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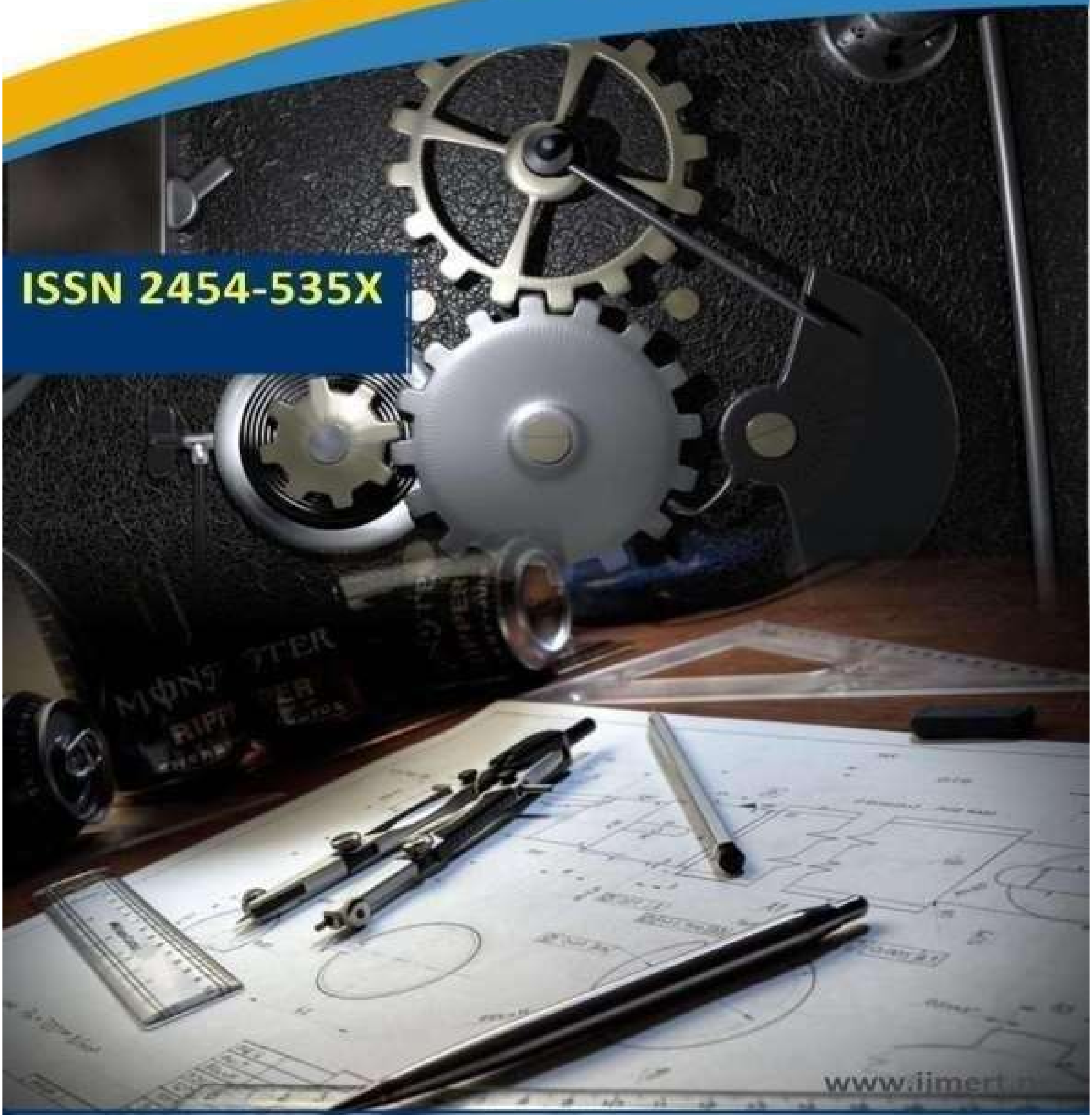

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DESIGN AND STATIC STRUCTURAL, IMPACT ANALYSIS ON TYPE IV HYDROGEN FUEL TANK USING ANSYS SOFTWARE

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ABSTRACT

Using ANSYS software for static structural and impact analysis, this research investigates the design and structural integrity of a Type IV hydrogen fuel tank. In order to maximise safety and performance in automotive applications, the tank has a unique dual-layer composition consisting of a 3mm outer shell made of carbon fiber-reinforced polymer (CFRP) with epoxy resin based on bisphenol A and bisphenol F and an inner layer made of high-strength aluminium alloy (7068-T6511). The static structural study, which ensured compliance with strict safety criteria, evaluated stress distribution and deformation in the tank under high-pressure circumstances using finite element analysis (FEA). The impact study verified the structural integrity and longevity of the combined materials by running simulated scenarios and further examining the tank's resistance to collision forces. The results show that although the CFRP exterior layer greatly adds to the tank's lightweight and improves its impact resistance, the aluminium inner layer efficiently retains the hydrogen at high pressures. These results highlight how these composite materials may improve the sustainability, safety, and effectiveness of hydrogen storage systems. According to the study's findings, the usage of high-strength aluminium alloy in conjunction with epoxy resin and CFRP not only satisfies but surpasses the performance standards set now for hydrogen fuel tanks, which has encouraging implications for the development of hydrogen-powered vehicles in the future.

Keywords: impact analysis, hydrogen fuel tank, and finite element analysis (FEA).

I. INTRODUCTION

More people are realising that hydrogen fuel is essential to the world's transition to sustainable energy. Hydrogen, a clean and effective energy source, has the potential to significantly contribute to the decarbonisation of a number of industries and sectors, including power production, transportation, and industry. Because of its high energy content by weight and capacity to create water as the sole waste when used in fuel cells, its usage as a fuel is essential to attaining a low-carbon future.

Hydrogen Production

Numerous technologies, such as steam methane reforming, water electrolysis, and thermochemical reactions, may be used to manufacture hydrogen fuel. Every approach has pros and downsides that should be taken into account, including cost, environmental effect, and efficiency. A production method's selection is often influenced by the technical infrastructure, resource availability, and particular application requirements.

Hydrogen Storage and Distribution

The effective delivery and storage of hydrogen fuel is a major obstacle to its widespread use. At room temperature, hydrogen has a low volumetric energy density, thus it must be transported and stored under high pressure, as a liquid at cryogenic temperatures, or via chemical carriers. As a result of these demands, many

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hydrogen storage methods have been developed, such as solid-state hydrogen storage, high-pressure tanks, and liquid hydrogen storage.

Hydrogen Fuel Tanks

Hydrogen fuel tanks are crucial components in hydrogen fuel infrastructure, designed to safely store and dispense hydrogen for various applications, especially in the automotive industry. There are four main types of hydrogen tanks, categorized based on their construction materials and design:

Type I Tanks: These are the simplest form of hydrogen storage tanks, made entirely of metal, such as steel or aluminum. They are heavy and typically operate at lower pressures compared to other types.

Type II Tanks: Type II tanks are constructed with a metal liner and partially wrapped with composite materials like carbon or glass fibers. This design reduces the weight of the tank while allowing for higher storage pressures.

Type III Tanks: These tanks feature a metal liner fully wrapped with composite materials, further reducing weight and enabling even higher storage pressures. The metal liner ensures gas impermeability, while the composite wrap provides strength.

Type IV Tanks: The most advanced among all, Type IV tanks have a non-metallic liner (often made of plastic) that is fully wrapped with composite materials, such as carbon fiber. This design offers the highest strength-to-weight ratio, allowing for maximum storage capacity and safety at high pressures. Type IV tanks are particularly suitable for automotive applications, where weight reduction is crucial for performance and efficiency.

Problem Identification

The transition to hydrogen as a fuel source poses several engineering challenges, especially in the storage and transportation of hydrogen. Traditional fuel tanks are inadequate for hydrogen storage due to hydrogen's unique properties, including its low volumetric energy density and the requirement for storage under high pressure or at cryogenic temperatures. Furthermore, safety concerns, such as the risk of hydrogen embrittlement in metal components and the need for tanks to withstand high-impact scenarios, necessitate innovative solutions. Type IV hydrogen fuel tanks, made from composite materials, offer advantages in weight and strength but require careful design and analysis to ensure safety, durability, and cost-effectiveness.

Objective of the Project

The primary objective of this project is to enhance the safety, durability, and performance of Type IV hydrogen fuel tanks through design and comprehensive analysis. Specific goals include:

1. To propose design standards to optimize the structural efficiency of Type IV hydrogen fuel tanks.
2. To evaluate the tank design for static structural integrity, including stress distribution and deformation under operational loads.
3. To analyze the fatigue life of the tank under cyclic loading conditions, ensuring long-term reliability.
4. To assess the tank's impact resistance through explicit dynamic analysis, simulating high-impact scenarios.
5. To use ANSYS software for all analytical evaluations, leveraging its capabilities for precise and comprehensive analysis.

II. LITERATURE REVIEW

Senthil kumar, Bibin et.al-(1): Among many hydrogen storage patterns including high-pressure gaseous storage, cryogenic liquid storage and chemical hydrogen storage, high-pressure gaseous storage has become the most popular technique. The basic requirements for the design of storage

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vessels are safety, reliability and economy. However, the composite pressure vessels may work under the highpressure and high-temperature environment.

Pawan N Naik, et.al-(2): Three-dimensional modelling and analysis of a hydrogen gas container with different combination of materials have been successfully carried out. Static structural analysis and fatigue life estimation of hydrogen fuel tank using aluminium, Aluminum + Epoxy, and Aluminium + carbon fibre have been successfully carried out using finite element tool.

Juan pedro berro ramirez, et.al-(3): A FE model of a type IV wound composite pressure vessel has been developed. In order to simulate properly the burst test, a continuum damage model dedicated to wound composites has been used. The results obtained are fairly good: the difference between the simulated burst pressure and the actual one is 7.74%. In this structure, fiber breakage is the most important damage mode, as it leads to tank burst. Even if this mode drives the burst process, the use of a complex damage model is justified by the existence and prediction of other phenomena related to matrix cracking or delamination

Rahul Krishna, Elby Titus, et.al-(4): The hydrogen revolution following the industrial age has just started. Hydrogen production, storage and conversion have reached a technological level although plenty of improvements and new discoveries are still possible. The hydrogen storage is often considered as the bottleneck of the renewable energy economy based on the synthetic fuel hydrogen. Different hydrogen storage methods and materials have been described already and need to be study more.

Karen Law, and Jayanti et.al-(5): The performance and cost of compressed hydrogen storage tank systems has been assessed and compared to the U.S. Department of Energy (DOE) 2010, 2015, and ultimate targets for automotive applications. The on-board performance and high- volume manufacturing cost were determined for compressed hydrogen tanks with design pressures of 350 bar (~5000 psi) and 700 bar (~10,000 psi) capable of storing 5.6 kg of usable hydrogen. Shitanshu Sapre s et.al-(6): The ply based modeling approach was used to develop the FE model of the composite structure. The FE analysis was conducted to investigate the mechanical and thermal behavior of each layer under severe loading conditions. The paper presents a comprehensive analysis of composite tank including stress, strain, deformation and failure pressure of the tank.

III. METHODOLOGY

Hydrogen fuel cell technology is gaining momentum as a potential solution for clean and sustainable transportation. A critical component of this technology is the hydrogen storage tank. Type IV hydrogen fuel tanks, composed of a polymer liner reinforced with composite materials, offer a promising option due to their lightweight and high-pressure capacity. However, ensuring the safety and durability of these tanks is paramount. Here, we review the literature on the application of static structural analysis and explicit dynamics simulations for evaluating the performance of Type IV hydrogen fuel tanks.

Design a 16mm thick inner liner made of high-strength aluminum alloy (7068-T6511). This layer provides excellent strength and serves as a primary barrier against hydrogen permeation. Envelop the aluminum liner with a 3mm thick layer of CFRP epoxy resin(bisphenol A and bisphenol F-based). CFRP offers a lightweight yet strong solution for containing pressure and enhancing overall structural integrity. Consider incorporating metallic or composite stiffeners strategically placed on the CFRP layer to improve buckling resistance and manage stress concentrations.

Modeling:

Utilize CATIA V5 to create a 3D model of the modified tank design, incorporating the proposed 16mm high-strength aluminum alloy liner, 3mm CFRP outer layer, and optional stiffeners.

Ensure the model accurately reflects the dimensions, material properties, and overall geometry of the tank.

Material Used

For the Type IV hydrogen fuel tank, the materials chosen are crucial for achieving the desired balance of weight, strength, and safety:

Inner Layer: High-strength aluminum alloy (7068-T6511) liner with a thickness of 16mm. This layer provides excellent strength and acts as the primary barrier against hydrogen permeation.

Outer Layer: A 3mm layer of CFRP epoxy resin (bisphenol A and bisphenol F-based) for containing pressure and enhancing structural integrity while maintaining a lightweight design.

Table 1: Material Properties

Material Properties	High Strength Aluminum Alloy (7068 T-6511)	Cfrp Epoxy Resin
Density	2.85g/c^3	1.8g/c^3
Tensile Strength	710MPa	5000MPa
Young'S Modulus	73.2GPa	250GPa
Specific Heat	1.05J/g-•c	1.3J/g-˚c
Thermal Conductivity	190W/m-K	400W/m-K
Melting Point	476-635˚c	200˚c

Table 2: High Strength Aluminium Alloy (7068 T6511) Materials Composition

Component Elements Properties	Metric
Aluminium, Al	85.48-88.85%
Copper, Cu	1.6-2.4%
Magnesium, Mg	2.2-3.0%
Zinc Zn	7.3-8.3%
Manganese, Mn	0.10%
Silicon, Si	0.12%
Titanium, Ti	0.10%
Chromium, Cr	0.050%
Zirconium, Zr	0.050-0.15%

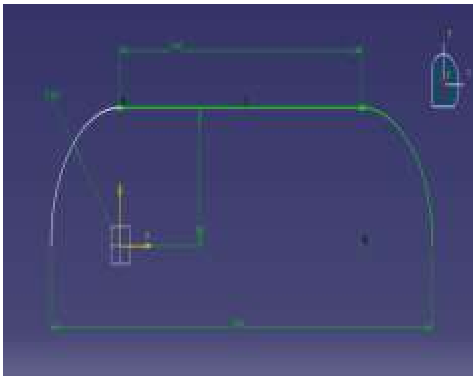

Fig1: Geometry model

Fig 2: Isometric Type IV Hydrogen fuel tank

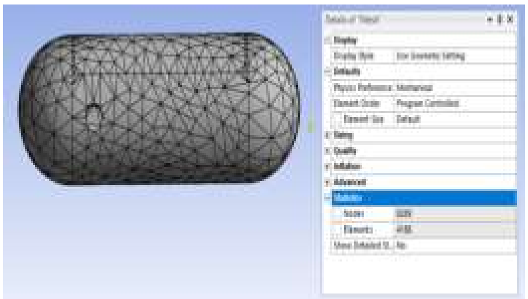

Fig 3: Meshing model

IV. RESULTS AND DISCUSSIONS

Type 4 hydrogen fuel tanks are specifically designed for hydrogen storage in various applications, primarily in the automotive industry. These tanks are distinguished by their construction, which utilizes advanced materials to handle the high pressures required for hydrogen gas. Unlike earlier types, Type 4 tanks feature a fully composite structure, often with an internal liner made from materials like high-strength aluminum to ensure gas impermeability.

Material Selection for the Tank Construction

For the construction of the Type 4 hydrogen fuel tank investigated in this project, the material arrangement was reversed. We opted for a 16mm high-strength aluminum alloy (7068-T6511) liner as the innermost layer, providing exceptional strength and acting as the primary barrier against hydrogen permeation. This aluminum layer is then enveloped by a 3mm thick layer of CFRP (Carbon Fiber Reinforced Polymer) epoxy resin(bisphenol A and bisphenol F).

The CFRP with epoxy resin serves as the outer layer, offering an excellent strength-to-weight ratio. This choice is crucial as it significantly reduces the overall weight of the tank while maintaining the tank's structural integrity under pressure.

Static Structural Analysis

The static structural analysis conducted as part of this study focused on evaluating the mechanical integrity of the tank under typical operating conditions. The analysis simulated the stresses and deformations of the tank materials when subjected to internal pressures typical of hydrogen storage (up to 800 bar). Key aspects considered included the stress distribution across different layers of materials and the deformation responses of these materials under maximum load conditions.

The findings from the static structural analysis are crucial for assessing the effectiveness of this reversed material configuration. The analysis will determine how well the 16mm high-strength aluminum(7068 T6511) liner performs as a primary barrier and how the 3mm CFRP Epoxy Resin (bisphenol A and bisphenol F) outer layer contributes to the overall structural rigidity of the tank under pressure.

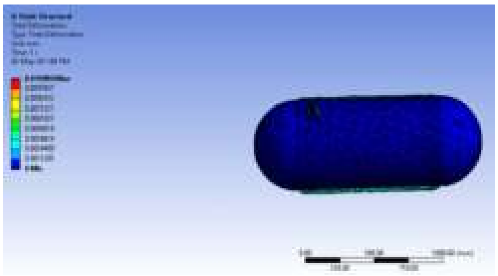

Fig 4: Total Deformation Of Tank At 80Mpa Pressure(800bar)

Equivalent Stress:-The Type IV hydrogen fuel tank with 16mm High strength Aluminium as inner layer and 3mm CFRP have achieved and maximum stress distribution of 91.32N/mm2 in the ansys workbench simulation.

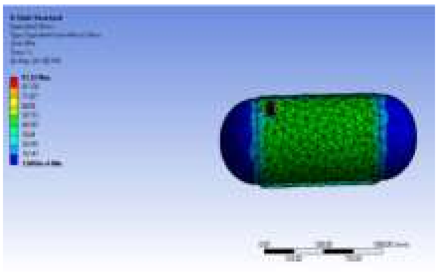

Fig 5: Equivalent stress

Fatigue Life:-In the above simulations we have got an minimum life expectancy as 717320 cycles of pressurization and depressurization process before failure occurs.

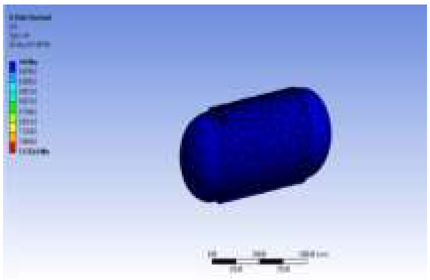

Fig 6: Fatigue Life of The Tank

Fatigue life is the number of cycles of stress that a material can withstand before it fails.

Fatigue strength is the stress level that a material can withstand for a given number of cycles. The worksheet shows a graph of a Goodman diagram, which is a plot of stress vs. cycles to failure for a material. The Goodman diagram is used to predict the fatigue life of a material under a fluctuating load.

Impact Analysis

To complement the static structural analysis, an explicit dynamics analysis was also conducted. This type of analysis is crucial for understanding the tank's response to dynamic loading conditions, such as those experienced during a high-speed impact or sudden pressure surges. The dual-material strategy of using aluminum and CFRP proved effective in distributing the dynamic loads across the tank's structure, thus preventing localized failures and ensuring that the tank could withstand typical accidental impacts without leakage or rupture.

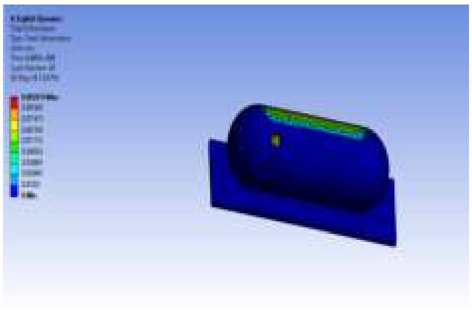

Fig 7: Impact Analysis Results

Within ANSYS explicit dynamic analysis, the concept of "energy summary" plays a crucial role. This summary tracks various forms of energy throughout the simulation, including the "sum of impact energy." This particular term refers to the total amount of energy introduced into the system during an impact event. By analyzing the energy summary plot, we can gain valuable insights into the energy transfer mechanisms within the model. The graph likely depicts the "sum of impact energy" over time steps in the simulation. A decreasing trend in this value might indicate energy dissipation through mechanisms like plastic deformation, heat generation, or sound waves. Conversely, a sudden increase could suggest a secondary impact or energy transfer within the model. Monitoring and interpreting the energy summary, particularly the "sum of impact energy," is essential for validating the accuracy and understanding the energy flow within your ANSYS explicit dynamic analysis.

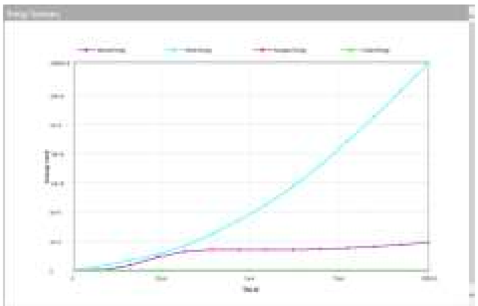

Fig 8: Energy Summary Of Impact Analysis

V. CONCULSION

Using ANSYS Workbench, this study examined the safety and structural performance of a Type IV hydrogen fuel tank under impact and static loading scenarios. The design of the tank included an outside layer made of 3 mm carbon fibre reinforced polymer (CFRP) epoxy resin (bisphenol A and bisphenol F) and an inner liner made of 16 mm high-strength aluminium (7068-T6511). A minimum fatigue life of 717320 cycles was found in the static structural study, indicating high durability for the selected materials and structure. This suggests that before fatigue becomes an issue, the tank can tolerate pressure changes for at least this many cycles. Additionally, the study showed that the stress distribution throughout the tank wall was quite uniform, which suggests that the structure would hold up well under pressure. Using explicit dynamics in ANSYS Workbench, the impact analysis produced a maximum deformation of 0.090274 mm. This number gives information on the tank's resilience to shocks during use or transit, including with

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any stress concentrations that may have been seen. It is important to bear in mind that a single impact scenario and static analysis are simplified examples. There are many different dynamic loads and possible effects in real-world usage. As a consequence, one should regard the findings as cautious approximations. More research that takes into account a larger variety of dynamic loads and impact scenarios is advised in order to provide a more thorough evaluation of the tank's general safety and fitness for usage in practical applications.

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