Warith Scientific Journal of Engineering and Technology, vol. 1 (2025)

Warith Scientific Journal of Engineering and Technology

Journal homepage: wsjet.uowa.edu.iq

Stress- Strain Performance of Composite Tubes Subjected to Internal Pressure

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ARTICLEINFO

Keywords:
Stress
Strain
Composite
Internal Pressure
Piping System

ABSTRACT

Fiber reinforced plastic (FRP) piping system has been successfully used for over fifty years in applications requiring the corrosion resistance of plastic and the strength of metallic systems. FPR piping is readily available in a wide range of types, sizes, and wall thickness to meet numerous design requirements. The knowledgeable piping designer can design a successful project by using established standards and criteria. All the tests have been done using the "hydraulic testing machine" the results have been obtained from the meter which is connected to the machine, along with the use of internal pressure load to test and observe the behaviors of the fabricated tubes, having in mind that all the tests have been done under the room temperature.

1 Introduction

This Pipelines have been in use for centuries. For example, the Romans employed lead piping in their aqueducts over a millennium ago to deliver water to Rome. In China, as early as 400 B.C., bamboo pipes coated with waxed fabric were used to carry natural gas to Beijing for illumination purposes [1–5]. Additionally, clay piping systems were utilized around 4000 B.C. in Egypt and other regions for drainage. A major advancement in pipeline engineering emerged during the 18th century with the production of cast-iron pipes, which became widely used for water supply, sewage systems, and gas distribution [6-7]. Composite materials one from the important modern materials that use in a lot of applications such as pipes or bottles capable and fuel tank and fuel containers of holding internal pressure, one of this application the topic of this research in the pipes, in this study, the composite materials used to fabricate the pipes, so this chapter will going to introduce the composite materials and the types and the classification of it and also the significant of composite materials to make the pipes line that will be more safety and more light than before in order to reduce the fuel consumption by reducing the weight if the pipes use as an equipment in transportation sector [8-10].

One of the key benefits of composite materials is that, when properly engineered, they tend to demonstrate the most desirable traits of their individual components—and sometimes even exhibit new characteristics not found in either material alone. The formation of a composite can enhance a wide range of properties, such as strength, rigidity, resistance to corrosion and wear, visual appeal, weight efficiency, fatigue durability, behavior under varying temperatures, as well as thermal and acoustic insulation or conductivity [11].

In fiber-reinforced composites, the primary elements are the fibers themselves and the surrounding matrix, which serves to bind the fibers together. Additional components may include surface treatments like coupling agents and coatings, as well as fillers. Coupling agents and coatings are typically applied to fiber surfaces to improve compatibility and adhesion with the matrix, which leads to more effective stress transfer at the fiber–matrix boundary.

https://doi.org/10.57026/wsjet.v1i1.4
Received 5 September 2024; Received in revised form 30 October 2024; Accepted 16 November 2025; Available online 3 January 2025

Fillers, particularly in polymer-based matrices, are commonly added to reduce material costs and enhance dimensional stability [12–14]. The thickness required to support a given load or to maintain a given deflection in a fiber reinforced composite structure is obtained by stacking several laminas in a specified sequence and then consolidating them to form a laminate. Various laminas in a laminate may contain fibers either all in one [15].

2 Material and Methodology

The Importance of the bursting pressure test for the different type of composite tubes specimens in different layers is to study the performance of composite materials under internal pressure loading and for investigation effect of fibers types on stress and strain. Woven roving glass fiber/epoxy, carbon fiber/epoxy and kevlar fiber/epoxy had done to find which one from these composites is suitable to design and fabricate the tubes. The method generates stresses in the material, primarily in the hoop direction, and provides important information on the mechanical properties of the tubes that are subjected internal pressure First, confirm that you have the correct template for your paper size. This template has been tailored for output on the custom paper size (21 cm * 28.5 cm).

2.1 Specimen Design

The specimens used for testing are cylindrical tubes that are hollow and open at both ends. Each tube measures 320 mm in total length and has an internal diameter of 45 mm—matching the outer diameter of the mandrel used during the filament winding process. The gauge length, defined as the span between the reinforcement areas, is 100 mm. The thickness of the tube walls varies depending on several process parameters, including the tension applied during winding, the winding angle, and the type of reinforcement material used (see Figure 1).

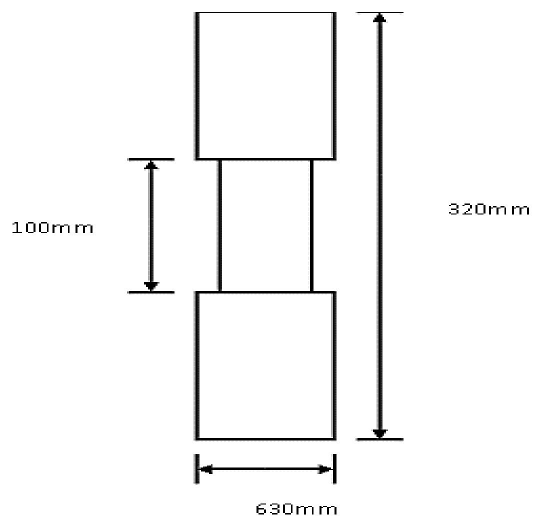

Figure 1. Schematic of the Testing Pipes Size and Design

Each of three materials mentioned above (Glass fiber, Kevlar fiber and Carbone fiber) were used in this study. Pipes (UPVC Pipe, BS 3506, 40 mm, Class 0) as shown in Figure 2 were prepared, cut to multiple 320 mm length pieces, each fiber material were used to rolling nine pipe pieces, each pipe were rap with Epoxy material using a fine brush. Fiber rolling was done slowly, uniformly and carefully to prevent any deterioration throughout the composite pipe. The rolling procedure was done with 0-90 degree for each specimen. The handle fabrication of the Specimen shown in Figure 3.

2.2 Test Set Up

The initial design utilized a fixed-end gripping mechanism, which secured the test specimen at both ends, thereby preventing any longitudinal movement. This setup was achieved by connecting the two end units using metal rods. After preparation of the specimens, both ended of the specimens were closed with a metal lock, one of the metal locks consists of a valve to permit the flow of the oil inside the specimen. In addition, air valve was made in the specimens ending part, this valve permits the exclude of the air out of the specimen in one direction; the air was not allowed to pass through the valve inside the specimen. The metal lock was fixed by embedded it in the silicon material and by using rubber bands to prevent the leakage of the fluid throughout the ends and to control the internal pressure inside the specimens. The setting time for the silicon material was around 20 minutes. (Figure 4 shows a specimen burst).

Figure 2. Pipes Cutting and Optimal Pipes for Specimens Fabrication

Figure 3. Handle Fabrication of the Specimen (Kevlar Fiber)

Figure 4. Typical Photograph of Specimen Burst

3 Experimental Work

3.1 Stress -Strain Curve

The burst test was carried out for all specimens (Figure 5) showing the significant values in Table 1. The hydraulic pump and all testing Equipment were shown in Figures 5 and 6, then connected to the specimens ending with the valve by using rubber joint; the pump was filled with normal oil. The pump was involved of pressure gauge with 700 bar as a maximum pressure

The stress is represented by the applied hoop stress (σH) and this is plotted against the measured strain in the hoop direction. The sequence of events during pressurizing can be summarize in the following way:

- As the pressure increases, the first sign of damage is detecting when the manual pumping more is resisting gradually at a hoop stress of approximately.
- Creaking sound occurs, which gets higher when the pressure increases.
- The maximum hoop stress/strain value shown in Figures 7, 8 and 9 represents the hoop bursting stress/strain.

Figure 5: Metal Plug and it is Modification for Testing Procedure (Glass Fiber)

Figure 6. Typical Photographs of the Testing Equipment

4 Results and Discussion

4.1 Stress -Strain Curve for All Specimens with Two Layers

Figure 7 shows the stress- hoop strain relevance for the glass fiber, carbon fiber and Kevlar fiber, each with two layers. It clearly shows the linear curves between stress and strain, it represented the linear elastic properties. The Kevlar fiber with 2 layers' product a highest stress more than carbon fiber and glass fiber. The minimum value of stress is recorded to the class fiber with two layers. The carbon fiber with two layers bears a hoop strain less than other two types of fiber. Table 1 shows all of significant values.

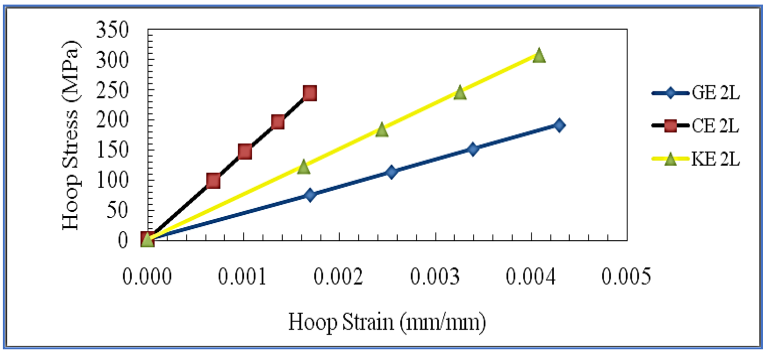

Figure 7. Hoop Strain- Stress Curve for All Specimens with Two Layers

Table 1: The significant values of the stress- strain curve

Specimen name	Hoop burst	
	Hoop stress (MPa)	*Hoop strain (mm/mm)*
GE 2L	192	0.00429
GE 4L	233	0.00520
GE 6L	220	0.00492
CE 2L	245	0.00170
CE 4L	286	0.00198
CE 6L	268	0.00186
KE 2L	309	0.00408
KE 4L	347	0.00458
KE 6L	329	0.00434

4.2 Stress- Strain Curve with Four Layers

Figure 8 shows the hoop strain- hoop stress relevance for the glass fiber, carbon fiber and kevlar fiber, each with four layers. It clearly shows the linear curves between stress and strain, it represented the linear elastic properties. The highest stress is recorded to the kevlar fiber. Carbon fiber followed the kevlar fiber and recorded hoop stress more than glass fiber. The minimum value of hoop strain recorded to the carbon fiber, the glass fiber product a maximum value of strain.

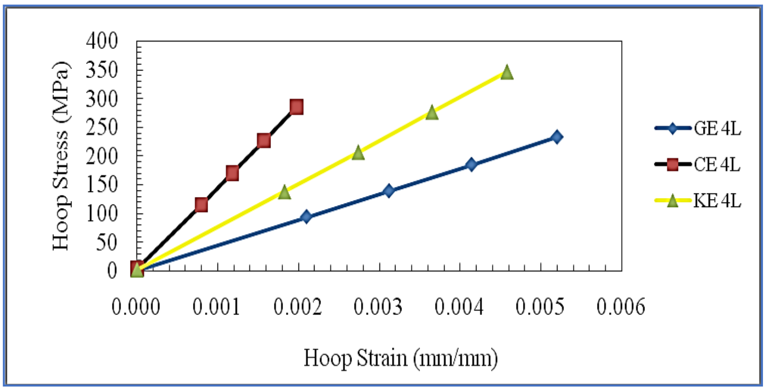

Figure 8. Hoop Strain-Stress Curve for All Specimens with Four Layers

4.3 Stress- Strain Curve All Specimens with Six Layers

Figure 9 shows the hoop stress-strain relevance for the glass fiber, carbon fiber and Kevlar fiber, each with six layers. The stress strain curves show the linear elastic properties. The glass fiber products the highest strain more than Kevlar fiber and carbon fiber respectively. The highest value of stress recorded to the Kevlar fiber. The glass fiber products stress less than the other two types Kevlar fiber and carbon fiber.

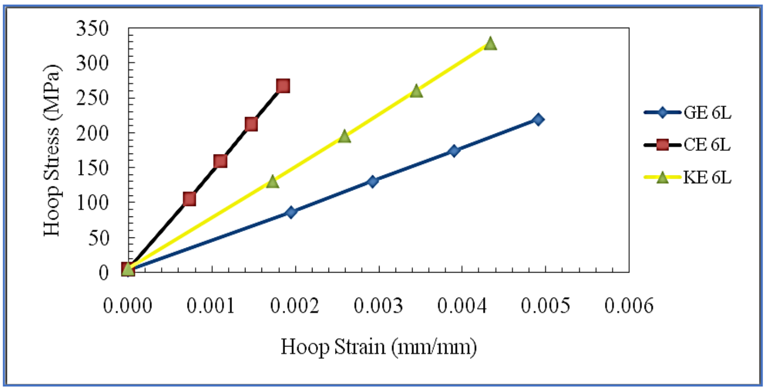

Figure 9. Hoop Strain- Stress Curve for All Specimens with Six Layers

5 Conclusion

The stress-strain curves influence directly with the number of layers, the hoop stress-strain curves maximum values increase according to number of layers increasing and both of them linearly increasing that mean the GE, CE and KE composites behave as brittle materials in hoop stress-strain curves because it does not show any plastic deformation but fail while the deformation is in elastic zone and also it does not have any yield point, and do not have strain-harden which means that the ultimate strength and breaking strength are the same then the curve dropped dramatically when the fail is done. To investigate the specific, behave of composite material, different types of specimens has been made to optimize the design; woven roving carbon fiber, woven roving glass fiber and woven roving Kevlar fiber were fabricated to make a comparison between them results. The results were varying from parameter to another, in burst pressure test the KE specimen's results was best than each of GE and CE. KE specimens can carry the highest pressure between them, CE specimens came after KE specimens in internal pressure load carrying then the GE was the lowest one

6 References

[1] Daniel Gay, Suong V. Hoa and Stephen W. Tsai, (2003). *Composite Materials Design and Application*, 1st edn. London: CRC Press LLC.

[2] Henry Liu (2003). *Pipeline Engineering* 1st edn. United State of America, Taylor.

[3] Jerry Alan Peck, (2007). UV-cured FRP joint thickness effect on coupled composite pipes. *Composites*: Part A. Vol. 37. 413–422.

[4] John Case, Lord Chilver and Carl T.F. Ross (1999). Strength of Materials and Structures, 4th edn. New York: John Wiley & Sons Inc.

[5] Ken Newman. (2002). Tubing Limits for Burst and Collapse. *Thin-Walled Structures.*Vol. 46. 320-332.

[6] Mallick, P.K. (1997). *Composite Engineering handbook*, 1st edn. New York: Marcel Dekker, Ing.

[7] Mallick, P. K. (2007). *Fiber-Reinforcement Composites.* 3rd edn. United State of America: Taylor and Francis Group, LLC.

[8] Shuichi Wakayama a, Satoshi Kobayashi a, Takayuki Imai a, Takayuki Matsumoto. (2006). Evaluation of Burst Strength of FW-FRP Composite Pipes after Impact Using Pitch-Based Low-Modulus Carbon Fiber. *Composites: Part A Applied Science and Manufacturing.*Vol. 37. 2002–2010

[9] Paulo Davima, Pedro Reis and Conceição António, (2004). Drilling Fiber Reinforced Plastics (FRPS) Manufactured by Hand Lay-Up: Influence of Matrix (Viapal VUP 9731 and ATLAC 382-05). *Journal of Materials Processing Technology.* Vol. 155-156. 1828-1833

[10] Vinson, Jack R. and Sierakowski, Robert R. (2004). *The Behavior of Structures Composed of Composite Materials*, 2nd edn. New York: Kluwer Academic Publishers Dordrecht.

[11] Garret Meijer, Fernand Ellyin. (2002). A Failure Envelope for ±60_ Filament Wound Glass Fibre Reinforced Epoxy Tubular. *Composites: Part A Applied Science and Manufacturing.*Vol. 39. 555–564

[12] Aziz Onder a, Onur Sayman a, Tolga Dogan , Necmettin Tarakcioglu.(2008). Burst failure load of composite pressure vessels. *Composite Structures.* VOL 89. 159–166

[13] Daniel Gay, Suong V. Hoa and Stephen W. Tsai, (2003). *Composite Materials Design and Application*, 1st edn. London: CRC Press LLC.

[14] Campbell, F. C. (2004). *Manufacturing Processes for Advanced Composites,* 1st edn. United Kingdom: Elsevier Ltd.

[15] G.P. Zou, N. Cheraghi, F. Taheri. (2005). Fluid-induced vibration of composite natural gas Pipelines. *International Journal of Solids and Structures.* VOL. 42. 1253–1268.