Analysis of Composite Pressure Vessels (CPV) with Metallic Linear for In-Space Applications

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ABSTRACT:

The advantages and superior properties of composite materials made it more popular in its usage and started to replace all other materials ferrous and non- ferrous, especially in the last two decades. Composite materials were used extensively in aerospace and aeronautics fields, because of their high strength and stiffness to weight ratios. Hence, they are widely used in long range missiles particularly in pressure vessels and other vital components. This led us to investigate the state and the behavior of composite pressure vessels during pressurized cycles; since residual stresses were developed. Residual stresses were the subject of extensive investigation in the past few years as they determine the overall strength and durability of polymeric composites. There are two main reasons for the development of residual stresses first, thermal stresses due to differences in expansion coefficients, and second, stresses due to shrinkage during curing or solidification of the matrix or the presence of inclusions. According to theoretical analysis, these residual stresses are induced in fibrous composite material acting around the liner of composite vessels and in such a case important consideration have to be

taken in order to prevent such a problem or minimize it. Since such type of stresses may cause failure or even collapse of the liner itself prior to ultimate failure of the pressurized vessel.

So mainly, the main aim of this paper is to present an experimental and theoretical procedure for analyzing the existence of residual stresses in composite pressure vessels. Therefore, the work contains an introductory part of composite pressure vessels and its usage, production techniques, followed by theoretical analysis and finally manufacturing of pressure vessels and experimental work. The experiments proved the existence of residual stresses through the testing of the vessels which were clearly pointed out. Finally results and discussion with conclusions and remarks were presented.

KEYWORDS: Pressure vessel; Residual Stresses; Buckling; Stacking Sequence.

NOMENCLATURE:

P	Internal pressure.	$P_{OVERYIELD}$	Post yield over pressure.
$Q_{i,j}$	Stiffness matrix.	θ	Fiber orientation.
σ_θ	Circumferential stresses.	σ_ϕ	Axial stresses σ_θ^L is hoop stress of liner
P_y	Initial yield pressure.	α	factor of safety for working pressure(P_w)
β	Buckling factor.	P_{ULT}	Ultimate Failure Pressure
P_{if}	Interface pressure between liner and composite.		

1. INTRODUCTION:

The laminated structure is growing enormously in use and replacing other types of structures around the world and will continue to be in demand for a long time. It is therefore playing an increasingly very important role in structure design and applications; especially it's applications for aircraft and spacecraft vehicles, because of its high strength and stiffness to weight ratio compared to other structures. The utilization of composite laminates has greatly increased during the last decade by employing them in structures as a major component. Composite laminates are used as skins and in supporting structures such as beams and wing spars. Composite shells, pressure vessels, plates, arches, and beams are the building blocks for the majority of today's complex aerospace structures. Pressure vessels are made in different shapes and materials and are used in diverse applications. The application range from air receivers in gasoline stations, to nuclear reactors in submarines, to heat exchangers in refineries and ending up with fuel and compressed air tanks in long rang missiles. [1]

Since there are different environmental and strength conditions which are required to be satisfied for materials of pressure vessels, they can be made of fibrous composite materials with high strength to weight ratios as shown in Fig. (1.1). The advantages of using such a material are remarkable in the case of tubular vessels, where the hoop stress is twice the longitudinal stress, if the fiber quantities and orientation are optimally designed to resist the applied load caused by internal pressure.[1,2]

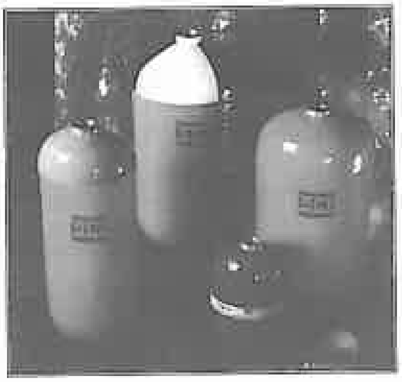


Fig. (1.1) Example of fibrous vessels

Using composite pressure vessels as structural parts in aerospace industries draw our attention to investigate the methodology of designing and manufacturing composite pressure vessels. Many investigators have developed the use of fibrous composite instead of conventional materials. The first research work on the subject of using glass fiber for the production of rocket motors was started in 1950 and then it was upgraded to producing with Kevlar fibers and epoxy resin, which is used for first, second and third stages of rocket motor cases in Trident-I missile, (C-4) and the second and third stages for Trident-II missile. Carbon fibers with epoxy resin are used in fuel tanks and reinforcing cylindrical sections on the body of the missile with weight saving up to 20% - 30%. The Trident-I contain about 60% of its components as composite parts. Space applications have extreme requirements on the lightweight construction of rocket structures to achieve a high payload. Solid rocket motor cases have to withstand the operating loads of the vehicle as well as the internal pressure due to combustion. Composite materials can fulfill these requirements and are commonly used. The solid rocket motor case S44 is also used in the Brazilian Space Program as the 4th stage of the satellite launcher **VLS**.[3] **NASA** missions are becoming increasingly more demanding of propulsion capability, driving the mass of propulsion systems higher, even as the science mass of electronics is reduced. Typically, the propulsion tank is the single largest highest dry mass item of an in space propulsion system.[4] It is therefore important to make sure that the safety of these structures is maintained especially in areas were repetitive cyclic loading might be present. This led us to further investigate the behavior of composite pressure vessels during repetitive cyclic loading (pressurized cycle); were residual stresses might have been developed.

Residual stresses are an important factor influencing the strength of polymeric composites. The causes of residual stresses are usually differences in thermo mechanical properties of constituents. They are often observed when composite materials are formed at temperatures higher than working temperatures. For example, residual stresses arise during curing of epoxy resins embedding another reinforcing material or during solidification of thermoplastic-containing continuous fibers.

Residual stresses are the subject of extensive investigation in the past as they determine the overall strength and durability of polymeric composites. There are two main reasons for the development of residual stresses in structures; thermal stresses due to differences in expansion coefficients, and stresses due to shrinkage during curing or solidification of the matrix inclusions. According to theoretical consideration, these residual stresses are induced in fibrous composite material acting around liner of composite vessels and in such case important consideration have to be taken in order to prevent such problem or minimize it. Since such type of stresses may cause failure or even collapse of the liner itself prior to ultimate failure of the pressurized vessel. Therefore theoretical analysis of composite vessels and manufacturing steps were presented, the experimental prove for residual stresses existence through the testing of the vessels were clearly pointed out.

2. COMPOSITE PRESSURE VESSELS (CPV):

Fibrous composite vessels consist, in general, of two main layers one is the liner and the other is a mechanical layer; each layer has important functions. The liner could be either permanent or temporary. The liner which is made of removable materials such as plastic, ceramic, or rubber is named as "temporary", whereas, the one made of metallic material, is named as "permanent" liner. The main function of liner is to act as mandrel, and to prevent leakage i.e. (leakage proof). The second layer is a mechanical layer which consists of a number of reinforcement layers. The main function is to carry mechanical loads acting on the vessel mainly the internal pressure. The construction of the composite vessel is shown in Fig. (2.1) and an example of its usage are shown in Fig. (2.2). [5]

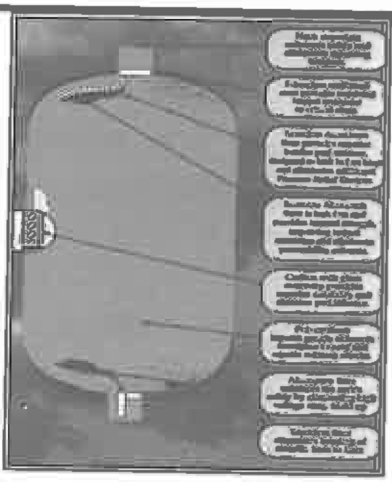


Fig. (2.1) Cross-section of Composite Pressure Vessel

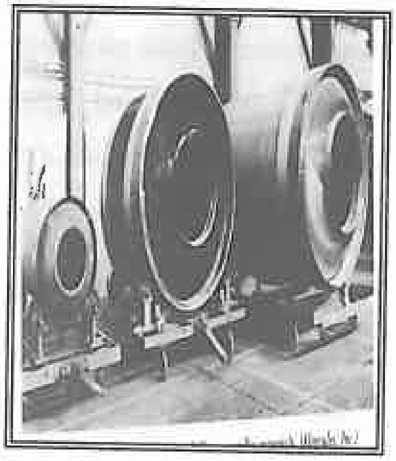


Fig. (2.2) Real composite fuel tank of Trident-I missile

With the advantages of using fibrous composite, it could be possible to satisfy the requirement of spacecraft and aircraft vehicles conditions.

3. PRODUCTION TECHNIQUES

The main consistent materials used to produce hollow shapes fiber glass components are as follows:-

- Reinforcement, which is glass fiber and represent about **70%** of the total raw material used .
- Matrix which represent about **20%** of the total raw materials.
- The rest around **10%** are additives for special purpose(To protect against sun rays, accelerators, etc)

From the above it is clear that the main material is glass fiber and the production of such material completely depends on ***Silica, which is widely available in Libya***, and with high purity around ***99%***. The main technology used for production of Glass Reinforced hollow shapes is presented, It is also advantageous to compare with other different production technologies.

TECHNOLOGY COMPARISON

Indeed there are many different types of manufacturing techniques used to produce hollow shapes. Those types include continuous process, discontinuous process, braiding process. The most important factors which are used to decide and select the type of production process of the GRP pipes are as follows;

- Area of Application of the product.
- Production quantity.
- Production capacity.

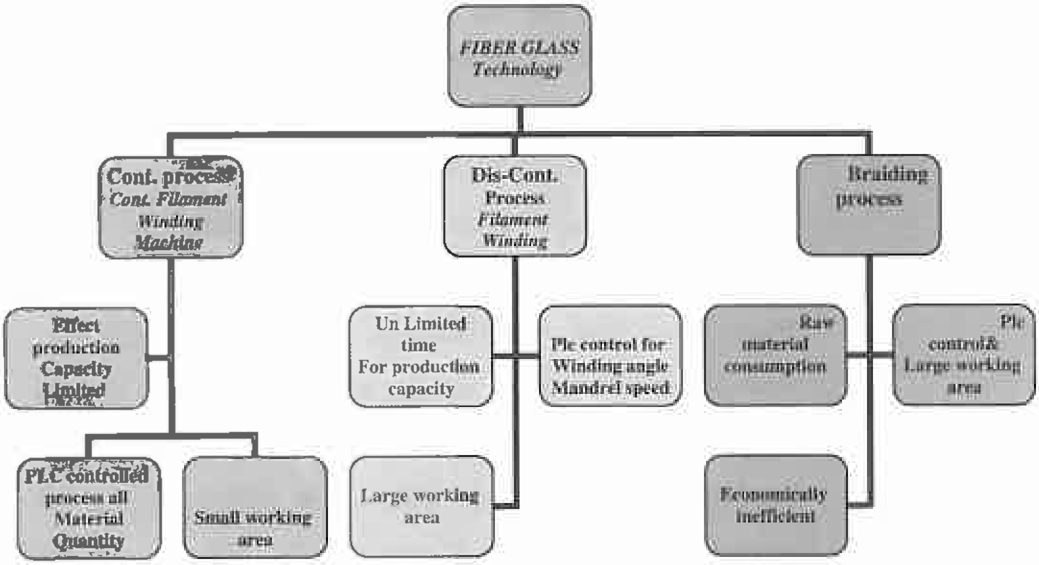


Fig.(3.1) Technology comparaison

Since all above different technologies have certain advantages and disadvantages, when considering production capacity, the continuous process is preferred since there is limited time to reload components or change output design in comparison with discontinuous process fig (3.1).

Continuous process. This process is considered most efficient, by making the hollow shape on one or more mandrels. The shape moves past stations that apply fiber glass tapes, pre-impregnated with resin or glass fiber and resin. Winding angles are controlled through a complex combination of longitudinal mandrel speed, mandrel rotation or the rotation of planetary glass application stations. This process when started, produce continuously without stopping; Stopping is done only in the case of reload components or change output design

Continuous Filament Winding Method

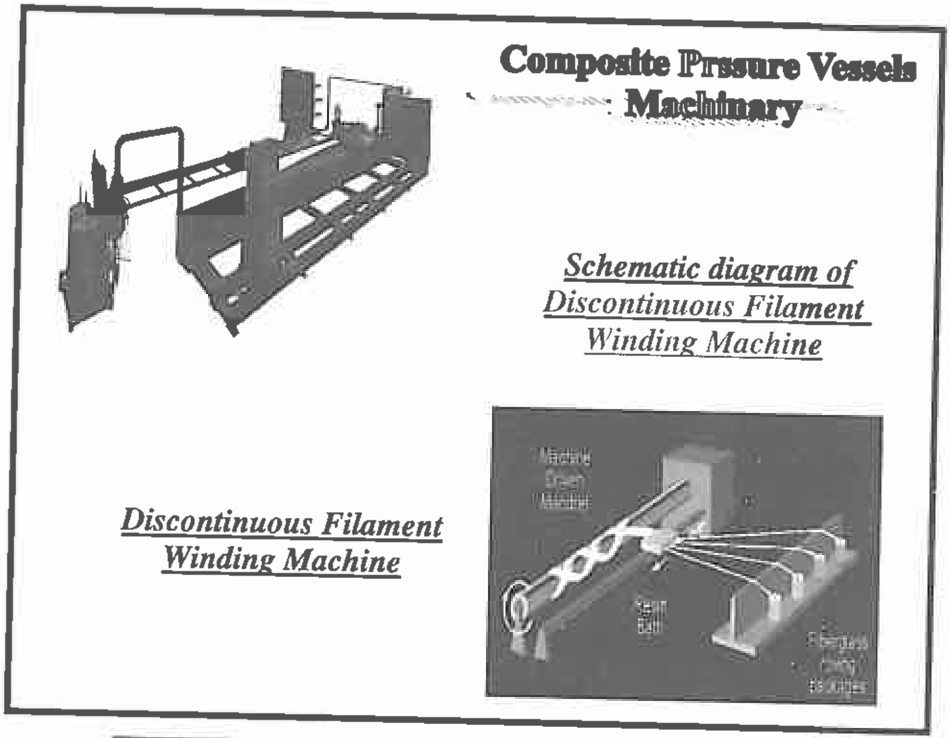
- The most advanced hollow shapes technology in the world, uses the "Continuous Filament Winding Method" with the equipments used, it is possible to produces shapes between 300mm. and 2400 mm in diameter. Up to 32 atm. at 2500 N/m2 - 5000 N/m2 and 10000 N/m2 stiffnesses.
- Using technology developed by material specialists, a very dense laminate is created that maximizes contribution from three basic raw materials.both continuous glass fiber rowings and choppable rowing are incorporated for high hoop strength and axial reinforcement. Sand fortifier is used to provide increased stiffness with placement near the neutral axis in the pipe wall core.

Discontinuous process

The process does not produce continuously without stopping and each time the process is stopped for reloaded of new component. Illustrations of the process and the machines are shown in fig.(3.2).

Continuous Filament Winding Machine

The basic machine for manufacturing (winder) is composed of a continuous steel band supported by beams which form a *cylindirically shaped mandrel.* The beams rotate, friction pulls the band around and roller bearing allows the band to move longitudinally so that the entire mandrel continuously moves in a spiral path towards the end of the machine. As the mandrel moves, fine graded filler, glass fibers, resin and surface materials are metered on in precise amounts under the direction of a programmable logic controller(plc) and computer (pc) the plc-pc modules provide integrated process control based on pre-programmed recipes. Only basic pipe data such as *diameter, pressure, and stiffness class* is needed to be input and the computer calculates all the machine settings. Material consumption as well as pipe thickness are continuously monitored and logged to ensure high product quality and efficiency.



Composite Prssure Vessels Machinary

Schematic diagram of Discontinuous Filament Winding Machine

Discontinuous Filament Winding Machine

Continuous Filament Winding Machine

Fig. (3.2). Illustrations of the process and the machines.

BRIEF PROCESS DESCRIPTION

- The polyester resin is pumped to the continuous winding machine and hardener is added in through an in-line mixer. The mix will have a gel-time, depending on the product to be made.
- The other constituent materials are applied in a controlled manner according to their need.
- After material application, the composite matrix passes through a curing section where the laminate solidifies in an exothermic reaction.
- The continuously formed cylinder is cut to the required length by a cutting device, which are synchronised with the speed of the advancing pipe.
- Then, pipes are transported from the winding machine into the calibration unit. This unit ensures that the spigot ends of pipe meet the specifications with regard to calibration length, chamfering and diameter.
- After the pipe is produced it is ready for test in the hydrostatic pressure test machine and it is placed in the test position in the machine in such a way that it will simulate as near as possible the actual forces which will occur in the installed pipe.
- The test pressure is maintained for a pre-determined duration.

4. THEORATICAL ANALYSIS OF COMPOSITE VESSEL:

In the designing and analysis of composite vessels, some important considerations have to be highlighted. The vessel liner consists of cylindrical part and two elliptical domes. Hence, during the reinforcement placing, the winding angle should be controlled in such a manner that placing fiber without skipping over the dome. The analysis of composite vessel starts with yield analysis, which means that the average total stresses acting on the vessel walls, is a combined stresses acting on the liner layer and mechanical layer (reinforcement). But, still the work is sharing between liner and mechanical layer so the strains are almost the same since the thickness of the liner is so small that the liner should be involved in the analysis. The vessel is acting under internal pressure, let it be ***P***. Therefore the two main loads are as follows; [1]

$$\mathbf{N_x = Pr/2} \qquad (4.1)$$

$$\mathbf{N_y = Pr} \qquad (4.2)$$

Where; N_x , N_y are axial and circumferential loads respectively

These equations are in equilibrium, and with the use of classical laminate theory (**CLT**) we obtain;

$$[\sigma] = [Q] * \{\varepsilon\}$$

$$\begin{pmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{pmatrix} = \begin{bmatrix} Q_{11} & Q_{12} & 0 \\ Q_{21} & Q_{22} & 0 \\ 0 & 0 & Q_{16} \end{bmatrix} \times \begin{pmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{pmatrix} \qquad (4.3)$$

Where; σ_x, σ_y and τ_{xy} are normal and shear stresses on geometrical coordinates

Where this equation is for geometrical coordinates, it is required to define the stresses along fiber direction as;

$$\begin{pmatrix}\sigma_1\\ \sigma_2\\ \tau_{12}\end{pmatrix}=\begin{bmatrix}\overline{Q_{11}} & \overline{Q_{12}} & \overline{Q_{16}}\\ \overline{Q_{21}} & \overline{Q_{22}} & \overline{Q_{26}}\\ \overline{Q_{61}} & \overline{Q_{62}} & \overline{Q_{66}}\end{bmatrix}\times\begin{pmatrix}\varepsilon_1\\ \varepsilon_2\\ \gamma_{12}\end{pmatrix} \tag{4.4}$$

In this part, we are interested to calculate interface pressure **P_{if}** between the liner and composite. The stresses in the liner could be resulted from the pressure drop across liner, which is the difference between internal pressure **P** and interface pressure **P_{if}**

$$\frac{P_{if}}{P}=1-\frac{\sigma_\theta^L\, t_L}{\Pr} \tag{4.5}$$

So the initial yielding pressure (**P_{yield}**) of liner is calculated as,

$$P_{yield}=\frac{\sqrt{2}\ \sigma_{yp}}{\left[\left(\sigma_\theta^L-\sigma_\phi^L\right)^2+\left(\sigma_\theta^L\right)^2+\left(\sigma_\phi^L\right)^2\right]^{\frac{1}{2}}} \tag{4.6}$$

Where σ_θ^L = is hoop stress of liner, the stresses in the liner will be as follows;

$$\begin{pmatrix}\sigma_\phi\\ \sigma_\theta\\ \tau_{\phi\theta}\end{pmatrix}^L=\begin{bmatrix}\frac{E}{1-\nu^2} & \frac{\nu E}{1-\nu^2} & 0\\ \frac{\nu E}{1-\nu^2} & \frac{E}{1-\nu^2} & 0\\ 0 & 0 & G\end{bmatrix}\times\begin{pmatrix}\varepsilon_\phi\\ \varepsilon_\theta\\ \gamma_{\phi\theta}\end{pmatrix} \tag{4.7}$$

And the strain for the vessel, which, is same for liner and composite (over warping), is represented by;

$$\begin{pmatrix} \varepsilon_{\phi} \\ \varepsilon_{\theta} \\ \gamma_{\phi\theta} \end{pmatrix} = A^{-1} \begin{pmatrix} \frac{\mathrm{Pr}}{2} \\ \mathrm{Pr} \\ 0 \end{pmatrix} \tag{4.8}$$

With this, the yield pressure is calculated and after the pressure is increased to reach post yield over pressure, named as (**$P_{OVERYIELD}$ = post yield over pressure**). Now, the value of pressure is increased and the liner will enter the plastic region. Hence, the stresses due to post yield over pressure become very important. Therefore, only pressure difference (ΔP) acting on the reinforcement layers (which is the difference between internal pressure and yield pressure), is given by.

$$\Delta P = P_y - P_{internal}$$

And the **$P_{OVERYIELD}$ = post yield over pressure** could be calculated as;

$$\begin{pmatrix} \Delta\varepsilon_{\phi} \\ \Delta\varepsilon_{\theta} \\ \Delta\gamma_{\phi\theta} \end{pmatrix} = A_C^{-1} \begin{pmatrix} \frac{\Delta \mathrm{Pr}}{2} \\ \Delta \mathrm{Pr} \\ 0 \end{pmatrix} \tag{4.9}$$

Where; **A_c is** for composite only.

So, the total strain of the vessel due to internal pressure will be calculated as the sum of the strain due to initial yield pressure (**P_y**) and the strain due to post yield over pressure (**$P_{OVERYIELD}$**). In this stage, still the fibers carry the load and there is no failure in fibrous layers so far. When the pressure is increased further to reach the **Ultimate Failure Pressure** (**P_{ULT}**), which is defined as the pressure due to an increases of pressure (over initial yield and post over pressures) of liner, up to occurrence of failure in filaments layers, is calculated by ***Maximum Strain Failure Criteria*** as follows;

$$\frac{\Delta\varepsilon_{\phi}}{\Delta\varepsilon_{\theta}} = \frac{A^{-1}_{C11} + 2A^{-1}_{C21}}{A^{-1}_{C21} + 2A^{-1}_{C22}} = R_{\Delta\varepsilon} \tag{4.10}$$

$$P_{ult} = P_y + \frac{1}{r}\left\{\left(A_{C21}R_{\Delta\varepsilon} + A_{C22}\right)\left(\varepsilon_{ult} - \varepsilon_{\theta Y}\right)\right\} \tag{4.11}$$

Since the hoop strain (ε_θ) is important at the ultimate pressure value, which should be always within 60%-70% of the axial strain (ε_ϕ), to ensure and enforce the failure occurs in cylindrical portion of vessel and not at the region of connection between the dome with the cylindrical part of the vessel.

The final stage of this cycle is **residual stresses** which plays a very important role in this analysis of fibrous vessel, and is defined as the internal pressure reduced to zero bars in the warped vessel. So, in this case, the strength of the pressurized warped vessel depends upon the effect of ***compression stresses*** acting on the liner and due to the ***tensile stresses***, acting on the fibrous layer. The interface pressure has to be recognized and can't be neglected. Therefore this residual stresses should be limited to prevent the occurring of buckling of the liner. The value of factor β ranges between **0.6 to 0.8**. Also, anther factor of safety for working pressure (P_w) is defined as α and its value is about **0.75** [1].

$$P_W = (\alpha + \beta)\, P_Y$$

5. CASE STUDY:

In this case study, a case of special warped vessel was studied and described as follows:-

Warped vessel diameter = 500 mm, Internal pressure = 30 bars or 3 MPa,

$\beta = 0.6$; $\alpha = 0.75$; the factor of safety is about **2**

The selection of material used to manufacture the liner, is an important issue. The liner should have the ability to enter the plastic region without any failure and also have the ability to transfer the loads to the reinforcement layers. The liner material can be AL 6061-T6 and other can be stainless steel 304. In this case, Al 6061-T6 was used as liner with the following mechanical properties; [2]

E = 68.9 GPA, ν = 0.33 G = E/ 2(1+ν), σ_y = 290 MPa., ρ = 2800 Kg/m^3.

and the reinforcements materials were selected as carbon fiber with epoxy resin with designation as **(AS4 3501/6)** and the fiber volume fraction is **63%** and the resin with the additives is about **37%** . The mechanical properties of such class of material are; [1, 2]

E_{11} = 131 GPa, G_{12} = 6-55GPa, E_{22} = 11. 2 GPa, ν_{12} = 0.28

ν_{21} = 0. 024, ε_{ult} = 0.0 14

Two main tasks to be performed which are:-

(1) performing theoretical analysis of the vessel

(2) Manufacturing such warped vessel and pressurizing it up to failure.

The cross section of the warped vessel with complete geometrical description and fiber orientation is shown in Fig. (5.1)

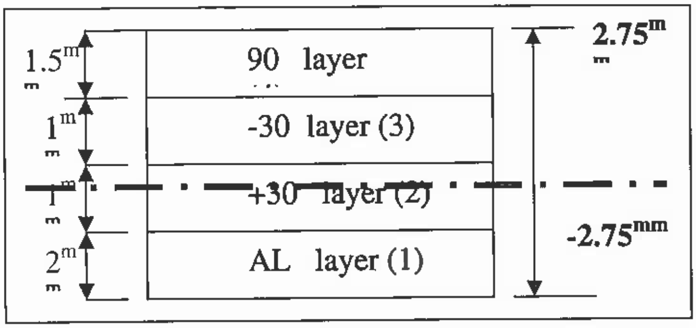


Fig. (5.1) Geometrical description of warped vessel.

6. EXPERIEMENTAL WORK:

The main task of this research to show the existence of residual stresses (***Compression*** on the liner, and ***Tension*** on the filaments) after zero bars of the warped vessel and its effect on the liner, which could be a source of failure even without complete rupture of the reinforcement layers taking place

There are two parts of this experimental work, which include manufacturing the warped vessel and second subject such vessel to hydrostatic test, with controlled incremental pressure of **5 bars**. The warped vessel was manufactured using two axis **CNC** filament winding machine with the selected raw material mentioned above and selected liner (with optimum design of domes of elliptical type to ensure winding of the fiber without skipping). And the complete process was done to obtain the warped vessel as shown in Fig. (6.1)

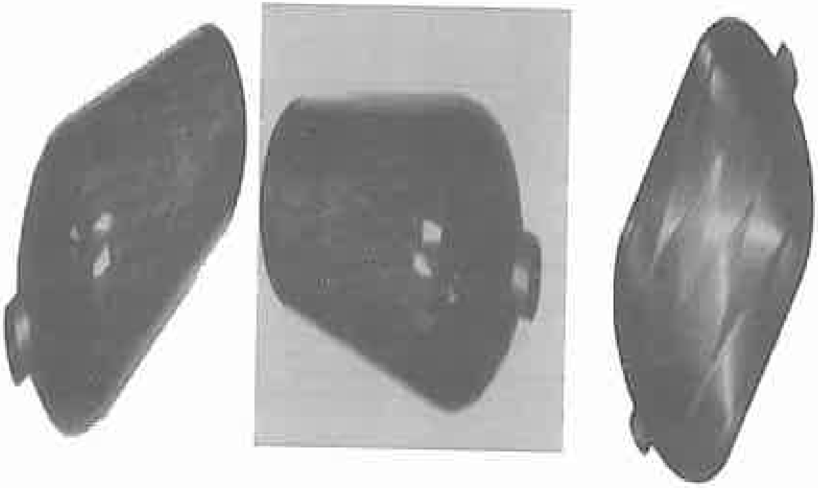


Fig. (6.1) complete warped vessel with liner

7. RESULTS AND DISCUSSION:

The importance of fibrous composite vessels drew our attention to investigate the analysis, material selection for both liner and reinforcement filaments, selection of design parameters such as β, α and sharing in the prevention of failure especially caused by induced residual stresses. The manufacturing method also has an effect on the product. As it could be seen from the theoretical analysis of warped vessel, the following results are obtained as presented in Table (7.1).

Table (7.1) summary of theoretical analysis for warped vessel

Task:		**Analysis and Manufacturing Pressure Vessel with Filament winding.**
Vessel Diameter. in ((mm))		500
Vessel Materials.	Liner	Aluminum 6061 T6
	Over warp	AS4 Carbon Fiber- Epoxy Resin.
Weight of the Vessel. In ((Kg)).		28.733
Stacking Sequence of the Vessel.		[AL/+30/-30/90]
Total no. of Layers.		Liner + 3 Layers. = 4 Layers.
Total Vessel Thickness. In ((mm))		5.5, [AL $_{liner}$=2, ±30°=1,90=1.5]
Pressure Cause Initial Yielding of liner in (P_Y)		**66 bars**
Interfacial Pressure (P_{if}) bars		**18**
Pressure Difference ($\Delta P = P_i - P_y$) bars		-36
β ratio B/W residual stresses to stress cause initial yield		**0.6**
$P_{\text{over peak pressure}}$ bars $=[1+\beta]*P_y$		**105.6**
α factor $P_w \leq [\alpha+\beta]*P_y$		$\leq$ 0.145
Ultimate Pressure Cause Failure. In bars.		**183.2**
Applied Pressure ($P_{applied}$)		**30**
Ratio of strain in helical to hoop fibers must be less than or equal ≤ 0.7		0.5979, So ***rupture*** will be in hoop fibers.

Experimentally, the above results were verified after the manufacturing of composite warped vessel was completed. The hydrostatic test was performed using water pump with pressure control. The tank was pressurized up to initial yield pressure value, **about 65** bars, i.e. the liner enter yield regime at pressure $[\mathbf{P_y}]_{\text{experimentally}}$ and under hoop stresses ($\boldsymbol{\sigma_{\theta y}}$). The pressure was increased up to post over pressure ($\mathbf{P_{op}}$) and then increased until failure of both liner and filaments (fibrous) which occurred at ultimate pressure around $[\ \mathbf{P_{ult}}]_{\text{experimentally}}$ = **180 bars.** The result of testing was shown in Fig. (7.1) to Fig. (7.3) below;

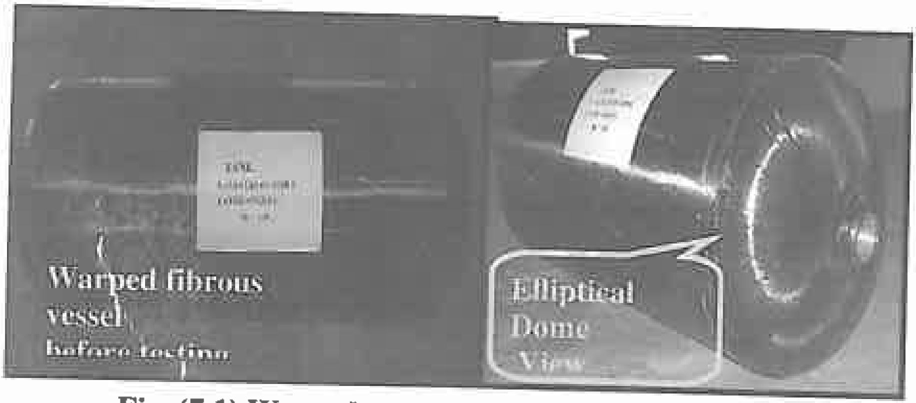
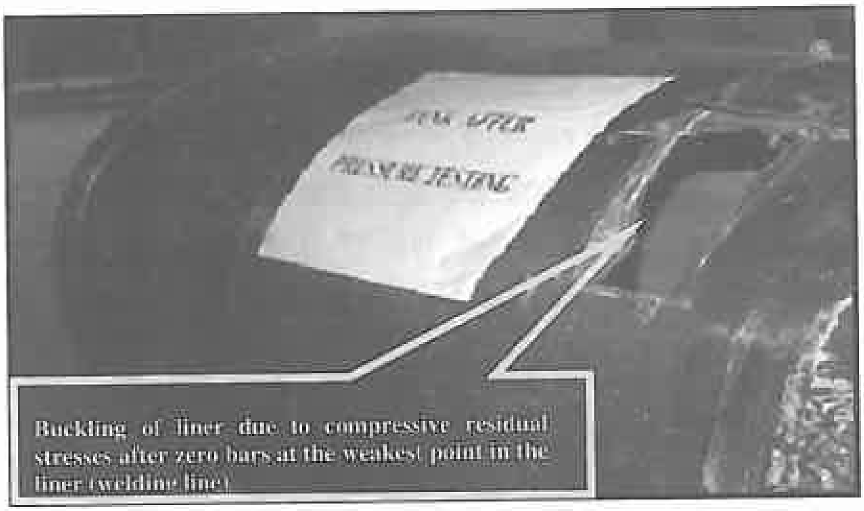


Fig. (7.1) Warped composite vessel before testing.

Fig. (7.2) Warped composite vessel after testing.



Buckling of liner due to compressive residual stresses after zero bars at the weakest point in the liner (welding line)

Fig. (7.3) Effect of residual stresses on liner (*as source of failure*)

As expected theoretically, the existence of residual stresses was proven, and it was clearly seen after pressurizing the vessel, up to ultimate failure; which could be high; attention should be drawn to the two class of stresses exist after **zero bars** of pressure;-

1) One is the compression stresses acting on the liner with value around ($\beta\ \sigma_{\theta y}$),

2) The other is the tension stresses acting on the filaments with value around ($\alpha\ \sigma_{\theta y}$), and these values greatly depend up on the choice of the factor (β, α), which could be source of failure without reaching complete rupture of the warped vessel.

8. CONCLUSIONS:

The use of composite warped vessel in many critical areas such as space and defense systems, led us to investigate the structure completely from starting point of pressurization of the warped vessel, up to the failure of the system. So the designed and analyzed warped vessel, have been manufactured and tested with hydrostatic testing unit. It was noted that the buckling of liner is more likely to occur in the liner. **This means that there exist residual stresses with both type's compression and tension even at zero bars of vessel** Fig. (7.3). **Hence, for second and subsequent uses, the vessel cannot be used for the designed ultimate pressures**. Therefore, such classes of stresses have to be taken into consideration in the design procedure with special choice of β factor; because it could be a source of failure even after the vessel function was finished. Normally such failure is invisible and as noted in Fig.(7.3) the buckling occur at welding line which is the weakest point in the structure.

The analyzed data using theoretical analysis are almost coinciding with experimental data, in case of comparing ultimate failure pressure and initial yield pressure for warped vessel in both theoretical and experimental. Finally choice of consistent material such as carbon fiber and epoxy resin with the additives also play very important role in the manufacture of the final product.

الملخص

إن المواد المركبة تمتاز بخواص و مميزات متالقه، الأمر الذي يجعلها الأكثر شيوعا واستخداما وحلت محل معظم المواد المعدنية والغير المعدنية في العقدين الماضيين. إن الاستخدام الأكثر شيوعا للمواد المركبة في مجال علوم الفضاء والطيران والذي يميزها عن المواد التقليدية حيث تمتاز هذه بخفة وزنها وزيادة عالية في المتانة و الصلابة. وتحديدا تستخدم المواد المركبة في الصواريخ بعيدة المدى وعلى وجه الخصوص خزانات الوقود وخزانات الضغط العالي. هذا ونركز من خلال الورقة البحثية على التحليل الهندسي والرياضي

لخزانات المواد المركبة المضغوطة أثناء تعرضها للأحمال الضغط {أحمال دائرية، أحمال طويلة} حيث يسبب الضغط المؤثر على هذا النوع من الخزانات اجهادات متبقية { Residual Stresses} ويستمر تأثير هذا النوع من الاجهادات حتى بعد تصفير الضغط الداخلي المؤثر على الخزان، بسبب طبيعة الهيكل الإنشائي المكون لخزان المواد المركبة المضغوطة .

تهدف هذه الورقة البحثية إلى إجراء تحليل هندسيا نظريا للاجهادات المتبقية { Residual Stresses } في خزانات المواد المركبة المضغوطة مع محاكاة ذلك بخطوات معملية موضحا تصنيع واختبار هذا النوع من الخزانات، حيث تضمن هذا العمل جزء تقديمي على خزانات المواد المركبة { الألياف }، استعراض للخطوات النظرية لتحليل الاجهادات المؤثرة عند تعرض الخزان للضغط الداخلي. الخطوات العملية لتصنيع واختبار خزان المواد المركبة المضغوط تمت تغطيتها وتوضيحها، متبوعا بمناقشة النتائج النظرية و العملية وبعض من التوصيات الهامة المتحصل عليها.

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