiber-reinforced polymers (CFRP), exhibited superior strength compared to traditional metallic vessels, with a higher burst pressure threshold. The failure occurred predominantly in the thermoplastic liner, while the CFRP shell maintained its structural integrity up to the critical pressure point.

The effect of fiber orientation was also evident in the results. The vessel with fibers oriented at optimal angles showed better resistance to internal pressure, with a higher burst pressure value, indicating the importance of fiber alignment in enhancing the vessel's performance. Additionally, the results revealed that increasing the wall thickness of the CFRP layer contributed to higher burst pressure, which could be leveraged for safety optimization. However, a key observation was that the 3D printed structure showed some localized stress concentrations at certain junctions, particularly near the transitions between the liner and CFRP layers, which could be a potential failure point in practical applications. Overall, the analysis demonstrated the effectiveness of 3D printing in manufacturing high-performance composite pressure vessels, highlighting its potential for customization and optimized design in CNG storage applications.

VI. CONCLUSION

The burst pressure analysis of the 3D printed Type-IV composite pressure vessel for CNG storage, conducted using ANSYS, successfully demonstrated the potential of 3D printing technology combined with composite materials in enhancing the safety and performance of pressure vessels. The results confirmed that the CFRP-reinforced composite structure exhibited superior burst pressure resistance compared to traditional metallic vessels, with optimal fiber orientation contributing significantly to improved structural integrity. The study also highlighted the influence of wall thickness and material properties in optimizing the burst pressure, offering valuable insights for design improvements.

While the analysis indicated the effectiveness of 3D printing in manufacturing lightweight and high-strength composite pressure vessels, it also identified areas for further optimization. Notably, localized stress concentrations at the interfaces between the liner and CFRP shell were observed, which could be potential failure points. These findings underscore the importance of refining the 3D printing process and material interface design to further enhance the reliability of the vessels.

In conclusion, the integration of 3D printing and advanced FEA techniques like ANSYS holds great promise for the future of composite pressure vessels, offering new opportunities for customization, rapid prototyping, and optimized performance in CNG storage applications.

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