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Review of challenges of the design of rocket motor case structures

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Abstract. This paper presents the state of the art and challenges in the design of rocket motor case structures RMCS it briefly describes the construction of RMCS then lists the different operational loads that govern its design. This is followed by a review of the different materials that are suitable for use. The inherent complexities of the design process using conventional and composite materials are discussed in details; the optimum design of RMCS is studied and summarized. Finally useful conclusions are summarized to serve as a guide to the researchers and designers in this field.

Keywords: Rocket motor case structures, rocket design, composite structures, optimum pressure vessel design

Nomenclature

A_{cr} : Critical area of the nozzle
D : Mean diameter of RMC
E : Young's modulus of elasticity
Fa : Axial force per length
F h : Hoop force per length
P : Design pressure of RMC
pc : Working pressure of combustion chamber
pd : Design pressure
σ th: Thermal stresses
ρ : Material density
RMC: Rocket motor case.
SRM: solid rocket motor
CPV: composite pressure vessel

1. Introduction

The missile structure is a precise container for different subsystems; it should verify the convenient stability against the random variations. On the other hand, strength to weight ratio should be as high as possible in order to satisfy the mission requirements. The development of missile structure is a basic demand to improve the mission performance in the aerospace field. The rapid progress in the structural

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design, analysis supports the daily challenges in this field; so, the required mission at different conditions can answer the inquiries beyond this sequence of development. Rocket motor case (RMC) is considered the major sensitive element that influences the flight performance of the missiles; so, in the following the definition of RMC.

2. Definition of rocket motor case

The RMC is a typical energy transfer system where the chemical energy in the fuel is changed over into thermal energy accompanied by high pressure, producing gases pass through the nozzle where the internal energy is converted to kinetic energy that generates the propulsive force (thrust). The Solid propellant rocket motor is one of the family of the rocket engine where is the fuel and oxidizer are mixed in a single solid it is the most commonly used compared with the other rocket motors due to its simplicity in design, easy manufacturing and its high reliability. The Chinese invented the first solid rocket motor (SRM) in the 13th century. Fuel and oxidizer are mixed and stored in the combustion chamber which allows SRM to perform its function without air dependence. The simple configuration of rocket motor consists of a dome, Igniter, motor case, insulation, propellant and nozzle [1] as shown in figure 1.1

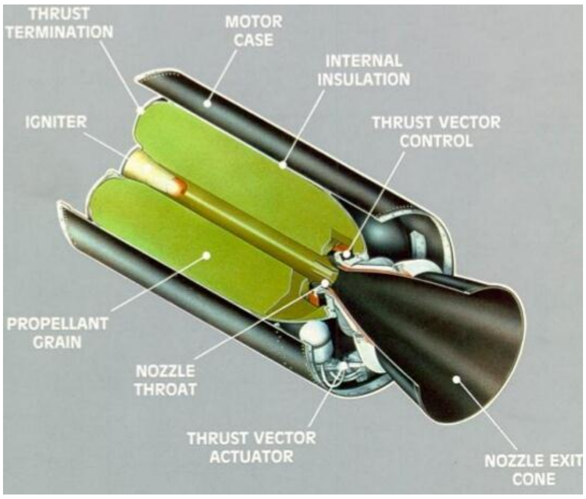

Figure 1.1 Typical solid rocket motor

The rocket motor case is considered a significant structure in SRM. The motor case structure should have enough strength and lightweight, where the combustion takes place producing high temperature of 2000 to 3500 ˚C and operating pressure of 3 to 30 MPA [2]. The structural material for the solid rocket motor case is divided into two main types: (1) conventional materials such as high resistance steel or high strength aluminum and titanium alloys, (2) composite materials (carbon, Kevlar, glass). Composite materials are used in the majority of the new rocket motor cases due to its high strength to weight ratio, high impact strength and design flexibility which contributes in the development of the rocket engine industry.

3. RMC operational loads

The function of RMC is to produce specific value of thrust. It is considered as the main requirement which is constrained by some factors such as the maximum caliber of the rocket motor, the length of the rocket motor, type of propellant and its configuration. All these factors affected on the value of internal pressure and the value of thermal load that generates the axial thrust. RMC is subjected to different dynamic load pressure, thermal loads, axial thrust, aerodynamic loads and centrifugal forces which used for spin stabilization during flight.

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3.1. Pressure loads
The RMC can be considered as a high loaded structure with complicated design which applied to internal pressure, thermal and axial thrust loads where the value of pressure is calculated according to the type of the grain and its configuration [3]. Design pressure is:

$$p = (1.1:1.3)\, p_c\, e^{\frac{45K_T}{1-n}} \quad (1)$$

where, pc is the working pressure, KT is the temperature sensitivity of propellant, n is the pressure index.
The design pressure leads to generation of loads in the axial and hoop directions:

$$F\,h = \frac{PD}{2} \quad (2)$$

$$F\,a = \frac{PD}{4} \quad (3)$$

Fh, and Fa are the hoop and axial forces per length; respectively, D is the mean diameter of RMC.

3.2. Thermal loads
Due to the combustion process, gases are generated with a high temperature of 2000 to 3500˚C [4]. This range varies according to the type of propellant so it is important to use high-performance wall material, these walls work as insulators to protect the internal surface of the RMC and high temperature, which results from hot gases, so the operating time of the combustion chamber must be limited as the heat transmitted from gases must be smaller than its absorbing capacity also the temperature of the wall must be less than the critical temperature of the applied material. Due to the heat transfer between wall layers, the thermal stresses can be expressed as follows [5]:

$$\sigma_{Th} = \frac{\alpha\, E\, \Delta T}{2(1-\gamma)} \quad (4)$$

where α is the thermal expansion coefficient, ΔT is the temperature difference between the outer and inner layer of the wall. Pressure and thrust loads are eliminated at burn out, but the equilibrium of thermal loads doesn't occur, especially when the working time of the motor is small, so using different types of thermal insulators in order to increase the time of action of the motor. In order to calculate the thickness required for insulation an empirical equation is estimated where it is a function of some parameters such as inner diameter of RMC, inner temperature (Tin), design pressure value and thermal conductivity of material used for insulating [6].

$$\left(\frac{T_{in}}{D_{in}}\right) = 6.139\times 10^{-7} e^{k_{in}} \times p_d^{0.15} \times {T_{in}}^{1.04} \quad (5)$$

3.3. Thrust loads
From the principle of propulsion Thrust can be defined as the force that results from the ejection of gases through the nozzle. It can be calculated according to the formula [7]

$$T_{th} = P_c \times A_{cr} \times C_f \quad (6)$$

where, A_{cr} Is the critical area of the nozzle, P_c The Pressure of the combustion chamber at normal temperature and C_f Is the thrust coefficient ranges between (1.4:1.7).

3.4. Centrifugal forces
During the flight, the rocket rotates around the longitudinal axis with angular velocity c in order to be spin stabilized. A centrifugal force results from its rotation, which acts on its surface area this centrifugal force is functioning in some factors such as element mass m, angular velocity ω. It can be calculated by the formula [8]

$$F_C = \frac{m\omega^2 D}{2} \quad (7)$$

$$\omega=2\pi n \tag{8}$$

$$m=\rho At \tag{9}$$

where n is the number of revolutions in second, ρ density of structural material. The centrifugal force generates load in the hoop direction N_h which as a result generates hoop stress, it can be calculated by the following formula:

$$\sigma_{hc} = \rho\, \pi^2 D^2 N^2 \tag{10}$$

4. Material development of RMC structure

As the material is the most important challenge to the design of the rocket motor case, the selected material must have superior properties to satisfy performance requirements; so, the selection of the material is being evaluated on the basis of strength to weight ratio, specific stiffness, machining ability of the material, availability, service conditions, cost and thermal expansion.

4.1. History of the conventional materials

At the beginning of the missile industry, rocket motor cases were made from metals and the metals were considered as the basic structural materials for many decades. MYSOREAN in India used the first rockets which are made from metal cylinders to contain the powder. Metal cases have many advantages such as rough handling, ductility these properties allow yielding to occur before failure also can be subjected to high temperature (700-1000) ˚c so no need for large insulation. The conventional and temper steel is the most common steel which was used in manufacturing in the past as it has strength up to 240 KSI [9] and it provides great available data about material properties and manufacturing process. Ni-Cr-Mo-V material is the most commonly used due to its minimum yield strength up to130 KSI. Its high fracture toughness provided it with a good advantage to have leaked before failure condition. All these advantages are very useful in limiting catastrophic failure during proof test. These alloy steel can produce residual stresses according to manufacturing process and thermal treatment which are used during fabrication of the case. Molybdenum and Chromium alloy steel is one of the low alloy steel which have good steel machinability and good heat resistance due to the existence of molybdenum and chromium. Aluminum, titanium alloys represents the high strength alloy steel which has strength up to 1600 MPA [10]. The Margining steel is a new generation of the alloy steel, these types contain low carbon, which obtain its strength from aging at minimal temperature and its strength is up to 300,000 psi [11] as we can control the level of strength by aging treatment and contents of the hardener. High yield steel is more up to date than Margining steel as a result of their toughness and protection from tearing these provide it with less catastrophic failure in the rocket motor case and pressure vessels also its strength ranges between (180:300) KSI [12].

4.2. History of the composite materials

The composite materials are the materials which consist of two or more different materials with different properties combined at the macroscopic level. Combining of several components produce a new material with properties that exceed the constituent materials, this concept of composite is found in the nature and the wood is an example of composite material where the fiber is represented by cellulose fibers and the matrix is the natural glue which is called Lignin. The first use of composite was in 1500 B.C [13] when the ancient Egyptian used straw with mud as mixture to create strong buildings where the straw is an example for short fiber, they also used the linen wrapping system for their mummies to increase the ductility of the dried brittle dead bodies later, in 1200 A.D the first composite bow was invented by the Mongols. Wood, bone and animal glue were mixed as combination to form a bow; these composite bows help Genghis Khan with military dominance because it was powerful and accurate. In 1937, modern composite appears in the United States when the salesmen from fiber Glass Company started to sell fiberglass to those interested in. The main idea for typical composite materials relies upon strengthening fiber into resin to form a composite material as shown in the figure 4.1.

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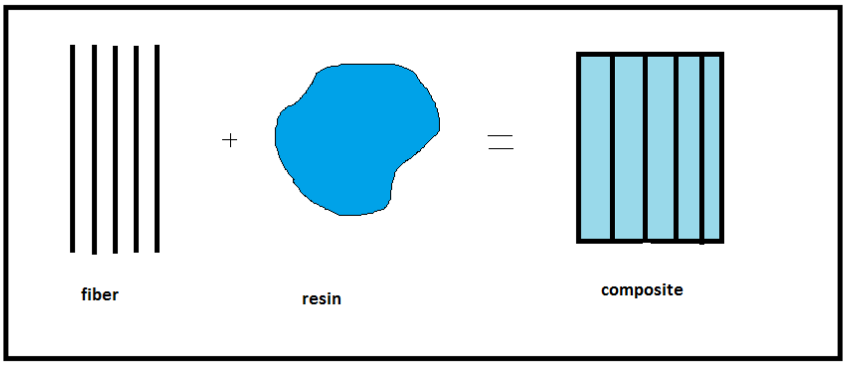

Figure 4.1 Basic components of composite material [14]

Composite materials can be classified according to reinforcement or matrix the reinforcement types are fiber reinforced, particle and structural reinforced. The matrix can be metal, polymers and ceramics. The overall mechanical properties of the composite depend mainly on the mechanical properties of the fiber. In the beginning, the types of fibers are glass, aramid, carbon, boron, Ceramic, and metallic. Meanwhile, the matrix has a very important role in composite unit, it can basically hold the fiber in proper orientation, transfer forces between fibers, increase the ability to resist the crack propagation, protect the fiber from environmental conditions; also it contributes more toughness and ductility for structure. To achieve excellent mechanical properties of the fiber, the extent of the matrix must be at least equal to fiber extension. The matrix can be divided into metal, ceramics and polymers where the polymer matrix is the most common one which used in composite rocket motor cases, the two main groups of polymer matrix are thermoset and thermoplastic matrix [15]. Thermoset-matrix is a type of matrix that formed by a chemical reaction where resin, catalyst and hardener are mixed together to form the required hard matrix, the chemical reaction is an irreversible there are a lot of types of resin which used in many industrial applications but the most common types are epoxy resin, polyester resin and vinyl ester. Thermoplastics matrix is this type like metal which need to be heated at elevated temp at which softening occurs, then cooling to establish hardening, the cycle of crossing the melting point can be repeated many times without any significant effect on the properties of the material in any state. The most common types of thermoset-matrix are polypropylene with nylon or glass, polyvinyl chloride, acrylic nylon and Teflon [16] .

4.2.1. Advantages of composite materials

Composite materials have succeeded remarkably in their relatively short history as the composite materials have high tensile strength and high compressibility these advantages give them multi-use in a wide range of application. The composite materials offer superior properties that can not be achieved separately by its individual components, these properties such as weight, stiffness, strength, etc. The composite offer more advantages over conventional materials as discussed below:

- High strength to weight ratio: this means the strong and light applications can be produced by using composite materials, from this property, we can produce huge rockets with very high strength with a relatively very small weight also produce large airplanes which can move faster with light weight and better fuel consumption.
- Online monitoring with the help of partial integral sensor which used to monitor the structure and discover fatigue before happened.
- Composite materials give the ability for easy overlap of parts, so complex metal parts can be replaced by composite structure these techniques reduce the time for joining also reduce time of production.

- High specific stiffness this mean it has a high (stiffness to density ratio) composite gives stiffness equal to steel at one fifth the weight of steel [17].
- The high level of chemical resistance and corrosion resistance. The Composite outer surface is formed by plastics so it offers high corrosion resistance.
- High impact strength. Composite can withstand the sudden impact force from an explosion.
- Flexibility in design, the produced components of the composite materials are near to the required net shape so this reduces the time for machining and cost.
- Composite materials have better characteristics than conventional materials such as vibration and noise because the composite structure damped the vibration than metals. This feature is used in more application such as the leading edge of the airplanes.
- Composite materials offer lower cost for tooling which used in processing and manufacturing than metallic materials.
- Durability is one of significant characteristics that distinguish the composite materials.

5. Pressure vessels used in rocket motor case

From the previous introduction, it was found that the propulsion unit is the most important part in the structure of rockets. The rocket motor case should have enough strength and lightweight in order to increase the flight range and also increase the missile payload. The best technique for achieving weight reduction by replacing the conventional materials used in manufacturing of composite materials as discussed before. The rocket motor case can be represented of pressure vessel taking the internal working pressure in the design consideration

Due to the importance of the pressure vessel as discussed before, its design is very complicated and there are many factors must be considered such as the orientation of the fiber, properties of the materials and the stacking sequence which is the most important design factor. The Design of the pressure vessels is done according to several standard codes such as ASME (American society for mechanical engineers), IS (Indian standard), GB150 (Chinese standard for pressure vessels) and ISO also developed a new international standard for pressure vessels. All these codes result from several experimentation, then they are designed to be applicable for any application satisfying a factor of safety between 3 and 4.5 [18]. There are main parameters which affect on the design of pressure vessel such as selected material, thermal loads, pressure, etc. Studying these parameters helped us in the design of high performance pressure vessel. Pressure vessels are designed like any machine for doing the required job satisfactorily, So if the structure of the pressure vessel has a problem which negatively affects its performance, accordingly this unit is considered as failed. There are several research works which have been done on the design, analysis and manufacturing of the cylindrical pressure vessel either made of metals or composite materials due to its important applications. Some of the research paper related to design, manufacturing and testing of the pressure vessel will be discussed. Zhang. J. [19] studied the mechanical behavior of two types of stainless steel in order to develop new pressure vessel with minimum thickness using cold stretched steel and cryogenic stretched steel performing several experimental work on steel plate by heating it to temperature equal to 20˚c where cold stretching is happened then bringing it to -196˚c where cryogenic stretching is happened and measuring the allowable stress , simulating the two operations by using finite element analysis to compare between the results proving that the allowable stress can be increased twice by using cryogenic stretching compared with cold stretching and as a result we can reduce the thickness of the pressure vessel by 60:75%. Kaveker.M. [20] studied the effect of replacing the material of pressure vessels from metal to composite materials in order to be used in low weight structures such as aerospace applications. Using E-glass fiber with epoxy resin to form a composite structure, analyzing two models using finite element tool (ANSYS) then comparing the weight and stress results between the two models proving that composite model has 75%weight reduction compared with steel model, the structural efficiency of the composite model is better than steel model. Raparla [21] designed multilayer pressure vessel that can withstand high pressure loads and made a comparison between mono block vessel with the designed vessel depending on the wrapping sequence of layers over the mandrel, multilayer vessel was produced by using different types of layers,

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the design was done according to principles of ASME code, using ANSYS package in order to make analysis on the vessels and the results proved that using multilayer vessels instead of solid vessels can save the weight of the material by 26.02%,so cost and time of manufacturing will be decreased. Variation of stresses from inner to outer surface of multilayer vessel is 12.5%, which is less than the value of solid vessel that is around 17.5%. Thus, for application which subjected to high pressure and thermal loads the multilayer vessels are more suitable. Kabir [22] presented an analysis on composite pressure vessel CPV subjected to internal pressure, which is over wrapped with metallic liner this pressure vessel was made by using filament winding technology. During the winding there is different thickness in dome area and this affected on the on axis stress distribution, applying numerical analysis by using NISA-II, Proved that:

- Using the metallic liner decrease the principle stress on the on axis direction.
- Structural deformation can be limited by taking variable thickness during analysis.

Takaya, Xai [23] utilized multi-layer composite pipes and studied the deformation and the stresses on the structure, by using different ply angles they proved that the sequence of stacked layers affected on the deformation and stresses in the CPV. Mackerel [24] displayed a bibliographical review for analyzing the structure of the pressure vessels using finite element techniques, analysis of the pressure vessel was done from two points of view, the first one was the theoretical point of view and the other was the practical point of view. This biography contains 670 reference papers and it was divided into some categories; static and dynamic stress analysis, manufacturing of pressure vessel and pipe component and developing of pressure vessel using finite elements. Liang, C.C. [25] designed a composite pressure vessel by using technology of filament winding with optimum deign for the dome by using membrane theory, taken some considerations during design such as winding conditions, shape factor, Tsai-Wu failure theory and geometric limitation they proved that all the previous designs for the dome by using elliptic curve method are approximated methods, by maximizing the shape factor and taken the depth parameter during deign they achieve the optimum design for the dome.

Parnas, L. [26] studied the behavior of RMC under various loadings by Appling these conditions analytically on CPV model taking some loading conditions into consideration during design such as working pressure, applying loads result from rotation, the effect of variation of temperature and humidity along the body. Applying theory of classical lamination for plate, then analyzing using thin wall and thick wall approaches they approved that the two approaches give the same results for the optimum value for winding angles and burst pressure.

- The optimum winding angle ranged between (52.1:54.1) degrees relying upon the material kind in pure inner pressure loading case.
- By taking the effect of the rotational speed besides internal working pressure this makes the optimum winding angle shifted to 90 degrees.
- Taking the effect of the axial force causes decrease the value for winding angle.
- By considering a linear variation in temperature along the body and constant value for moisture, the mechanical performance is decreased due to high temperature

Hocine, A. [27] introduced an analytical and experimental investigation of pressure vessel which produced from carbon/epoxy envelope covered by a metal liner. An aluminum 6061 which has exposed to classical heat treatment is used for production of the liner. Assuming that composite laminate is an anisotropic purely elastic material, and metal liner assumed to be an Elasto plastic material. Providing an exact solution for the values of stresses and strains on the cylindrical part of the CPV by using the analytical model. Using Tsai-Wu criterion in order to predict the fracture behavior of each composite layer. Estimating the effect of changing the winding angle on the pressure vessel behavior by using three stacking sequences [±50°], [±55°], and [±60°]; based on the value of optimal angle 55° for a

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filament winding structure which subjected to internal pressure. Numerical simulation and Experimental tests were utilized to verify results of the analytical solution

BORA [28] investigated and analyzed the design of filament wound composite tubes by using ANSYS tool (APDL) in order to do more parametric studies, several studies were done by applying different loading conditions on filament wound orthotropic tubes. The analysis results were plotted and it was consistent with experimental results, they proved that variation and interchanging of the layer orientation are basic parameters for optimization. Bakaiyan [29] Studied composite pipes made by filament winding technology, these pipes subject to thermal stress and internal pressure. Applying analysis on the pipes which are based on three dimensional an anisotropic elastic theory. The Tsai-hill theory had been applied to predict the strength value of the fiber. It was found that hoop stress to axial stress ratio increases as the winding angles tend close to circumferential direction. The stacking sequences [+55°/-55°/+55°/-55°] and [+35°/-35°/90°/90°] have low coefficients of failure criteria so it's considered as the ideal sequence. Rao.V.V.S [30] developed 3d finite element analysis procedures to study the effect of temperature and moisture on a multidirectional composite plate, free vibration analysis on a multidirectional composite plate proved that the multidirectional plate with fiber aligned in more than 3 directions is unstable at higher level of moisture. They proved that for 6 direction composite plate the fiber in the diagonal direction increases the stiffness of the plate. Sayman [31] studied the stress analysis for multilayer composite thick or thin cylinders under thermal load Appling this study on the glass epoxy composite cylinder at different orientation either symmetric or ant symmetric. Measuring the mechanical and hydrothermal properties, then comparing the results with the finite element results it was found the stresses either tangential or axial are high in the case of cross-ply orientation [0˚/90˚] s, because the mechanical properties are different between 0˚and 90˚layer. There is no failure occur in all cases as the value of thermal coefficient and hygroscopic coefficient are small in case of glass epoxy however these values are high in carbon fiber epoxy. Geuchy [6] simulate the rocket motor case with pressure vessels made of conventional and composite materials, using the genetic algorithm for optimizing design by choosing the best configuration for the layers of composite. After analyzing the two structures on ANSYS software the results showed that:

- CPV is more applicable for simulating a large rocket motor case as it has the ability of weight reduction more than conventional material.
- Optimum fiber orientation is not the same for different composite material.
- According to experimental data, it was found that the thermal load is more effective for long time working motor cases, but it can be neglected in the case of short time working motor cases.
- The applied temperature must be less than the glass transient temperature in case of using composite materials.

Tolga [32] used different methods to find the first pressure required for failure in pressure vessel made of a glass epoxy composite layers, which represent anti-symmetric structure, by using FORTRAN software and applying Tsai and maximum stress theory to calculate the burst pressure taking the effect of temperature during calculation. These methods had been adopted on different stacking angles [45/55/60/75/88] degrees at different temperatures. The result of analysis proved that

- The optimum angle is 54.74˚and 25˚c is the most efficient temperature value.
- In cases of anti-symmetric winding angle pressure vessel failure occurs faster than the case of symmetric winding angle pressure vessel.
- Burst pressure increases proportionally with the number of layers.
- The value of the failure pressure for anti-symmetric pressure vessel with plastic liner is higher than the value without liner.

Zhang [33] performed numerically an approach to calculate the in plane properties of thin tubes made by helical filament winding technology, using two scale model for calculating helical tube properties

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after analyzing the required properties are obtained, proving that the fiber architecture effect on stress and strain distribution. Kawahara [34] manufactured CPVs that contains a titanium liner wrapped with a filament winding using carbon fiber (Torayca T-1000 G), which considered as high performance fiber and the resin system was EPON 826. Procedures of Manufacturing and curing temperature of resin system were mentioned. A Thin layer of adhesive was used to bond the composite laminate and the titanium liner. Onder [35] investigated the burst pressure of the multilayer composite pressure vessel at different orientations even symmetrically or anti-symmetrically. Using NASYS software for analyzing and comparing results with the experimental data it was found that the result is very close, the high temperature causes thermal stresses and these effects on the value of burst pressure. Zhang [36] studied the thermal stresses on CPV with closed ends subjected to thermal and pressure loads depending on the theory of thermo elasticity. The analytical approach for calculating the stress results in composite pressure vessel are compared with finite element analysis results proving that the first approach can give better results for the first stages of design and for more analysis the finite element analysis is better. Sulaiman [37] designed conventional pressure vessel made of aluminum and overwrapped carbon epoxy fiber, Appling internal pressure load only and studding the effect of the fibers at the value of the burst pressure depending on Tsai-Wu, Tsai-Hill and maximum stress failure theories. The result after analyzing showed that the value of the optimum angle was 55˚. Velosa, J.C. [38] manufacture CPVs consists of a thermoplastic liner (high density polyethylene) which wrapped with a glass fiber reinforced polymer matrix structure. Thermosetting resin as the matrix was used. ABAQUS 6.5.1 FEA package was used to predict the mechanical behavior of CPVs. Predicting failures of composite laminate and thermoplastic liner by using Tsai-Wu failure theory and Von Misses criteria respectively MAHDY [39] compared between a steel cylinder and composite cylinder with steel liner from strength and weight reduction point of view proving that a composite cylinder with steel liner able to achieve 25% weight reduction also developed analytical model which can calculate the thickness and optimum shape of the dome. Karanpreet [40] studied stiffened composite pressure vessel subjected to internal pressure and bending moment using MSC.PATRAN to perform structural analysis proving that the placing the stiffeners around the surface can save the weight of the cylinder and also increase the ability of the cylinder to resist buckling load comparing between orthogonal and curvilinear stiffeners .Using Particle Swarm and gradient based Optimization to find the optimum dimensions for stiffeners geometry and optimum thickness for each layer in the structure the result proved that curvilinear is better than orthogonal stiffeners as it can save the weight of composite laminate by 8% more than straight stiffeners. Kumar [41] analyzed different types of stiffeners designs such as circular, semicircular, honeycomb, liner x-cross and square section on low carbon steel pressure vessel in order to reduce the rocket weight which represented by pressure vessel this pressure vessel was modeled as a cylinder without caps. The cylinder length equal to 300 mm , inner diameter 200 mm and external radius equal 236 mm using ANSYS software, performing static structure analysis on the models and comparing with the analytical solution to validate the results, stiffeners was modeled of thickness equal to 8mm on surface of the cylinder with thickness 10 mm considering fixed ends for the cylinder as a boundary condition, and Appling pressure equal 50 MPa then solving the model, the results proved that the best stiffener was the helical stiffener form strength and weight reduction point of view as it can save the weight by 28% and 23% less von misses stress in comparison with the basic pressure vessel which without any stiffeners on the surface.

6. Testing of composite pressure vessels

It is necessary to calculate the mechanical characteristics of CPVs in order to perform the best design. So, The calculations of the physical and mechanical characteristics are done according to ASTM composite standards[42] which represent the best tool for calculating any composite structure properties. These standards are useful for guiding users of these materials in proper manufacturing and testing to have good assurance of the product quality. Some of these standards will be listed as follows. ASTM E2981-15 used non-destructive tests for filament wound pressure vessels which used in some aerospace applications. ASTM D3379 used for testing the mechanical properties of the fiber, the standards ASTM

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D638 and ASTM D695 are used for determination tensile and compressive properties of the matrix. ASTM D3171 used for calculating Physical and mechanical properties for laminate. ASTM D792 used for measuring the density of the composite laminate. ASTM D3039 was used to perform uniaxial tensile test for composite. ASTM D3410/D3410M-03 used for calculating the compressive properties of polymer matrix structures. ASTM D3518/D3518M-94 standard can be used for calculating the in-plane shear response of the composite material. ASTM D2992 - 18 standard used for calculating the value for pressure design for cylinders made from fiberglass. There are several tests which have been performed on the CPVs as follows: Tarakcioglu [43] investigated the fatigue behavior of composite pipe which manufactured by filament winding technology at winding angle equal to 55˚ and it consists of six anti-symmetric layers these pipes were made from E glass epoxy and the test were done according to ASTM D229 standard. Using 25 MPA PLC hydraulic testing machine which is controlled in order to apply internal pressure. At three different levels of stresses the tests have been done with the results. The relationships between delamination areas and fatigue cycle were investigated and the final failure of the composite pipes has been investigated. Martins, L.A.L. [44] Tested composite tubes made by filament winding technology and subjected to internal pressure in order to investigate the value of the failure pressure Appling the tests on four tubes with different winding angles. Tubes are winded at 55˚ to have the highest values for pressure failure, using ABAQUS to model the cases and performing finite element analysis and a good agreement was achieved between the finite element analysis and the experimental results. Hwang, T.K [45] performed hydro-burst pressure test on CPV, which made by filament winding in order to calculate the properties of the fiber material according to ASTM standards for testing pressure vessels. As these properties are considered as the most important parameters in design of high performance CPV , using a newly test (hoop ring test) which provide the ability of pressure testing by using this ring specimens which taken from full scale CPV using this test method have more advantages as it can measure the strength of fiber and also measure the full scale pressure vessel stiffness, the results from this test proved that using hoop ring test method is effective for measuring the stiffness and strength of the fiber of the CPVs. Gemi,L.[46] performed the fatigue test on E-glass epoxy pipes made by filament winding technology which subjected to internal pressure and the thickness of the pipes is divided into four layers with winding angle equal to ±75°, performing these tests according to ASTM D-2992 by Appling different load values in order to investigate the behaviors of the fatigue failure. Increasing the applied load causing fast damage as expected, damage can be happened into steps such as whitening, initiation of the leakage and failure. It was shown that Appling low load values make the leakage remarkable and followed by failure and Appling high values of loads causes the leakage coincide with final failure .

7. Conclusion

- This review paper proved that there are many factors affecting design, manufacturing and testing of CPVs.
- Using composite materials has good advantages on saving weight and enhances performance.
- Testing complexity must be taken in mind before planning to manufacture CPVs.
- Finite element tools used for design analyzing CPVs such as ANSYS, ABAQUE are good tools for saving time of design.
- Design of CPVs is based on elastic constitutive relations and traditional thin-walled laminated shell theory.
- There are several failure criterions for composite materials such as maximum stress, maximum strain, Tsai-Hill, and Tsai-Wu but the last theory was the best one as it gives accurate results more than the others[47].
- Filament winding is the best technique for production of CPV in short time with excellent mechanical properties.
- Optimum angle for winding CPV is 54.74°[48].
- Changing the design parameters of the CPV is the best technique for optimization in order to design high performance CPVs.

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