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A REVIEW ON DESIGN AND ANALYSIS OF SUBMARINE AUV PRESSURE HULL USINGDIFFERENT MATERIALS WITH FEM

K. AJAY, M. LOKESH KUMAR, K. AKHIL, UG students, Department of Mechanical Engineering, NRI Institute of Technology, Vijayawada, A.P, India-521212.
Mr.G. DURGA PRASAD Associate Professor, Department of Mechanical Engineering, NRI Institute ofTechnology, Vijayawada, A.P, India-521212.

ABSTRACT

The pressure hull is a critical component. In This study the main load-bearing structure of submarines is the pressure shell. This paper focuses on the modeling and structural analysis of an Autonomous Underwater Vehicle (AUV) pressure hull using different materials, employing the Finite Element Method (FEM). FEM analysis provides detailed the stress distribution, deformation, and failure modes of the hull under various loading and depth conditions. Obtained Results the sandwich materials can significantly enhance the performance and durability of the pressure hull.
Keywords: AUV, safety, under water vehicles, stress distribution FEM.

Introduction

A brief study of A submarine hull has two major components, the light hull and the pressure hull. The light hull (casing in British usage) of a submarine is the outer non-watertight hull which provides a hydro dynamically efficient shape. The pressure hull is the inner hull of a submarine that maintains structural integrity with the difference between outside and inside pressure at depth

Literature

There are different types of methods used to design modelling a submarine pressure hull with different materials, advantages and disadvantages. We studied some of the journal papers and mentioned them below: Chenxing Xin a,et.al., [1]This study explores a cylindrical submarine pressure shell with a corrugated stiffening structure. Aluminum shells were tested under high hydrostatic pressure to determine failure loads. Results showed minimal variation in critical buckling loads, confirming test reliability. Numerical simulations matched experimental results well, demonstrating the effectiveness of reverse modeling techniques. This approach offers valuable insights for designing and predicting submarine shell performance. [2] This study examines the buckling behavior of wave-shaped pressure hulls under uniform external pressure, focusing on how slant angles (0° to 30°) influence performance. A formula was developed to estimate the load-bearing capacity of these hulls. Experimental and numerical analyses, including hydrostatic testing of a hull with a 15° slant angle, validated the results. Findings indicate that wave-shaped hulls with a slant angle of 14°–16° offer superior load-bearing capacity compared to cylindrical hulls. The study provides key insights into optimizing pressure hull design for improved structural performance. [3] This study examines the resistance and towing performance of a tourist submarine model at a 1:5.0 scale in a towing tank.

Tests showed that resistance is lower on a calm surface than in deep water, with a steep rise above 5 knots in deep water. CFD analysis using OpenFOAM largely agreed with the experimental data but overestimated resistance by up to 7% at 6 knots. [4] This paper explores the design and development of subsea Autonomous Underwater Vehicles (AUVs), focusing on enhancing their structure, motion, and communication capabilities for better seabed observation. It addresses the limitations of traditional methods and presents a disk-shaped autonomous underwater helicopter (AUH) as a solution for more effective seabed exploration and detection. [5] This paper reviews the structural failure of composite pressure hulls in deep-sea applications, focusing on three primary failure modes: overall buckling, material failure, and snap buckling. The study highlights that overall buckling is a major concern, particularly for thin or long composite shells used in underwater vehicles.

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It summarizes theoretical, numerical, and experimental findings that have advanced understanding of the buckling failure mechanisms under external pressure. [6] This study examines the impact of various exostructure elements on a submarine's resistance compared to the pressure hull.

The research, conducted using the RANS-based CFD method, focuses on a 25m long tourist submarine designed for depths up to 40m and a speed of up to 3 knots. The study finds that exostructural elements significantly increase the submarine's resistance, more than doubling it compared to the smooth pressure hull. [7] Underwater safety relies on accurate speed logs, which are placed in areas with smooth, continuous water flow. This study numerically describes the flow around two submarines in deep-water and near-surface conditions to identify hull zones for probe installation.

The numerical methodology used is reliable at the engineering level, with results showing strong nonlinear effects due to proximity to free-surface. The side probe sensor could be installed at P1 location, as it presents continuous flow without recirculating zones or vortex cores. The probe will be located close to the acceleration region at bow. [8] The study examines the performance parameters of an Autonomous Underwater Vehicle (AUV) based on varying hydrodynamic characteristics based on angular positions. It uses Computational Fluid Dynamics (CFD) analysis to calculate hydrodynamic coefficients, total resistance, and moments. The data is used to evaluate energy requirements, power requirements, thruster operating data, and navigational performance results. Variations in yaw angle significantly affect drag force, lateral force, and yaw moment. [9] This study analyzes and optimizes a sandwich composite deep submarine pressure hull using finite element modelling technique. The goal is to minimize buoyancy and maximize deck area and buckling strength factors. The hull is designed using T700/Epoxy and (4)5505/Epoxy composite materials, with a thick core recommended for shell resistance. The study considers material failure, buckling, and deflection, and applies the design to extreme depths. [10] This paper discusses design methods for the plastic hull of an Unmanned Underwater Vehicle (UUV), focusing on its cylindrical body and spherical domes. It compares literature methodologies and proposes an innovative method for designing underwater hull domes and predicting collapse pressures.

The paper presents theoretical and experimental investigations, demonstrating a consistent relationship between classic naval design and innovative methods. The paper introduces correction coefficients to improve predictive capacity of algorithms, resulting in satisfactory results. [11] A database of hydrodynamic loads for a generic submarine hull with a casing is proposed due to a lack of data on loading effects. Steady-state Navier-Stokes simulations were conducted on the Joubert BB2 generic submarine hull, finding that adding a casing can alter in-plane hydrodynamic loads by at least 30% and introduce out-of-plane loads. Experimental results show good agreement between CFD predictions and measurements, except for the out-of-plane moment. [12] A shallowly submerged submarine under the free surface experiences a larger resistance force, lift force, and pitch moment, which vary periodically with Froude number. The interaction between the bow and aft shoulder waves has a dominant effect on these forces. The study analyzes the free surface's effect on the hydrodynamics of a shallowly submerged submarine, focusing on whether the interaction between the bow and aft shoulder waves or the bow and stern waves has a more dominant effect. [13] This paper provides a comprehensive review of marine impact on marine composites, focusing on the complexity of damage and dependence on various materials and impacts. It reviews over 1500 references and a bibliography of nearly 200 studies from 2007 to 2017.

The paper emphasizes the need for specific data and information on the impact on marine composites, as the materials and impacts in the marine industry are distinct from those in the aerospace industry, which has driven most research and standards development. [14] This study measured surface pressure distributions and boundary layer profiles over a submarine model's nose surface in a wind tunnel. It examined the effects of nose shape on the wind around the model. The study also examined the effects of Reynolds numbers, pitch angles, longitudinal pressure gradient, boundary layer velocity profiles, and separation probability on the nose's plane of symmetry. The results provide insights into wind behavior and surface pressure distributions. [15] The study investigates the suitability of S-Glass/carbon Fiber reinforced polymer composite for submarine hulls under hydrostatic pressure. The composites were tested for mechanical stability and impact resistance. The study used Finite Element Analysis to analyze the bow, stern, and foil, revealing that the optimal shape and thickness were found to be elliptical bows, conical sterns, and elliptical hydrofoils. The study also found that the composites absorbed 10.3 J of impact energy due to excellent interfacial bonding. [16] Submarines are underwater weapon systems that covertly attack enemies. Their pressure hull is crucial for protecting crews from high pressure and air pollution. Analytical and numerical methods have shown that the pressure hull dimensions proposed in the initial scantling equations are safe for shell yielding and buckling pressure, with strength calculations within an error range of 4.96%. [17] Underwater vehicles are increasingly important for ocean exploration and sub-sea operations, with pressure hulls providing load capacity and buoyancy. Ring- stiffened hulls are widely used, with a carbon fiber reinforced polymer chosen for optimization.

The pressure hull is designed for 2000m water depth, consisting of a metal liner and outer winding fiber reinforced composite material. Three composites were selected for failure criteria. [18] This paper proposes a bio-inspired hull shape for an underwater vehicle (AUV) using humpback whales' body shape. The design considers hull drag and displacement volume, improving space utilization and voyage. The optimization is performed using response surface methodology (RSM) and translational propagation Latin hypercube design (TPLHD). The proposed BHS is suitable for underwater vehicles with longer distance, higher speed, or better sensor carrying capacity. [19] The study examines the dynamic buckling of a cylindrical shell under a side-on underwater explosion shock wave using a three-dimensional acoustic-structural numerical simulation. Key findings reveal fluid perturbation, pressure division, stress wave deflection, shell deformation, and a dumbbell-shaped damage pattern. These insights can be used to design pressure hulls and enhance underwater equipment impact resistance. [20] The study examines the mechanical properties of HY 80 steel from the hull of the Polish submarine ORP Jastrząb, which has been in service for 60 years. Static and dynamic tests were conducted, and a Johnson-Cook model was developed using finite element analysis. Results showed the steel maintained its mechanical properties over 55 years, with yield and strength values close to catalog values.
Future research will address deformation measurement issues and refine failure parameters. [21] The study examines the hydrodynamic performance of a portable autonomous underwater vehicle (AUV) using computational fluid dynamics (CFD). It introduces the mechanical structure and dynamic model, estimates hydrodynamic coefficients, and analyzes the impact of surface waves. The method is validated through experiments and a physical platform for further investigation. Future research aims to shape design and control strategies for AUVs. [22] The study examines the collapse behavior of filament- wound cylindrical submarine hulls under hydrostatic pressure using finite element analysis (FEA). It compares the strength of composite and aluminum hull models, assessing stacking angles and ply thickness. Results show that using accurate engineering constants can predict collapse pressure, highlighting the advantages of lightweight materials for improved performance while maintaining structural integrity. Future work includes experimental tensile tests to refine engineering constants. [23] The study optimizes a composite submerged pressure hull under 3 MPa hydrostatic pressure using various layup configurations. Using Carbon/Epoxy, Glass/Epoxy, and Boron/Epoxy materials, the hull's thickness is 41 mm, and the maximum Von-Mises stress is 89.997 MPa. The optimum design parameters are assessed using ABAQUS and ISIGHT. The minimum buoyancy factor for the steel hull is 0.50417, and the optimized layup is [011/9053/030]. [24] This study explores the use of the inverse Finite Element Method (iFEM) for Structural Health Monitoring (SHM) in submarine pressure hulls. The research focuses on optimizing sensor placement to enhance SHM systems' effectiveness.

The iFEM approach offers precise shape-sensing capabilities, providing critical data on submarines' structural condition and performance in deep-sea conditions. The iQS4 shell element, a variant of iFEM, proves effective for developing SHM systems for complex shell structures. [25] This study examines the impact of corrosion damage on submarine pressure hulls, focusing on corroded ring-stiffened cylinders. The research found a significant reduction in residual strength for corroded models compared to intact ones. Numerical simulations validated the method for assessing corrosion-affected hulls. The study also highlighted the need for accurate analysis methods to estimate residual strength and the influence of corrosion on buckling failure modes. [26] This study optimizes a Multiple Intersecting Cross Elliptical Pressure Hull (MICEPH) to increase payload capacity and withstand hydrostatic pressure and underwater explosions. The design was analyzed for fluid-structure interaction and UNDEX using ABAQUS/Explicit. Results showed the highest acceleration in the athwart direction, with the first bubble pulse significantly affecting it. The analysis predicts pressure hull failure indices and captures the dynamic response to UNDEX, providing a robust method for evaluating pressure hull performance. [27] The project analyzed pressure vessels with different head types and materials using ANSYS software. The study found that elliptical heads have lower stress concentrations. The analysis focused on static and thermal stresses in vessels supported by saddles, determining the most suitable design and material for minimizing stress.
The vessels were designed for industries with low weight to strength ratios, suitable for wet conditions and high relative humidity. [28] This study introduces sliding stiffeners as an innovative structural design approach for Autonomous Underwater Vehicles (AUVs) pressure vessels. The study uses CATIA and ANSYS to analyze four material cases, including steel, rubber, and Ti64Al sandwich beams. The static and modal analysis of stresses, strains, and deformations provide insights into the optimal structural design for AUV pressure vessels. The pressure hull's stresses and deflections are calculated under an external pressure of 65 bars [29]. This paper presents a "virtual wind tunnel" simulation to study the influence of hull and sail shapes on underwater vehicles. Numerical results were validated against experimental data and modern technologies like optronic periscopes and sonar integration were explored. The simulation was run for 2000 iterations, with a magnitude of 2.022×10^{-3} remaining consistent after 800 iterations. [30] The study focuses on optimizing the hydrodynamic shapes of autonomous underwater vehicles (AUVs) to reduce drag force and energy consumption. Using Navier-Stokes equations and k-e Realizable turbulence modeling, the research achieved validation results with differences of 3.6% and 1.4% compared to numerical and experimental data. Geometry no. 5, featuring optimized nose and tail designs, showed the lowest drag force of 7.6349492 N. [31] The study aims to improve the prediction of the residual ultimate strength of submarine pressure hulls after collisions, a problem that current methods struggle with. It uses numerical simulations and empirical equations to address this gap. The equations, valid against test data, are effective for initial design and serviceability assessments. Future research should focus on full submarine dimensions and fractured pressure hulls. [32] The study examines probes for optimal defect assessment using the Phased Array Ultrasonic Testing (PAUT) method.

Two sets of probe design parameters were selected based on pressure hull characteristics and analyzed through modeling. Defect assessment results were compared using ultrasonic signals from simulated defects in specimens designed to simulate actual pressure hulls. The final design parameters improved the probe's ability to detect defects and improved defect length measurement accuracy, enhancing the technique's applicability. [33] This article provides a comprehensive review of the hydrodynamic characteristics of autonomous underwater vehicles (AUVs), covering experimental techniques, towing tank fixing, hydrodynamics-based shape optimization, drag reduction studies, and turbulence models used in numerical simulations. It also introduces numerical methods for analysis and recommends hydrodynamically optimized shapes. The study aims to improve design, control, and optimal path planning for AUVs in the deepest oceans. [34] This paper examines the buckling analysis of a stiffened cylindrical pressure hull under bearing load in

Vietnam's sea environment. The study uses finite element analysis software packages to model the structure. The results show that the buckling strength for different thickness models is higher than the buckling strength. The model is divided into three meshing strategies, with the Lmesh size of 50mm, 75mm, and 100mm, resulting in varying ultimate strength values. The Lmesh size of 50mm is the best choice for nonlinear analysis. [35] This study compares three pressure hulls for underwater vehicles, focusing on carbon fibre, steel (HY100), and titanium alloy.

Finite element analysis using ANSYS revealed that carbon fibre had the best buoyancy factor and minimum mass. HY100 had the least deformation but a higher failure index. Titanium alloy came in second place in all parameters. This research could be useful for pressure hull designing underwater vehicles. [36] This project focuses on designing an autonomous underwater vehicle (AUV) using SolidWorks CAD simulation software. The AUV was designed part by part, and the battery enclosure stress and strain simulation and flow simulation of 3-blade propeller T100 thrusters were conducted. The stress and strain simulations showed the enclosure box's durability and the maximum depth the AUV could reach without plastic deformation. The flow simulation provided tools for testing the thruster's maximum velocity and overall acceleration. SolidWorks was used for easy error detection in the design process. [37] This study focuses on the multi-objective optimization of composite pressure hulls under hydrostatic pressure to minimize weight and increase buckling load capacity. Three models were constructed, using Carbon/Epoxy composite (USN-150) with or without a core layer and metallic submarine hull from HY100. The optimization process was performed using ANSYS Parametric Design Language (APDL). The results show that carbon fiber-epoxy composite (USN-150) with a core layer has the minimum weight, minimum B.F., and minimum buckling load, making it a preferred material for achieving minimum weight. [38] Submarines are manned underwater vehicles with operating speeds ranging from 8 to 20 m/s and depths ranging from 200 to 600 m. They are used in underwater warfare and coastal defense. AUVs, underwater robots, have operational speeds ranging from 0.5 to 2 m/s and depths ranging from 200 to 6000 m.

They collect data samples, map hydrothermal vents, and map out tsunamis. The distance between SB and SF1 is 52 mm. [39] Underwater vehicles are increasingly important for ocean exploration and sub- sea operations, with pressure hulls providing load capacity and buoyancy. Three composites, CFRP, BFRP, and GFRP, were analyzed for optimum strength. The Tsai-Wu criteria were used to evaluate the failure of the composite material, with CFRP showing better results than GFRP and BFRP fibers. CFRP has higher tensile strength with lower density, and its properties depend on the layouts of the carbon fiber and the proportion of carbon fibers relative to the polymer. [40] Pressure hulls are central load-bearing structures in naval submarines and autonomous underwater vehicles (AUVs). They resist compressive forces related to hydrostatic pressure, typically consisting of cones and ring-stiffened cylinders. This paper uses 3-D modeling to simulate 65 Bar pressure and analyzes 3D shell and solid FEA models using Ansys Simulation. Structural analysis is performed under 6.5 Mpa external pressure, revealing the designis safe with Von mises stresses below the yield strength.

III. Conclusion

FEM analysis provides detailed insights into the stress distribution, deformation, and failure modes of the hull under various loading conditions. Results demonstrate that sandwich materials can significantly enhance the performance and durability of the pressure hull. for this a submarine operating at 1000 meters, high-strength steel or titanium alloys are suitable materials for the pressure hull, with the choicedepending on cost, weight, and additional performance requirements.

- High-Strength Steel (HY-80):

Calculated Hoop Stress: 404.12 MPaYield Strength: 550 MPa

- Titanium Alloy (Ti-6Al-4V):

Calculated Hoop Stress: 404.12 MPaYield Strength: 828 MPa

- Aluminum Alloy (5083):

Calculated Hoop Stress: 404.12 MPaYield Strength: 228 Mpa.

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