Effect of Combined Stress on Carbon- Epoxy Composite Curved Pipe

Fadhel Abbas Abdullah **Omar Emad Shukry**

Mechanical Engineering Department, Al-Mustansiriayah University, Baghdad, Iraq.

fadhel975@yahoo.com

Submission date:- 13/6/2018	Acceptance date:- 2/7/2018	Publication date:- 28/8/2018

Abstract

The aim of this research is to study the behavior of carbon epoxy composite curve pipe under internal pressure and bending moment. Two specimens made from woven roving (Mat) carbon fiber composite pipes /epoxy composite with 50% volume fraction are used for manufacturing curved pipe. The experimental work included manufacturing pipe specimens by vacuum bag technique. Pipe specimens were having 100mm inner diameter, 490 mm length of curvature outer arc and 409 mm inner arc of curve pipe with (43 degree) and wall thickness is (4 and 3 mm). The test rig was designed and performed to study the effect of internal pressure and bending moment on the composite pipes. Also, the tensile test of the samples was done. The analytical expression solution has been accomplished to determine the strain, stress, for hoop and longitudinal direction. It is evident that the hoop stress and strain for woven roving carbon composite pipe was more than longitudinal stress and strain by almost (13%) and (18%) respectively. The maximum internal pressure in the case of internal pressure only was more than compared to the internal pressure with bending moment with almost (52%). The most critical region for stresses is found in the inner arc of the curved pipe (intrude) area while the least area for stresses was in the outer arc of the curved pipe (extrude) area.

Keywords: Composite curve Pipes, Internal pressure, Stresses.

1. Introduction

Curved pipes are very important and common components of piping systems that can be found almost in many applications, curved pipes are widely used in pipe systems, to change the direction of the pipeline, and to provide flexibility. Curved pipes are widely used in industry; in particular, applications include large-diameter in chemical complexes, desalination plants, and water supply and nuclear power stations [1]. Today, the modern use - composite materials in the oil industry becomes more and more apparent. This is due to benefit from them, and reduce the weight of construction up to 80% indeed, the use of piping systems for fluid transfer and pressure vessels, drill pipe, and tanks for storing liquids, platforms to protect against fire etc., fiber glass tubes usually for a period of 50 years while the metal tubes for a period of 10-15 years because of corrosion [2]. D. Camilleri, et. al. (2017) [3] Studied the ultimate failure load of a composite of filament –wound fiber – reinforced composite for pipe elbow subjected to combined load. Results showed that in the first case the elbow subjected to Internal pressure loading only will try to straighten due to the difference in surface area between the intrados and the extrados, the most dangerous area in which the stresses were concentrated in the intrude and in the area of the crown and the last region was in the extrude of the pipe bend or elbow . Cesar Guzman. (2011) [4] studied the stress analysis of Steel Elbow pipe in four pipes and compared them to the straight pipe. It is subjected to an internal pressure (12.5 MPa), the results showed that the location for critical stress was in the inside zone of the curve pipe and outside zone for small pipe and along the sides for larger pipes. The max. Stress in elbow pipe is more than in straight pipe with same material. Long Bin Tan, (2015). [5] studied the finite element (FE) models of buried Glass Reinforced Composite (GRE) pipes used in the transfer of fuel through a diameter of 400 mm, and consists of multiple components, such as a hole valve, (45 degree and 90 degrees) tube bends. In this paper, two cases are presented to study the buried pipe response, Models A (45degree bend) and B (90-degree bend) consist of 511242 and 584056 linear elements respectively in terms of the induced hoop stress and the resulting pipe displacement, after application of pipe pressure 1 MPa and geostatic loads. The hoop stress (97 MPa) and axial stress (59 MPa). For the pipeline, it is recommended from, literature that excessive should be avoided so as to prevent pipe wall buckling or wrinkling. The maximum hoop stresses are generally occurring at the connections and are within in intrude location and in the crown for axial stress. The deformation in hoop direction is more than in axial direction. The findings revealed that the effect of the internal pressure and the loads reduce pipe ovalization. But tend to increase axial stresses in the pipe bends. S. B. Kochekseraii, et.al.(2004) [6] Studied the behavior of a multi-mitred pipe bend (MMPB) glass-reinforced plastic (GRP) and polyester resin . After the process of wrapping the plastic pipe ((PVC) by (GRP), it is subjected to internal pressure, in plane bending, and combined in plane bending to internal pressure. When the curved pipe is subjected to internal pressure and bending forces separately, the results of finite element analysis with experimental data are approximate and a small displacement occurs, while for curved pipe subject to combined internal pressure with bending loads, large-displacement was noticed. It was found in this case the finite element analysis was in good agreement with experiments result. C. MIKI, et.al. (2000) [7] Studied the strain or deformation of elbow steel pipe bend subjected both closing mode and opening mode bending tests were completed and internal pressure. The steel pipe bends were highly deformed and wrinkled before the crack began, in the case of the bending closure mode. The aim of this research is study experimentally the behavior of curved composite pipe with different material under internal pressure.

2. Experimental work

2.1. The Material Properties

In present work the composite material content of Woven roving carbon (Mat) and epoxy resin as shown in figures (1,2). Table (1) shows the properties of epoxy resin and carbon fiber.

Figure 1. The carbon mat **Figure 2. The epoxy resin**

Table1. The Properties of Epoxy and carbon

Material	Young's modulus(E) (GPa)	Poisson Ratio ($\boldsymbol{\nu}$)
Carbon (Mat)	230	.33
Epoxy	3.8	.33

2.2. Preparation of Samples

The volume fraction of this work is 50%, the specimens are made from carbon fiber, using two thicknesses (4 mm) and (3 mm), as shown in table (2).

Table (2) Thickness and Number of Layers used in this work

Material	Thickness of layer(mm)	No. of Layer	Thickness(mm)
C.M.4	0.17	12	4
C.M.3	0.17	9	3

Where:

C.M.4 Carbon Mat at 4mm thickness

C.M.3 Carbon Mat at 3mm thickness

The specimen used with specific dimensions as shown in figure (3).

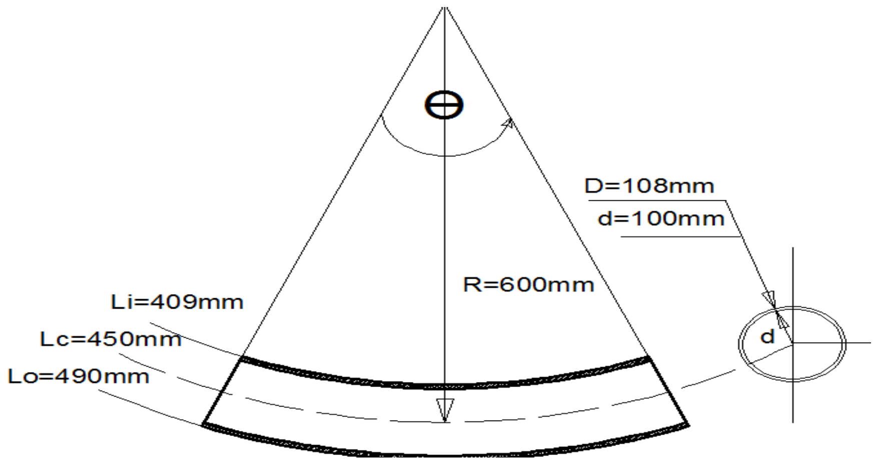


Figure 3. Dimension of specimen

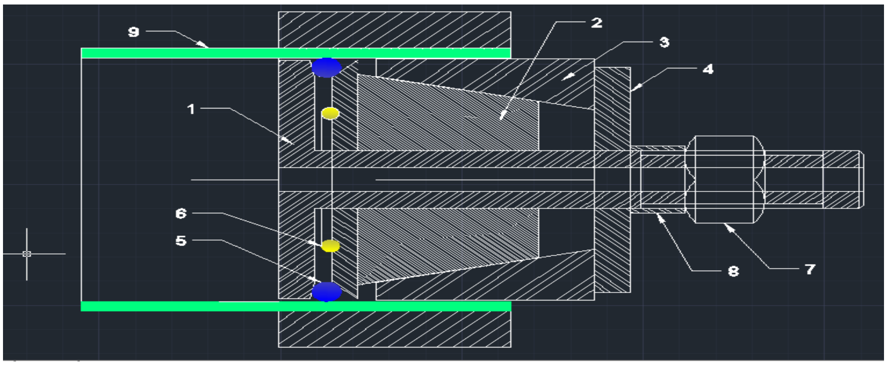
2.2.1. Molding and Cutting

A gypsum mold with same dimensions of specimen curve pipe was placed on iron pipe then grinding it by smooth sand paper saturated by water , after finishing this process taking the gypsum mold and fixed it on the specified place which was connected to the vacuum device ,preparing the PVA sack which was made from polyvinyl alcohol the process of interaction by saturated it from inside the gypsum mold with little of water and wiping it by type of powder from outside of the PVA sack to avoiding tear it during inserting the gypsum mold inside it, then the mold was inserted in a sack (bag) .This sack was closed tightly from top and bottom. Then, roving glass fiber on the PVA by layers around the mold and get the desired thickness, after that, placed another second PVA with the provisions of the closer from the top and bottom to avoid exit the epoxy resin. Opening vacuum device to avoid the presence of any bubbles inside the matrix and epoxy resin poured inside from top of PVC, then redistribute inside the PVA by hands, after finishing cast the specimen has been cut as it shown in fig (4) .

Figure 4. The Image of Specimens

2.2.2. End Fittings Design

For research tests, involving the pressure of the sample tubes, it was necessary to design an appropriate end-fitting for the task, thus, the presence of a strong joint between pipes ends and fittings is necessary, therefore, the two end fittings are designed to prepare the test as shown in figures (5).



1, 2, 3 = Compressing parts 5, 6 = Rubber seal, 4 = Flange, 7 = Nut,8 = bush,9 = Composite pipe

Figure (5). Design of Mechanical End Fitting

2.3. Pressure system

The system records the change in internal pressure with the change in length and time during the test. The compression system has been designed so that multiple loading conditions can be facilitated, while at the same time carrying internal pressure is lower than the yield point for each sample. Figure (6) illustrates the Specimens with manual oil compressor. The oil compressor can produce up to (300 bar).

Figure (6). The Image of manual oil compressor and specimens

2.3.1.1. Pressure Transducer

A pressure adapter is a sensitive device that continuously transmits the pressure inside cylinder, the controller uses this information to regulate pressure and avoid overpressure conditions. The compression adapter is connected to the digital universal data logger, data recorder from a signal converter from the pipe to data recorder program in the computer to display reading the pressure as shown in figure (7).

Figure (7) Pressure Transducer

2.3.1.2. Digital Universal Data Logger

This device transforms the change in resistance that occurs in the strain gage or pressure transducer to a value in mill amperes as an output value. Eliminates the use of Whitstone Bridge, this device has five ports shown in the figure (8), using one port for pressure transducer. It is also connected to the computer to display reading of pressure in each test.

Figure (8) a view of Universal Data Logger

2.3.2. Data acquisition system data

2.3.2.1. Strain Gage set –up

Strain gage is a device in which the electrical resistance varies proportionally with strain change, is the most common method of measuring strain due to traditional size and simple installation, strain gages properties (R=120Ω, GF =2.07 and grid length =(30*10mm) for recording the strain data, two strain gages are bonded on the surface in the middle of curved pipe (crown)at angle $\varphi=0^o$ and it placed in vertical and horizontal directions to read the hoop and longitudinal strain and bonding two strain gages in bottom or outer arc (extrude) at angle $\varphi=90^o$ and bonding two strain gages in the inner arc of the curved pipe (intrude) at angle $\varphi=-90^o$ and shown in figure (9) and show the six strain gages with angle

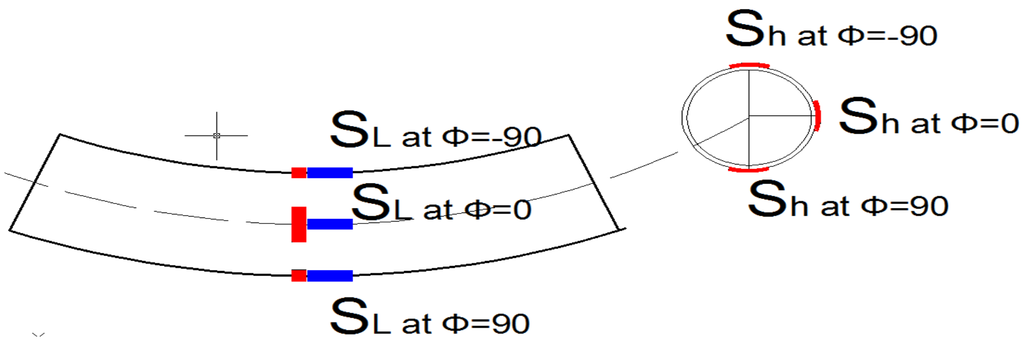


Figure (9) a view of Strain Gage on the Pipe with angle ∅

2.3.2.2. NI 9235

NI 9235 quarter-bridge strain gage modules with eight simultaneous channels per module [8] using six of them only, as shown in the figure (10). Where the NI 9235 was used to measure the strain of the strain gages, which converts data in volt with time.

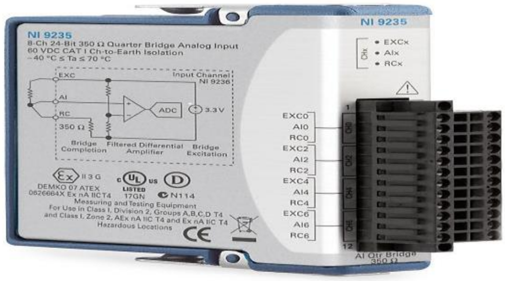


Figure (10) NI 9235 USB Data Acquisition Systems

2.4. Tensile tests

Mechanical properties of all samples were measured in accordance with ASTM D 638 [9]. There were three samples per specimen with (57mm) length and (13mm) width, a thickness is (3mm), and (4mm), Figure (11) shows the shape of tensile samples of carbon with thickness (4mm). Elastic modulus and poisson ratio used in the present study, which got it from experimental tensile test and used in stresses equation (1), (2), as listed in table (3).

C.M.4

Figure (11) Shape of Tensile Samples

Table (3) Experimental Tensile Test Values, Young Modules and Poisson ratio

Symbol material	E1 (GPa)	E2 (GPa)	ν_{12}	ν_{21}
C.M.4	91.64	91.64	0.36	0.36
C.M.3	92..31	92.31	0.349	0.349

2.5. Calculation of Longitudinal and Hoop Stresses of the Specimen

Stresses equation should be found in term of strain [10], because of the results are obtained from the experimental work. Where the stresses can be calculated according to the mechanical properties of each specimen material.

$$\sigma_L=\frac{E_2}{(1-\upsilon_{12}\upsilon_{21})}[\epsilon_H\upsilon_{12}+\epsilon_L] \qquad (1)$$

$$\sigma_H=\frac{E_1}{(1-\upsilon_{12}\upsilon_{21})}[\epsilon_H+\upsilon_{21}\epsilon_L] \qquad (2)$$

3. Results and Discussion

In this work, the pressure versus the stresses and strain behavior are presented for (2) specimens made from carbon fiber (C.M.). The variation of strain and stresses with the pressure increment are shown in figure (12) to (19). It can be seen that, the composite curved pipes which was woven roving(MAT) carbon fiber at thickness (4 and 3 mm) in hoop and longitudinal direction (C.M.4.H), (C.M.4.L) and (C.M.3.H), (C.M.3.L). Figure (12) shows the relationship between growing internal pressure reaching up to (22) MPa with hoop strain (ε_H) in three angles in outer arc (extrados position) of curved pipe ($\Phi=90^O$), in the middle (crown position) of curved pipe ($\Phi=0^O$), in the inner arc (intrude position) of the curved pipe ($\Phi= -90^O$) , It was the most dangerous region in angle ($\Phi= -90^O$) in the inner arc of curve pipe (intrude position) , because of the nature of the composite material were more flexible than the other angles which generate various deformation in the z-direction and appearing as a swelling in the middle of the curved pipe that makes it expand under the inner pressure and tries to change the tube from the bend pipe shape to the straight pipe ,when the elbow subjected to Internal pressure loading only will try to straighten due to the difference surface area between the intrados and the extrados, the most dangerous area in which the stresses were concentrated in the intrude and in the area of the crown and the least region was in the extrude of the pipe bend or elbow. Figure (13) longitudinal strain (ε_L) shows the relationship between growing in pressure reaching up to (22) MPa with longitudinal strain εL in three angles. It was the most dangerous region in the middle (crown position) of curved pipe ($\Phi=0^O$), because of the nature of the composite material. Also, it was concluded that the hoop strain ($\mathcal{E}_H$) more than of longitudinal strain ($\mathcal{E}_L$). For the same specimens (C.M.4.H), (C.M.4.L), figure (14) and figure (15) shows the influence of the pressure increment on the stresses [hoop stress (σ_H), longitudinal stress (σ_L)]. It is noted that all stresses increased with the growing in pressure. Also, note that the hoop stress (σ_H) was greater than longitudinal stress (σ_L) due to the variation in the hoop and longitudinal strain as it explained in figure (12) and figure (13). Figure (16), (17), (18) and (19) give the same relationship as figure (12), (13), (14) and (15) respectively, but now with thickness of (3mm) for woven roving carbon composite pipe (C.M.3). It can be seen from these figures, the following results: The pressure increment reaching up to (13.5) MPa for woven roving carbon composite pipe (C.M.3), wile for woven roving carbon composite pipe (C.M.4) the internal pressure was (22 MPa). Maximum results are given in Table (4)

Table (4) Results of the carbon fiber specimens under internal pressure only

type	$\Phi=90^o$				$\Phi=0^o$				$\Phi= -90^o$			
	σ_L	σ_H	ε_L	ε_H	σ_L	σ_H	ε_L	ε_H	σ_L	σ_H	ε_L	ε_H
C.M.4	107	132	.0006	.001	265	225	.002	.0014	223	298	.0013	.0023
C.M.3	92	118	.0005	.0009	229	193	.0017	.0012	195	257	.0011	0.002

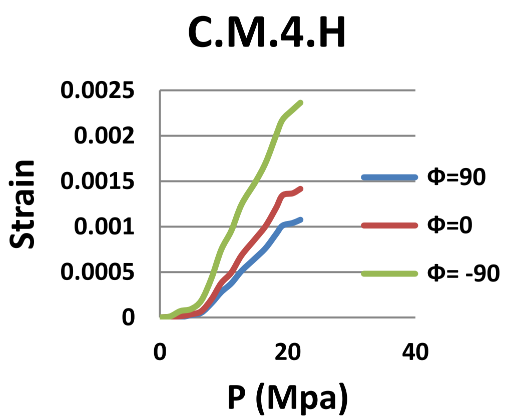


Figure (12) Hoop strain (ε_H), for carbon roving, t=4mm, with angle Φ=90, Φ=0, Φ= -90

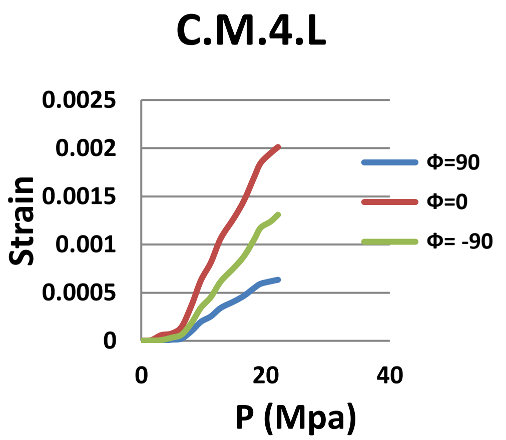


Figure (13) longitudinal strain (ε_L), for carbon Roving, t=4mm, with angle Φ=90, Φ=0, Φ= -90

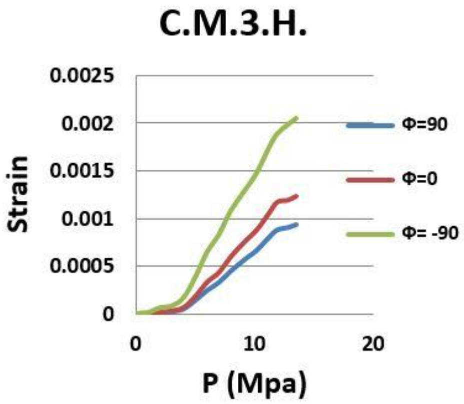


Figure (16) Hoop strain (ε_H), for carbon Roving, t=3mm, angle Φ=90,Φ=0, Φ= -90

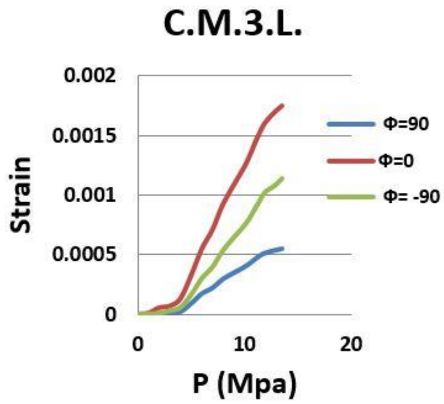


Figure (17) longitudinal strain (ε_L), for carbon roving , t=3mm, angle Φ=90,Φ=0, Φ= -90

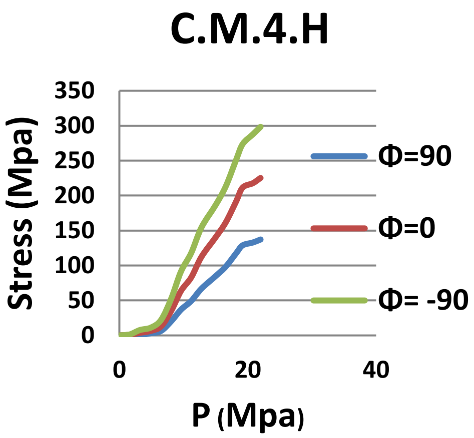


Figure (14) hoop Stress (σH), for carbon roving, t=4mm, with Φ=90, Φ=0, Φ= -90

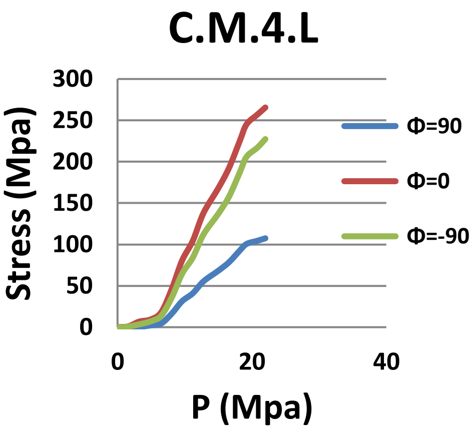


Figure (15) longitudinal stress (σL), for carbon Roving, t=4mm, with angle Φ=90, Φ=0, Φ= -90

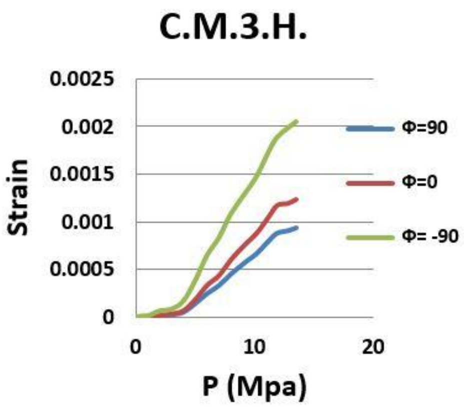


Figure (16) Hoop strain (ε_H), for carbon Roving, t=3mm, angle Φ=90,Φ=0, Φ= -90

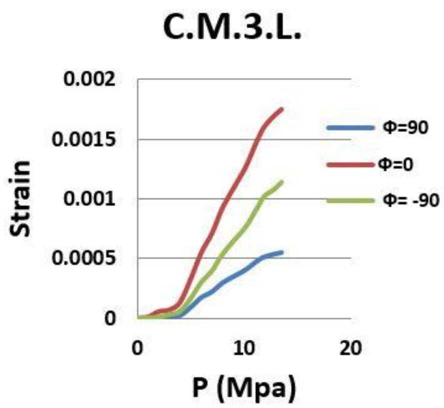


Figure (17) longitudinal strain (ε_L), for carbon roving , t=3mm, angle Φ=90,Φ=0, Φ= -90

Figures (20), (21) and (22) shows the effects of combined internal pressure reaching up to (14.5) MPa and bending load up to (1650N) on the stresses [hoop stress (σ_H), longitudinal stress (σ_L) and von mises stress (σ_{Von})] for (C.M.4), at three angles [Φ= 90^O , Φ= -90^O , Φ= 0]. It is noted that all stresses increased with the growing in pressure. As well as the hoop stress (σ_H) in angle (Φ= -90^O) in figure (20) is more than the (σ_H) in the crown position by (39%) while the (σ_H) in angle (Φ=0^O) is more than (σ_H) in the extrados position by (59%). Also, note that the longitudinal stress (σ_L) in angle (Φ=0^O) in figure (21) is more than the (σ_L) in the intrude position by (60%). Also, it can be seen that the (σ_L) in (Φ= -90^O) is more than the (σ_L) in extrados position by (45%), the von mises stress (σ_{Von}) in angle (Φ= -90^O) in figure (23) is little more than the (σ_{Von}) in the crown position by (0.153%) while (σ_{Von}) in angle Φ=0^O (crown position) is more than (σ_{Von}) in the extrados position by (100%), as listed in table (5)

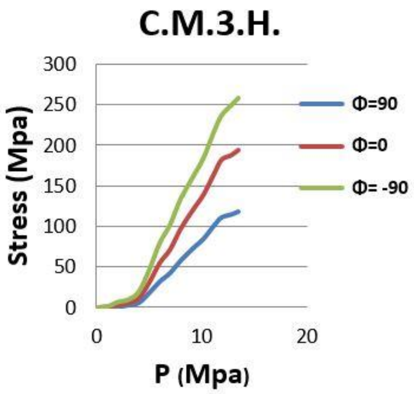


Figure (18) hoop stress (σH), for carbon Roving, t=3mm, angle Φ=90,Φ=0, Φ= -90

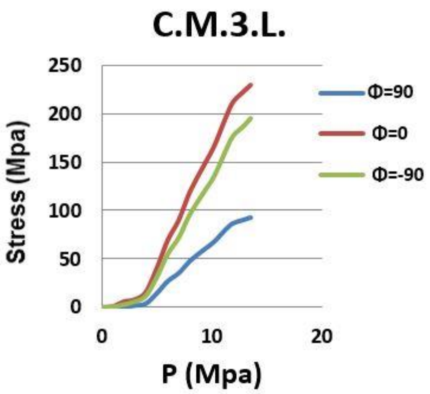


Figure (19) longitudinal stress (σL), for carbon roving, t=3mm, angle Φ=90,Φ=0, Φ= -90

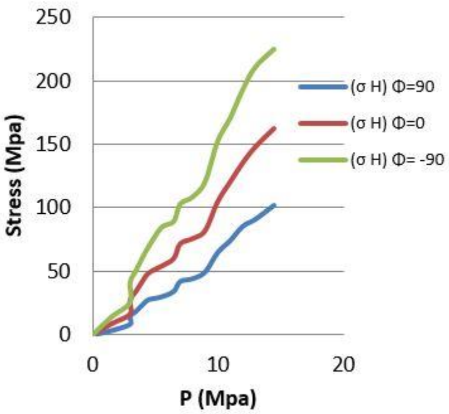


Figure (20) hoop stress (σH), for carbon Roving, with angle Φ=90, Φ=0, Φ= -90 And internal pressure with (1650N) load

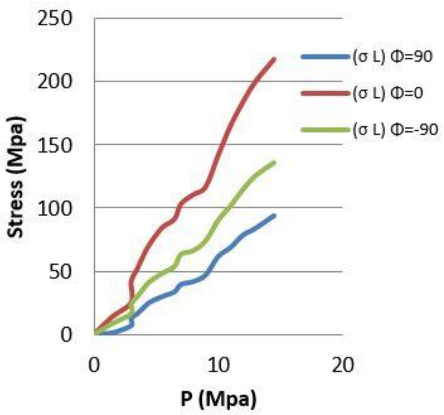


Figure (21) longitudinal stress (σL), for carbon roving, with angle Φ=90, Φ=0, Φ= -90 and internal pressure with (1650N) load

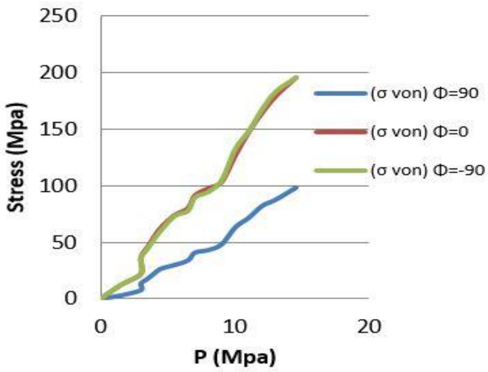


Figure (22) von Mises Stress for carbon roving, with angle Φ=0, Φ= -90^{o} , Φ=90^{o} and internal pressure with (1650N) load

Table (5) Results of the carbon fiber curved pipe under combined internal pressure and bending load

MAT.	F N	P Map	Φ= -90^{o}			Φ=0^{o}			Φ=90^{o}		
			σ H Mpa	σ L Mpa	σvon Mpa	σ H Mpa	σ L Mpa	σvon Mpa	σ H Mpa	σ L Mpa	σvon Mpa
C.M.4	1650	14.5	224.5	135.5	195.8	161.9	217.3	195.5	101.7	93.5	97.8

4. Conclusions

In this work, the main conclusions are:

1. The specimens of the woven roving (MAT) carbon fiber at a thickness (4 mm) in hoop direction at inner arc (intrude) of the curved pipe and woven roving (MAT) carbon fiber at thickness (4 mm) in longitudinal direction at in the middle (crown) of curved pipe at 4mm thickness respectively were more tolerant to stresses, and strain than their counterparts at (3mm) thickness.
2. The most dangerous region at inner arc of the curved pipe, which represents the area of (intrude) in the bend tube. The region in outer arc (extrados) of curved pipe is lower in all cases during the sample test under internal pressure.
3. The hoop stresses and strain are more than longitudinal stresses and strain at inner arc. Longitudinal stresses and strain more than hoop stresses and strain in the middle (crown) of curved pipe.
4. Conclude that the weakest or critical area in the curved pipe is located at the inner arc or intrude area and in the lateral area in the middle (crown) of curved pipe. The least concentrated area of stress and strain in the in outer arc (extrados) of curved pipe. Therefore, these dangerous areas should be strengthened by increasing the thickness of the woven roving (Mat) carbon composite by increasing number of layer and reduce the number of layer in non-critical areas by making the curve tube non-homogenous. Where this process can be done using Vacuum Bag technique.
5. The maximum stresses for curved composite pipe with in-plane bending and internal pressure were less than maximum stresses for curved composite pipe subjected to internal pressure only

Abbreviations

D, d	Out and Inner diameter	mm
E	Modulus of elasticity	GPa
E1	modulus of elasticity in 1 direction	GPa
E2	modulus of elasticity in 2 direction	GPa
Li,Lc,Lo	Length of inner ,center and outer arc	mm

P	Internal pressure	MPa
R	Mean radius of curve pipe	mm
θ	Angle of curve pipe	degree
Φ	Location of strain gauge around circumference of a pipe	degree
σ_H, σ_L,	Hoop and Longitudinal stress	MPa
$\varepsilon_H, \varepsilon_L$	Hoop and Longitudinal strain	
(ν)	Poisson ratio	

Xyy4dd

References

[1] Wood". A review of Literature for the Structural Assessment of Mitred bends ".International Journal of Pressure Vessels and Piping vol. 85, pp. 275–294, 2008.

[2] Long B.T" .Experimental Characterization of GRE Composite for Failure Envelope Validation . 10th International Conference on Composite Science and Technology ICCST/10, 2015.

[3] Duncan C. "Composite Fiber Reinforced Pipe Elbow Subject to Combined Loading". Proceedings of the ASME 2017 Journal of Pressure Vessels and Piping Conference PVP 2017, July 16-20, 2017.

[4] Cesar G. "Stress Intensification Factors at Pipe Elbows". Journal of ME 404, 2013.

[5] Long B.T. "Finite Element Modeling of Buride Glass- Reinforced Composite "10th International Conference on Composite Science and Technology ICCST/10, 2015.

[6] S. B. Kochekseraii, M. Robinson "Flexural Behavior of a Polyvinyl Chloride-lined Glass-Reinforced Plastic Composite Multi-Mitred Pipe Bend Subjected to Combined Loads: a Comparative Finite Element Analysis and Experimental Case Study" The Journal of Strain Analysis for Engineering Design, 2004.

[7] Chitoshi M. "Deformation and Fracture Properties OF Steel Pipe Bend with Internal Pressure Subject to In- Plane Bending", Tokyo Japan, Journal of 12WCEE, 1814, 2000.

[8] DATASHEET NI 9235" Operating Instruction and Specification NI 9235/9236 Channel, 24-Bit Quarter-Bridge Analog Input Module", 2015.

[9] American Society for Testing and Materials International, "Standard Test Method for Tensile Properties of Plastics", 2000.

[10] S.Y.Chen, J. Chen, C.D.Liu "Stress Analysis Engineering Design of Reducer Bend under Internal Pressure"14th International Conference of Pressure Vessels Technology, pp. 57-66, 2015.

تأثير الاجهادات المركبة على كاربون ايبوكسي مركب انبوب منحني

فاضل عباس عبد الله **عمر عماد شكري**

قسم هندسة الميكانيكية، جامعة المستنصرية، بغداد، العراق

fadhel975@yahoo.com

الخلاصة

الهدف من هذا البحث هو دراسة سلوك أنبوب منحنى من الألياف الكربون المركبة من الإيبوكسي تحت الضغط الداخلي وعزم انحناء. يتم استخدام العينات المصنوعة من الألياف الكربون المحاكة مع الايبوكسي وبنسبه حجميه مقدارها 50 % لتصنيع الأنابيب المنحنية. يتضمن الجانب العملي تصنيع عينات الانابيب بتقنية سحب الهواء. تم تصنيع العينات بقطر داخلي (100ملم)، (490 ملم) طول القوس الخارجي و (409 ملم) طول القوس الداخلي للأنبوب المنحني وزاويه التقوس للأنبوب مقدارها (43 درجه) وسمك (4 و3 ملم). تم ايضا تصميم جهاز اختبار لدراسة تأثير الضغط الداخلي وعزم انحناء على الأنابيب المركبة. كذلك تم إجراء اختبار الشد لجميع العينات. في الجانب النظري تم ايجاد صيغه رياضيه وحساب الاجهاد والانفعال الطولي والمحيطي. من الواضح أن الاجهاد والانفعال المحيطي للأنابيب المنحنية المركبة من الألياف الكربون المنسوجة كان أكثر من الإجهاد والانفعال الطولي بنسبة تقرب من (13٪) و (18%) على التوالي. كان الضغط الداخلي الأقصى في حالة الضغط الداخلي فقط أكثر بالمقارنة مع الضغط الداخلي جنبا إلى جنب مع عزم الانحناء بنسبه (52%).تم العثور على أخطر منطقة للاجهادات في القوس الداخلي (التقعر) بينما المنطقة الاقل للإجهادات كانت في منطقة القوس الخارجي (التحدب) للأنبوب المنحني.

الكلمات الداله: الانابيب المنحنية المركبة، ضغط داخلي، إجهادات.