

Stress Analysis in Composite Pressure Vessels – A Review

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ABSTRACT: This paper reviews some of the current developments in the determination of stress/strain, Progressive failure analysis and optimization of composite pressure vessel. The literature has indicated a growing interest in the field of stress concentration analysis and progressive failure analysis in the pressure vessels. The motivation for this research is to analyze the stress concentration, Stress and failures occurring at the openings of the pressure vessels and the means to reduce the effect of the same. Most of the researchers have worked on the stress concentration, Progressive failures due to crack is shell and optimization of vessel openings under internal pressure. Optimizing a composite pressure vessel demands an objective function. This function must represent the performance of the composite material, and in some cases may have some local minima. Optimizations methods use this objective function to try to find the best solution. In this paper the recent developments, theories for estimation of stress, failures and optimization are presented and the scope for future studies is also presented.

KEYWORDS: stress distribution, stress Analyses, stress concentration factor, composite pressure vessels.

I. INTRODUCTION

A practical application of designing with composite materials is the cylindrical pressure vessel. Filament winding, for example, is one common and relatively simple method for manufacturing axisymmetric shells which may be subjected to a variety of internal pressure and torsional load cases. Consider a composite, cylindrical pressure vessel. To be of any practical value, it is clear that such a vessel must contain some sort of hole, around which the stress concentrations must be determined and examined with consideration given to failure. Holes/openings in composites will create stress or strain concentrations and hence will reduce the mechanical properties. Stress concentrations around cutouts have great practical importance because they are normally the cause of failure. For most materials, the failure strengths of the materials are strongly notch (or hole) sensitive. It is important to minimize the stress concentration effect in the composite pressure vessel opening. Hence a better approach dealing with strength reductions due to stress concentration around a geometric discontinuity (such as openings) is the use of design and optimization techniques to reduce the stress concentration in composite pressure vessel. Fiber reinforced resin matrix composites have been widely used in many fields pressure vessel and piping because of high strength and stiffness to density ratios as well as excellent designability. However, composite structures are often subjected to various damage loads such as impact, leading to complicated failure mechanisms. Because of weaker load-bearing ability of laminates in the transverse direction than in the longitudinal direction, it is important to predict transverse impact responses of structures by developing theoretical and numerical methods. [31]. Optimizing a composite pressure vessel demands an objective function. This function must represent the performance of the composite material, and in some cases may have some local minima. Optimization methods use this objective function to try to find the best solution.

In this paper the contribution of various researchers in determination of stress analysis, progressive failures and optimization of vessel at opening in pressure is summarized for design of pressure vessel by using different approaches.

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II. STRESS ANALYSIS

In a cylindrical shell weakened by a hole, the stress distribution caused by an internal pressure load applied to the shell will differ considerably from that in an un-weakened shell. The maximum stress will be much larger if there is a circular hole in the shell than in the case where there is no penetration. This causes the rise in the stress distribution around the hole, to study the effect of stress concentration and magnitude of localized stresses, a dimensionless factor called Stress Concentration Factor (SCF), is used to calculate the stress rising around hole [2][14].

III. STRESS ANALYSIS AT OPENINGS IN PRESSURE VESSELS – A REVIEW

For the study of stress concentration at opening at pressure vessel an extensive literature survey is carried out.

V. P. Netrebko (2001) study based on the photoelasticity method, the behavior of stress intensity factors (SIFs) near cracks propagating from the edges of openings in plates made of elastic and linearly visco-elastic fibrous composite materials is studied. It is found that the relative value of the SIF, near the crack tips on the edges of openings in composite plates is a function of the ratio c/R , whose numerical values depend on the mechanical properties of materials of the plates. A. N. Guz, I. S. Chernyshenko, and K. I. Shnerenko (2001) worked on the stress-strain distribution in composite shells with curvilinear openings. Non-classical generalizing formulations and methods for solution of linear and nonlinear problems are stated. Numerical results obtained for thin and non-thin shells are analyzed with regard for features of the deformation of composites. V. F. Godzula and K. I. Shnerenko (2002) analyzed the stress-strain state of a deep spherical composite shell. In the general case, the shell is weakened by openings located at the poles. The variational difference method is applied to solve the problem. Calculations are carried out for an orthotropic shell of low shear stiffness. Levend Parnas, Nuran Katrc (2002) developed an analytical procedure to design and predict the behavior of fiber reinforced composite pressure vessels. The classical lamination theory and generalized plane strain model is used in the formulation of the elasticity problem. Internal pressure, axial force and body force due to rotation in addition to temperature and moisture variation throughout the body are considered. Some 3D failure theories are applied to obtain the optimum values for the winding angle, burst pressure, maximum axial force and the maximum angular speed of the pressure vessel. These parameters are also investigated considering hygrothermal effects. K. I. Shnerenko and V. F. Godzula (2003) based on the theory of Timoshenko-type shells, the influence of material inhomogeneity on the stress concentration in a shell with an opening is investigated. Mechanical characteristics of the shell material in the opening zone vary according to a given linear law. The problem is solved by a variational-difference method. Results for a spherical orthotropic shell with a polar circular opening are presented. Lotfi Toubal, Moussa Karama, Bernard Lorrain (2004) worked on a non-contact measurement method, namely electronic speckle pattern interferometer (ESPI), was used to investigate the tensile strain field of a composites plate in the presence of stress concentrations caused by a geometrical defect consisting of circular hole. ESPI uses the principle of 3D speckle interferometry to measure the deformation and contour of the measuring field with submicrometer accuracy. The ESPI technique clearly revealed the strain concentrations near the singularity. E. Oterkus, E. Madenci, M. P. Nemeth(2005) presented work on special-purpose, semi-analytical solution method for determining the stress and deformation fields in a thin laminated-composite cylindrical shell with an elliptical cutout. The analysis includes the effects of cutout size, shape, and orientation; non-uniform wall thickness; oval-cross-section eccentricity; and loading conditions. The loading conditions include uniform tension, uniform torsion, and pure bending. The analysis approach is based on the principle of stationary potential energy and uses Lagrange multipliers to relax the kinematic admissibility requirements on the displacement representations through the use of idealized elastic edge restraints. Specifying appropriate stiffness values for the elastic extensional and rotational edge restraints (springs) allows the imposition of the kinematic boundary conditions in an indirect manner, which enables the use of a broader set of functions for representing the displacement fields. Selected results of parametric studies are presented for several geometric parameters that demonstrate that analysis approach is a powerful means for developing design criteria for laminated composite shells. Aziz Onder, Onur Sayman, Tolga Dogan, Necmettin Tarakcioglu (2008) presented work on optimal angle-ply orientations of symmetric and antisymmetric shells designed for maximum burst pressure were examined. Burst pressure of filament wound composite pressure vessels under alternating pure internal pressure was investigated. The study deals with the influences of temperature and winding angle on filament wound composite pressure vessels. Finite element method and experimental approaches were employed to verify the optimum winding angles.

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P. Xu, J.Y. Zheng, P.F. Liu, (2009) Carbon fiber/epoxy composites have been increasingly used to develop the lightweight high pressure hydrogen storage vessel in areas of the hydrogen fuel cell vehicle. In this research, a 3D parametric finite element model is proposed to predict the damage evolution and failure strength of the composite hydrogen storage vessels, in which a solution algorithm is proposed to investigate the progressive damage and failure properties of composite structures with increasing internal pressure. The maximum stress, Hoffman, Tsai-Hill and Tsai-Wu failure criteria which are employed respectively to determine the failure properties of composite vessels are incorporated into the numerical method as individual subroutines. The birth-to-death element technique in the finite element analysis is used to describe the mechanical properties of carbon fiber/epoxy composite elements. Parametric studies in terms of the effects of different failure criteria are performed and the calculated failure strengths of composite vessels are also compared with the experimental results. D. V. Kubair (2013) worked on closed-form expressions for the elastic fields (stresses, stress-gradients, strains, and displacements) in radially graded continua without and with circular holes are derived. The stress concentration factor increases when the rigidity modulus progressively decreases away from the center of the hole (softening materials). The stress concentration desirably reduces in hardening materials in which the rigidity modulus progressively increases away from the hole. In hardening materials, the propensity of damage reduces with increase in the inhomogeneity length-scale due to the stress dilution. G. Romeo, F. Danzi, E. Cestino, F. Borello (2013) presented work on designing Very-Long Endurance Solar Powered Autonomous Stratospheric UAV. This UAV could play the role of a pseudo satellite and could offer the advantage of allowing a more detailed land vision due to its relative closeness to land (17-20 km) at a much lower cost than a real satellite. Two different configurations are under investigation in order to decide on the best solution that will completely satisfy the a priori imposed constraints. In recent years, the aeronautical community has increasingly focused on the design of solar powered platforms and zero emission airplanes; a coupled system (solar array and hydrogen fuel cells) can be used to supply energy throughout the entire day in order to ensure the continuous flight for several months. As known, a fuel cell system requires at least a couple of external tanks for fuel storage. Hydrogen and oxygen are stored using a pressure vessel installed inside the wing. In this way, the stored gases are subjected not only to pressure loads but also to in-flight loads that can abruptly change the optimum layout required to satisfy regulation requirements. A parametric analysis has been performed to define the optimum layout and the number of tanks necessary to supply the required power. Avinash R. Kharat, V. V. Kulkarni (2013) reviewed some of the current developments in the determination of stress concentration factor in pressure vessels at openings. The literature has indicated a growing interest in the field of stress concentration analysis in the pressure vessels. The motivation for this research is to analyze the stress concentration occurring at the openings of the pressure vessels and the means to reduce the effect of the same. Most of the researchers have worked on the stress concentration occurring at circular and radial openings in the shell under internal pressure. Also some of the researchers have worked on holes in the end covers. In this paper the recent developments, theories for estimation of stress concentration are presented and the scope for future studies is also presented. Avinash R. Kharat (2013) presented work on a stress analysis on thin-walled pressure vessels with different type of the reinforcement and optimize the suitable reinforcement for opening using finite element analysis software namely, ANSYS. General applications of Thin-walled cylinders are commonly used as structural members (e.g., hollow structural sections), piping systems, members of offshore platforms, cooling towers, aircraft fuselages, naval hulls of submarines, high pressure reactor vessels used in metallurgical operations, process plants etc. Y. Mohammed, Mohamed K. Hassan, H. Abu El-Ainin (2014) studied to analyze and experimentally validate the size effect on laminate composite glass fibers using cohesive laws. This work not only correlates the nominal strength with the size of the failure processing zone but also relates the size of the failure processing zone at failure load to the specimen dimension and geometry. Moreover, it aims to apply a new method to study the effect of structure size on the tensile strength of fiber polymer composite. The results of nominal strength are validated using a matrix of experimental work, and they agree very well with the experimental data. Abdelhak Khechai, Abdelouahab Tati, Abdelhamid Guettala (2014) presented on stress concentration factors (SCF) in cross-and-angle-ply laminated composite plates as well as in isotropic plates with single circular holes subjected to uniaxial loading. A quadrilateral finite element of four-node with 32 degrees of freedom at each node, previously developed for the bending and mechanical buckling of laminated composite plates, is used to evaluate the stress distribution in laminated composite plates with central circular holes. It is observed that the obtained results are very close to the reference results, which demonstrates the accuracy of the present element. Additionally, to determine the first ply failure (FPF) of laminated plate, several failure criterions are employed. Finally, to show the effect of E_1/E_2 ratio on the failure of plates, a number of figures are given for different fiber orientation angles. M. M. Shokrieh, A. R. Ghanei Mohammadi (2014) worked on categories of residual stress in composite materials, their effects and the importance of their measurement. It also summarizes issues in measuring

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residual stresses and introduces the range of techniques available. Qayssar Saeed Masikh, Dr. Mohammad Tariq, Er. Prabhat Kumar Sinha (2014) presented work on calculation of the stress developed in the thin and thick cylindrical pressure vessels. The analysis has been done for two different materials pressure vessels. The variations in the thickness of the pressure vessels have been considered for the analysis for different internal pressures. The common characteristic of the pressure vessels solved is that the radial and tangential stresses vary in the same nature of curve for different thickness of vessels. Lamé's equations, maximum normal stress theory, maximum shear stress theory have been applied for the analysis of the thick walled pressure vessels of brittle and ductile materials. Analysis also performed for open and closed end cylinders by using Burnie's equation and shear strain theory. Barlow's equation has been applied for the calculation and analysis of the high pressure oil and gas pipe analysis. The yield point stress and ultimate stresses have been considered for the ductile and brittle material respectively. The modeling details of the methodology, employed in the analysis, are extensively discussed and the numerical approach is proven to be very efficient for the software developed of pressure vessel for thin and thick cylinders. M. Hemmatnezhad, G.H. Rahimi, M. Tajik, F. Pellicano (2014) The present research aims to investigate the vibration characteristics of stiffened composite cylindrical shells using experimental, numerical and analytical techniques. The specimens are fabricated from continuous glass fiber (GFRP) using a specially-designed filament winding setup. The theoretical formulation is established based on Sanders' thin shell theory. In the analytical approach, a smeared method is employed to superimpose the stiffness contribution of the stiffeners with those of shell in order to obtain the equivalent stiffness parameters of the whole panel. Using the Ritz method, the governing eigenvalue equations are obtained and will then be solved for evaluating the natural frequencies of the GFRP stiffened composite shells. In order to validate the analytical achievements, experimental modal analysis is conducted on a stiffened cylinder.

Chi-Seung Lee, Jeong-Hyeon Kim, Seul-kee Kim, Dong-Man Ryu, Jae-Myung Lee (2014) In the present study, an evaluation method for the initial and progressive failure of composite laminates was proposed based on the Puck failure criterion and damage mechanics, respectively. In other words, the initial failure (crack initiation in the fiber and/or matrix) and progressive failure (crack growth in the fiber and/or matrix) were evaluated using the Puck failure criterion, and fiber- and matrix-dependent damage variables, respectively. In addition, the ABAQUS user-defined subroutine UMAT was developed based on coupling theories for the failure criterion and damage mechanics in order to efficiently analyze the progressive failure phenomenon in glass/carbon fiber-reinforced composite laminates. Avinash R. Kharat, V. V. Kulkarni (2014) presented work on the analysis of variance method which is used to serve the relation between nozzle size and stress produce in the nozzle area. To reduce the errors in the experimental result the randomize sequence method is used. To test the influence of the both parameters that is opening diameter and internal pressure on each other the randomized test sequencing is generated and experimental test is conducted to investigate the stress distribution near opening area. Yongjei Lee and Eun-Taik Lee (2015) studied, an analysis procedure is proposed to predict the pressure and the radial displacement relation and the bursting capacity of prestressed concrete cylinder pipes under internal loading. The finite element method is used to validate the proposed method. It is found that the debond of prestressing wire, the number of the reinforcing layers, and the layer attachment angle are important factors to pipe capacity. Nirav P. Patel, Dharmendra S. Sharma (2015) presented the work on analytic investigations emphasizes on the effect of stacking sequence, ply groups, loading angles, materials and corner radii on the failure strength and moment distribution in symmetric laminated composite plate weakened by a square hole. The generalized close form solution of bending moment around such cut-out is presented by using the Muskhelishvili's complex variable formulation. The layer wise stresses and failure strengths are studied and the failure strengths of laminates are investigated.

Liang Wang, Chuanxiang Zheng, Hongying Luo, Shuang Wei, Zongxin Wei (2015) presented a progressive damage model, which is sufficiently general to predict the ultimate load-bearing ability and complex failure behaviors of the aluminum-carbon fiber/epoxy composite vessel structure. The model is implemented in the commercial finite element software ABAQUS based on the integration of material property degradation method (MPDM) and cohesive element (CE) method. The MPDM is implemented by ABAQUS user subroutine UMAT to model the intralaminar failure of composite laminates, while CEs are employed to simulate the delamination initiation and evolution at the interfaces. Jinyang Zheng, Yang Hu, Li Ma, Yang Du (2015) Studied the delamination failure of composite vessels subjected to internal blast loading. Experiments were conducted on several e-glass/epoxy vessels with aluminum lining. Micro observation and fracture analysis indicated that delamination failure occurred under a wide range of explosive loadings. A finite element model was also established to explore the delamination initiation mechanism and the evolution of dynamic behavior. Delamination simulation was achieved using a tiebreak contact model and a cohesive criterion. Numerical results from the finite element analysis were compared with experimental data, which indicated

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that both dynamic response and delamination failure are in good agreement. A. Muca, M. Muc-Wierzgon (2015) an optimization design methodology of composite materials and structures subjected to fatigue life constraints is presented and discussed in the paper. It is assumed that laminates are made of plies having three different fiber orientations: 0° , $\pm 45^\circ$, 90° . A special type of new, discrete design variables is introduced in order to find optimal stacking sequences for laminated structures. The results of the optimization of buckling loads for compressed plates are demonstrated herein. The accuracy of the prediction procedure depends directly on the selected stiffness degradation model based on the experimental data. Brian Ellul, Duncan Camilleri (2015) studied the results of a progressive failure algorithm based on a sudden mode-dependant degradation methodology are presented and applied to filament wound cylindrical pressure vessels subject to an internal pressure undergoing first ply-failure, post failure and ultimate failure. In this case, the material properties are degraded according to the failure mode detected from the homogenised stresses at lamina level. The numerical models were corroborated with experimental tests results.

M.A. Caminero, G.P. Rodríguez, V. Muñoz (2015) worked on the characterization and the assessment of the damage in CFRP composite laminates with different stacking sequences subjected to low velocity impact and flexural loading. Charpy impact test and three-point bending test were used in order to obtain the impact response and flexural behavior of different laminates. An experimental test series was carried out to determine impact energy absorption, flexural strength and stiffness and failure mechanisms of composite laminates made from M21E=IMA, an unidirectional prepreg used in Airbus A350 XWB primary structures. K. Swaminathan, D.M. Sangeetha (2016) presented a comprehensive review of developments, applications, various mathematical idealizations of materials, temperature profiles, modeling techniques and solutions methods that are adopted for the thermal analysis of FGM plates. An attempt has been made to classify the various analytical and numerical methods used for the stress, vibration and buckling analyses of FGM plates under one-dimensional or three-dimensional variation of temperature with constant/linear/nonlinear temperatures profiles across the thickness. An effort has been made to focus the discussion on the various research studies carried out till recently for the thermal analysis of FGM plates. Finally, some important conclusions and the suggestions for future directions of research in this area are presented. It is felt that this review paper will serve the interests of all the academicians, researchers and engineers involved in the analysis and design of FGM plates.

Yongzheng Shao, Andrea Betti, Valter Carvelli, Toru Fujii, Kazuya Okubo, Ou Shibata, Yukiko Fujita (2016) studied on high pressure vessels with winding lamination of $[90^\circ/\pm 15^\circ]$ were manufactured adopting a vinylester and an epoxy resin reinforced with carbon fibres. An experimental setup was designed to test the vessels up to the burst pressure. The test results demonstrate a higher ultimate pressure of the carbon/vinylester composite vessel with respect to the epoxy reinforced counterpart. The full field strain measurements by the digital image correlation technique show a delayed initiation and propagation of the damage in the carbon/vinylester. Roham Rafiee (2016) conducted comprehensive reviews on the performed investigations in the field of mechanical behavior of glass-fibre reinforced thermosetting-resin (GFRP) pipes. Classified into six categories of stress/strain analysis, failure evaluation, environmental issues, viscoelastic behavior and creep analysis, fatigue analysis and impact analysis, the main streamline of the performed and on-going studies in current years have been outlined. The recent trend and challenges in conducted researches are highlighted and discussed. Performing a gap analysis, new perspectives which are still required to be developed more deeply for their industrial applications or have not been addressed in literature are nominated. J. Błachut (2016) presented work on Force-Induced-Dimple (FID), initial geometric imperfection leads to a far worse deterioration of buckling strength (for up to four times) than currently used modulated eigenshapes or lower bound increased-radius shape deviations from perfect geometry. The FID approach provides not only safer estimates of buckling resistance but also it is efficient in terms of computing time for a range of shell geometries. The physics behind the FID-concept is closer to reality than in the other two approaches. B.B. Liao, P.F. Liun (2016) studied dynamic mechanical responses and damage mechanisms of plastic fiber-reinforced polymer matrix composite laminate under low velocity impact. First, the plastic damage model is introduced for intralaminar damage, where Puck's failure criteria and strain based damage evolution laws for fiber and matrix are used, and the bilinear cohesive model is adopted for delamination. Second, an uncoupled numerical scheme for dealing with the intralaminar plastic deformation and damage evolution by finite element analysis (FEA) is originally proposed based on the strain equivalence hypothesis, in which the effective stresses and strains are first solved using the backward Euler algorithm and then the nominal stresses and damage variables are updated independently. Finally, the proposed algorithm is implemented using ABAQUS-VUMAT by the time stepping algorithm. For two composite specimens under transverse impact, the impact force-time curve, the impact displacement-time curve and the dissipated energy at different impact energies are studied by comparing the results using experiments and FEA. P. Blanc-Vannet (2016) addresses issue of

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the residual burst pressure of composite cylinders after mechanical impacts on their cylindrical part. More than 200 impact tests results on actual cylinders are gathered and a comprehensive analysis is performed; covering a wide range of cylinders characteristics (volume, pressure, liner material, geometry, and manufacturer) and testing conditions (facilities, inner pressure, impact energy). Despite such wide range of different conditions, a common behavior of the four models of cylinders tested is evidenced. Ik Hyeon Choi (2016) analyzed the transient response and damage of pressurized vessels subjected to a drop impact or foreign object impact; we must consider the change in stiffness due to pre-stress. The pre-stress condition induces a phenomenon where thin plates with in-plane pre-stress show different stiffness during out-of-plane deflections compared to the original plate without the in-plane pre-stress. Because the cylindrical wall of a pressurized vessel is under in-plane pre-stress induced by the vessel's internal pressure, we must consider the 'change in stiffness' to accurately analyze the impact response and damage. In this study, we investigated the low-velocity impact response of a composite laminated cylinder wall of a pressure vessel with high internal pressure. The shear deformation theory of a doubly curved shell and von Karman's large deflection theory, as well as a newly proposed strain-displacement relation including initial strain terms to consider the stiffness change induced by cylinder stress due to internal pressure, were used to develop a geometrically nonlinear finite-element program. Numerical results that were calculated for the cylinder stress showed larger contact force and smaller deflection. By comparing strain values, a simple superposition of strain value calculated without considering cylinder stress and initial cylinder strain value showed 10–20% more strain than that accurately calculated with considering the stiffness change due to cylinder stress. Gururaj Deshpande, Onkar Darphale, Siddharth Bakare, Sagar Birajdar, Nikhil Sonkamble (2016) presented work on stress analysis of composite pressure vessel made of Boron/Epoxy, Glass/Epoxy and Graphite/Epoxy with cutouts/inclusions of elliptical shape. Commercially available software ANSYS is used to investigate the behavior of thin walled composite cylindrical shell. Validation is carried out for the cases available in literature. The validated finite element model is then applied to perform stress analysis of composite pressure vessels with elliptical cutouts/inclusion for stacking sequences such as [0/90]s, [0/45/0]s, [0/45/90]s and [90/45/90]s. The numerical results of parametric studies are graphically presented and discussed.

Yang Dai, Miaolin Feng, Min Zhao (2017) presented solution for the topology structures of composite laminates with design-dependent loads. The methodology is based on the isoline method, the sensitivity filter with density gradient weighting, and the solid isotropic material with penalization (SIMP) method. In addition, the element stiffness matrix for composite layups is derived. Two- and three-joint constraint examples of the topology optimization design for composite structures are presented. The work efficiency of the isoline method and the distance regularized level set evolution (DRLSE) method are compared; five other filtering methods are also studied. The distribution rule of solid material and the relationship between the minimum compliance of optimal structures and the principal angle of composite layups are discussed. A. Gargano, K. Pingkarawat, M. Blacklock, V. Pickerd, A.P. Mouritz (2017) presented an experimental investigation into the explosive blast response of fibre-reinforced polymer laminates used in naval ship structures. Blast tests using plastic explosive charges were performed in air on square target plates made of carbon-polyester, glass-polyester, carbon-vinyl ester or glass-vinyl ester laminates, which are composite materials used in naval ships. The laminates were dynamically loaded by shock waves of increasing pressure and impulse, and the deformation, damage and residual mechanical properties were determined. The amount of blast-induced damage and the post-blast mechanical properties depend on both the fibre reinforcement and polymer matrix. E-glass laminates have higher resistance to blast-induced delamination cracking and tow rupture than carbon fibre composites. Furthermore, glass or carbon fibre laminates with a vinyl ester matrix have superior blast damage resistance compared to composites with a polyester matrix. The higher damage resistance is attributed to the higher flexural strain energy capacity and interlaminar fracture toughness properties of laminates containing glass fibres or vinyl ester matrix. V. Alcantar, S.M. Aceves, E. Ledesma, S. Ledesma, E. Aguilera (2017) presented work on two methodologies for weight minimization of Type 4 (plastic lined, fiber wrapped) compressed hydrogen pressure vessels: genetic algorithms and simulated annealing. We consider 70 MPa vessels with a safety factor of 2.25, and analyze the vessels with classical laminate theory. We propose an objective function based on Tsai-Wu criterion, composite thickness, a safety factor, and a penalization factor. The optimum results are analyzed and compared by a high resolution finite element model. Computer simulations show that the proposed methodology produces more efficient designs by reducing the weight by up to 9.8% and 11.2% when compared to previously published vessel optimization research.

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IV. SUMMARY OF THE LITERATURE REVIEW

Form the literature review it is seen that ASME and other codes are providing solutions for more general cases and requires higher factor of safety. Also limit load and stress concentration formulae are not available for non standard shapes and intersections and geometrical discontinuity. Studies have not been performed on effect of fiber orientation of composite material on stress concentration factor in case of pressure vessel openings. Past studies are mostly involved on the ply angles and stacking sequence of composite material. Stress Concentration Factor calculations in Reinforced openings in composite pressure vessel have not been performed which is very curial point. This study of the SCF will lead to better solution in composite vessel structure. Past studied mostly restricted to the ASME codes which provide the design limitation for size and the shape of the opening but there is no provision of formulae for estimating the stress concentration in case of size and shape for composite pressure vessel. The use of optimization process would be added an advantage in the study of SCF reduction near openings in composite pressure vessel. For position and location of the openings in longitudinal and perpendicular direction on composite pressure vessel are not considered in the ASME codes.

V. CONCLUSION

Stress Concentration/ Stress analysis is one of the important factors to be studied in the pressure vessels openings. A review of the literature related to the stress concentration and progressive failure in pressure vessels is presented. Majority of the researchers have worked on cylinders/shell and laminated plate. The position and location of the openings in longitudinal and perpendicular direction on composite pressure vessel is need to be studied.

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