THE EFFECT OF INTERNAL PRESSURE AND TEMPERATURE ON HOOP STRAIN BEHAVIOR IN SPHERICAL COMPOSITE SHELL

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ABSTRACT

This paper presents an experimental approach to analyze the strain due to internal pressure to the effect of temperature in spherical pressure vessels made from composite materials. Laminates from different types of fibers (woven and random glass and woven Kevlar 29) are used as reinforcements in the polyester matrix. Different arrangements for fiber plies are used in fabricating half spherical shell closed from the bottom by a circular steel plate supported by a steel collar to hold out an internal pressure up to 100 bar. The applied pressure developed with an air compressor. An electric heater element is placed to heat the interior up to 70°C. Some controlling equipment is used like pressure gages, heat sensors and strain gauges. It was found that locating of the strongest ply (Kevlar in this work) limits the hoop strain to its minimum values and that makes the vessel's exterior stable and settled on the structure without being affected by internal pressure or temperature. 12% reduction in hoop strain is established when the Kevlar ply placed in the outside ply instead of the middle ply at 70°C and this ratio was 8% at 25°C.

KEYWORDS: Spherical Shell; Composite Materials; Hoop Strain & Pressure Vessels

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INTRODUCTION

Spherical shell or storage tanks are compartments that hold fluids, compacted gasses (gas tank, pressure vessel, which isn't regularly marked or managed as a storage tank) or mediums utilized for the short or long storage of heat or cold.

The main advantage of the spherical construction over cylindrical is that the stress concentration in a spherical shape will be minimal while storing pressurized liquids. The stress resistance will be uniform, the wall thickness of a spherical shell will be about half the wall thickness needed for a cylindrical shell for holding in the same pressure. So, in a spherical container, thinner shell may be used which means lesser cost and weight. Also, the area that a sphere occupies will be lesser compared to a cylindrical container of the same volume.

The spherical tanks are very impervious to pressure making them appropriate for putting away high pressure materials. Unlike other tank shapes, it is additionally conceivable to decrease the panel's thickness. These tanks are working to hold city gas Like LPG, alkali, oxygen, nitrogen and etc. [1].

Since spherical storage is a little surface region for each unit volume than any other state of storage. This implies the amount of heat exchanged from the hotter surroundings to the fluid in the sphere, will be less than that for cylindrical or rectangular storage [2].

The high strength, high stiffness, and lightweight properties make composite materials particularly attractive to designers in a variety of industries [3]. Fiber-reinforced composites are extensively used in the manufacturing of various

components in engineering structures such as high-pressure vessels [4]. The developments of spherical tanks or pressure vessels made from composite materials have been the interest of many researchers during the last three decades. Some of them paid attention to the angular arrangement of reinforcing plies in the laminate and material types and their effect on stresses. Others studied the pressure vessels in general (cylindrical and spherical) for thermal stresses and materials with stack arrangement of plies.

Dogan T., 2006 [5], presented a complete study of composite pressure vessel struggling under internal pressure. And manages the temperature impact and twisting point of fiber wound with plastic liner. Calculated the vessel first-ply flunking by utilizing the lekhnitskii's hypothesis. Also testing the first-ply flunking in a simple form utilizing Tsai-Wu flunking criteria and furthermore finding the flunking of the plastic liner utilizing von misses criteria. The result shows that the layers situated symmetrically and against symmetrically for $[30^0/-30^0]_2$, $[45^0/-45^0]_2$, $[60^0/-60^0]_2$, $[75^0/-75^0]_2$ and $[90^0/-90^0]_2$ orientation. The temperature impact was established unsuccessful for the burst pressure. And the ideal twisting angle for analyzing the pressure vessel with inner pressure for laminates was equal to 54^0 and equal to 90^0 for lamina.

Rayapuri Ashok, *et al.*, 2013 [6], discussed the advantages of multilayer high pressure vessels over mono black vessels. Also burst pressure analysis is held for carbon fiber reinforced polymer pressure vessels. Tsai-wu failure criteria are used to analyze the burst pressure for various orientations from $[+25^0/-25^0]$ to $[+75^0/-75^0]$ taking an increment of $[+5^0/-5^0]$ to have six combinations. The work conclusions were that a percentage saving in materials of about 92% is gained when using multilayer CFRP compared with steel. And that the $[+25^0/-25^0]$ fiber orientation angle is the optimum angle for fiber orientation.

Subhash N. khetre, *et.al* 2014 [7], investigated the effect of pressure on pressure vessels made from composite materials. They used a 3-D finite element analysis with the aid of APDL programming to analyze the failure in a composite shell of continuous angle ply lamina. A range of layers is used in this analysis from 5 to 20 layers.

Ayad Abed Ramadhan, 2015 [8], made experimental studies on thin-walled composite cylinders made from Kevlar/epoxy under internal pressure load. The specimens are tested with a hydraulic pump which applied a static internal pressure. (2,4 and 6) layers specimens are checked experimentally to find the relation between the pressure increase ratio (PIR) and the failure load. They found that the pressure increase ratio increased when the number of layers increased. The maximum value obtained here is 254.4% of 2L to 6L.

Sonachalam M, Ranyit Babu. B.G, 2015 [9], the design for maximum burst pressure in symmetric and antisymmetric shells were examined. The work took the winding angle as a parameter to be dealt with for optimum design taking different orientation angles. The materials used are glass reinforced plastic (GRP). The results of finite element analysis obtained from the commercial software ANSYS 11.0 are compared with the results for steel.

Ahmed Ibrahim, *et al.*, 2015 [10], examined the stresses in a thin-walled pressure vessels. The cylindrical and spherical vessels are intended to hold gases or fluids at pressure ranges significantly higher than the ambient pressure. Soda cans were utilized as tinny wall pressure vessels. The flexible strains (ϵ_H & ϵ_L) of the extrinsic surface of the soda can be calculated through strain gages connected to the can surface and attached to a strain pointer. The longitudinal stress, hoop stress, and the intrinsic pressure was calculated from the generalized Hooke's law equations for stress and strain.

R.R.Das, *et al.*, 2015 [11], Examined 3 D finite element strategy based thermo- mechanical pressure examination laminated fiber sponsored polymer composite made spherical shell structural subjected to thermal field finite element

simulation by utilizing ANSYS 14.0. The thermo-mechanical stress concentrating the impact at the edges as well as at different basic area in a domain, the dynamic strength of shell structure under the thermal condition for various lamination 15, 30, 45, 60, 75, 90. Because of shell structure curvature impact. The pressure concentrations are not just restricted to free edge may exist inside shell limits, the structure discovered disfiguring minimum for design (0) and most extreme from (90).

EXPERIMENTAL WORK

Half-spherical samples are fabricated from composite materials with five different combinations and three different reinforcement fiber types. The samples are listed and defined in the table (1).

A mold is made of half steel 240 mm diameter ball and a steel ring using the hand lay-up method to fabricate the test samples as shown in figures (1 and 2).

Figure 1: The Mold

Figure 2: Painted Specimen

The test sample is fastened to a steel plate with a gasket washer between. An electrical heater element is fixed to the plate to generate heat inside the sample, shown in figure (3). An air compressor is used to generate internal pressure in the range of 100 bar. Thermocouples type K is used and a thermostat for temperature observation and control. The deflections in the sample due to pressure and heat are collected by a dial gauge and couple of strain gauges. A control panel is employed to record data.

Six combinations (layer arrangements) of composite materials are used to form the spherical shell as described in the table (1).

Table 1: The Layer Arrangements and Materials

Sample	Fiber Materials	Risen Material	Ply Arrangement
S ₁	Random fiberglass	polyester	G _r - G _r - G _r
S ₂	Woven fiberglass	polyester	G _w - G _w - G _w
S ₃	Random fiberglass and Kevlar 29	polyester	G _r - K - G _r
S ₄	Random fiberglass and Kevlar 29	polyester	2G _r - K

S ₅	Random fiberglass and Kevlar 29	polyester	2G _r - K - 2G _r
S ₆	Random fiberglass and Kevlar 29	Epoxy	2G _r - K - 2G _r

Glass fiber (E glass) and Aromatic polyamide (Kevlar 29) are the fibers used in this work. E glass is the most commonly used glass because it draws well and has good tensile strength of (1.4 – 2.5) GPA and Young's modulus of (76 GPA), also has a good stiffness, electrical and weathering properties. Kevlar has the higher tensile strength of (2.8 – 3.6) GPA and Young's modulus of (125GPa) [12]. Table (2) gives the mechanical properties of the materials used in this work, the values are drawn from laboratory test.

Table 2: The Mechanical Properties of the Materials that used in this Work

Properties	Material			
	Kevlar 29	Fiber Glass E-Glass	Epoxy Resin	Polyester Resin
Density (kg/m ³)	1400	2520	1220	1280
Modulus of elasticity (Gpa)	62.4	73.2	3.5	3
Shear modulus (Gpa)	3	35.5	1.28	1.14
Poisson's ratio	0.42	0.22	0.36	0.32

Figure 4: The Bottom Plate with gasket and Heating Source

Figure 5: Air Compressor

RESULTS

The data gathered from the experiments are translated into curves defines the relationship between the internal

pressure and hoop strain with the effect of temperature. Chart (1) gives the pressure – strain curves for the first four samples at 25°C. We can notice that the most samples that obeys the deflection is s_1 which consists of three plies of random fiberglass G_r . The hoop strain in s_1 reaches the maximum hoop strain 0.0111 at 10 MPa (100 bar). This value decreases about 9% in s_2 which is formed from three plies of woven fiberglass G_w . when Kevlar fibers are used, there was a 20% and 28% reduction in samples s_3 and s_4 respectively. s_3 consists two random fiberglass plies and one Kevlar ply between them, while, s_4 has the Kevlar ply on the external surface. This indicates that the Kevlar ply is the dominant ply in the laminate and this effect shows up when the pressure grows up from 2.5 MPa.

Chart 1: Internal Pressure Vs Hoop Strain for Samples s_1 , s_2 , s_3 And s_4 At 25°C

Chart (2) reviews the strain behavior of the same four samples, but, after heat generation to raise the internal temperature to 70°C in order to explore the temperature effect. As it can be seen, s_1 still the most strained samples with a 10% increase in its maximum value for 25°C. s_2 followed s_1 with an 8% decrease from s_1 and 11% rise from s_2 at 25°C.

In the same vein, the samples s_3 and s_4 hoop strain rising for about 14% and 7% respectively from the case of 25°C, and the samples s_3 and s_4 were 17% and 29% lower in hoop strain than s_1 .

Chart 2: Internal Pressure Vs Hoop Strain for Samples s_1 , s_2 , s_3 and s_4 At 70°C

From the last view, it can be concluded that the presence of Kevlar ply, especially at the outer ply has the most effect on the amount of hoop strain and that the sample experiences less strain compared with the other samples.

Chart (3) shows the hoop strain behavior for the samples s_5 and s_6 at 25°C and internal pressure up to 10 MPa (100 bar). Both samples consist five plies, four random fiberglass and one Kevlar ply in the middle. The difference in the two samples is the type of resin used which is polyester in s_5 and epoxy in s_6 .

Chart 3: Internal Pressure Vs Hoop Strain for Samples s_5 , And s_6 At 25°C

Chart 4: Internal Pressure Vs Hoop Strain for Samples s_5 , And s_6 At 70°C

It can be observed that the maximum hoop strain in s_6 at (10 MPa) is 14% less than the strain value of s_5 and this, of course, returns to the properties of epoxy resin. When temperature raised to 70°C , the maximum hoop strain value in s_5 increased 38% as showed in a chart (4), while, the increment in s_6 is almost unnoticeable that is 1.7%.

CONCLUSIONS

From this work, we can draw that the location of the strongest ply among the other plies has the domain effect on the hoop stress behavior and the presence of the Kevlar ply in the outside surface of the spherical pressure vessel in sample

s4 clarifies this phenomenon. Also, the effect of temperature is to increase the hoop strain which is axiomatic, but, the outer Kevlar ply restricts the thermal strain especially with the use of epoxy as the resin material.

The limitation of hoop strain due to internal pressure and temperature makes the hoop stress rise without reaching the allowable tensile stress. This limitation of hoop strain is of great importance when designing bearing structure of the pressure vessels to avoid any extra loads on the structure.

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