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Behavioural Analysis of a Thin-Walled Carbon Fibre Reinforced Composite Pipe Subjected to Bending Test

***Elijah, P.T. and Obaseki, M.**

Applied Mechanics and Design/Production Research Group, Department of Mechanical Engineering, Maritime University, Okerenkoko, Delta State, Nigeria.
*paul.elijah@nmu.edu.ng; martins.obaseki@nmu.edu.ng

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ABSTRACT

The behavioural analysis of a thin-walled carbon fibre reinforced composite pipe subjected to bending test using Instron machine is presented in this paper. A three-point bending test was performed on a thin-walled 230 mm length carbon fibre-reinforced composite pipe with an external diameter of 10 ± 0.01 mm and wall thickness of 1 ± 0.05 mm in the laboratory using the Instron 4483 machine based on the ASTM D790 standard to measure the modulus and flexural strength. Bending tests results showed a fracture load point of 0.2336 kN, maximum displacement at break point at 3.6 mm, maximum strain of 0.015 mm/mm, and a maximum bending stress of 0.94 kN/mm. Overall, the composites exhibited anisotropic characteristics under tension unlike monolithic materials. It was observed that when subjected to bending stresses, the composites did not undergo plastic deformation. Initial fracture continuously propagated across the fibres until it reached complete fracture. Further findings showed that the composites did not experience complete failure unlike steel pipes. This means that composites do not lose their form or shape until fracture.

1. INTRODUCTION

Continuous research and innovation in the last few decades have given rise to improved applications of composites - even in our everyday lives. As early as the 20th century, modern composites were used. In the 1930’s, an example of such modern composites, developed by reinforcing resins using glass fibres, were used in building boats (Kaw, 2005). Another application of these composites, commonly known as glass fibres is in the construction of aircrafts. The last 100 years in particular has seen an upsurge in the research, development, and increased use of composites (Kaw, 2005).

Applications of composites can be seen ranging from large complex structures such as airplanes, buildings, automotive, to small household appliances. Pipes are very important structures used especially in the transport of fluids. According to Obaseki and Elijah (2020), they are used very often in the oil and gas industry, pipes are considered the major component and are used in the transport of oil-gas-solid particle to various locations. Composite pipes are increasingly finding their applications in the oil and gas industry, replacing conventional steel pipes. Filament wound pipes of glass fibre reinforced plastics are the most commonly used pipes today and an understanding of the design and modeling of such composite pipes becomes increasing necessary.

Fibre glass composites pipes have been used in the petroleum industry for transportation of natural gas for a long time. However, they have not been used in high volume high-pressure natural gas transmission applications in any significant way (Etcheverry and Barbosa, 2012). There are a number of different resins and fibre reinforcement materials used in composite pipes manufactured today. However, fibre glass is the most prevalent reinforcement material used in over 90% of all resin/filament wound composites manufactured today (Beckwith, 1998; Laney, 2002; Bakaiyan *et al.,* 2009; Akinyele *et al.,* 2020).

There are two types of composite pipes majorly used in the oil and gas industry. These are either reinforced thermoplastic pipes (RTP) or flexible pipes. RTP's are usually employed both onshore and offshore because they can be easily reeled for installation and storage. Flexible pipes on the other hand are used majorly in offshore applications in deep water. Composite pipes compared to steel pipes are flexible and can be supplied in spools (Bai and Bai, 2014).

Composite pipes are increasingly used both onshore and offshore in the oil and gas industry due to a broad spectrum of characteristics. Primary applications of composite pipes can be found in risers, subsea injection lines, drill pipes and coiled tubing, pipe systems for fluid transport, and wellbore completions (Williams and Sas-Jaworsky, 2000; Trifunovic, 2011). Riser pipes are typically large and heavy, and significantly increase the weight of the processing platform especially in deep water locations. Composite riser pipes are better used in these situations because of their better strength to mass ratio (Lou and Lundberg, 1997; Trifunovic, 2011).

Composites have undergone continuous research and development in order to understand several ways in their design and deployment. This can also be seen in the oil and gas industry (Williams and Sas-Jaworsky, 2000; Wessel, 2004; Mahieux, 2005). As exploration for oil delves into deeper waters and harsher environments, the use of steel becomes increasingly expensive, difficult to maintain and performs poorer under these conditions. It is then no surprise that composites are increasingly being used in the oil and gas industry. According to Marsh (2000), the oil and gas industry accounts for approximately 17% of composite thermoset pipe usage by industry in the world today (Trifunovic 2011). Composites are used in secondary applications such as floor grates, footpaths of platforms, staircase railings and fire protection structures. This is because of their high corrosion resistance, light weight and higher degree of safety (Elijah and Etebu, 2019). Composite pipes offer good cost savings compared to steel pipes because of their overall better characteristics such as light weight, higher strengths and excellent resistance to corrosion (Obaseki *et al*., 2017; Obaseki and Elijah, 2020; Obaseki *et al.,* 2020). Presently, filament wound fibre glass reinforced epoxy matrix pipes are the most commonly used pipes in the oil and gas industry (Botros *et al*., 1997; Lou and Lundberg, 1997; Bai and Bai, 2004).

Regardless of the advances in composite pipe usage, there are a couple of limitations involved. These range from design, production and a lack of enough test data (Etcheverry and Barbos, 2012; Khalifa *et al.,* 2012). Different methods in strengthening the mechanical properties of high-performance composite materials have been employed so as to replace conventional steel pipes in usage today. Glass fibres have proven to be structurally dependable and have a balance between costs and performance and are increasingly employed in the oil and gas industry (Etcheverry and Barbosa, 2012). However, the industry has a lack of knowledge on composites behaviour under different temperatures, types of loading and influence of the chemicals on their mechanical properties (Frost and Cervenka, 1994; Herakovich, 1998; Xia *et al.,* 2001; Laney, 2002).

Thus, this paper conducted mechanical (bending) testing of composite pipes from a thin-walled carbon fibre reinforced plastic pipe using Instron machine to analyze the behaviour of a composite pipe.

2. MATERIALS AND METHODS

2.1. Materials

Instron 4483 machine from a mechanical workshop in Port Harcourt, Rivers State of southern Nigeria was used. Composite pipe from a thin-walled carbon fibre reinforced plastic pipe was obtained from GAP international limited, Warri, Delta State, Nigeria.

2.2. Methods

To conduct the test, the Instron 4483 machine was used as load was applied on the composite pipe. The aim of this test was to measure the modulus and flexural strength of a unidirectional composite pipe. The test was carried out on a thin-walled carbon fibre- reinforced composite pipe with an external diameter of 10 ± 0.01 mm and wall thickness of 1 ± 0.05 mm while the length of the pipe was 230±0.01 mm mainly due to a lack of material. The pipe was obtained from GAP international limited, Warri, Delta State, Nigeria. The justification for the selection of the composite pipe used for the test is due to a number of advantages it offered which are: better performance in terms of impact tolerance, delamination resistance and mechanical properties (hardness and ring tensile). The composite pipe used is relatively light-weight, non-corrosive and exhibit improved strength, stiffness, or toughness, or dimensional stability as a result of the embedding particles or fibers in a matrix or binding phase. Another reason is that it is inexpensive and readily available (because it is easily constructed and can be tailored to satisfy performance requirements). A 3-point bending test method was carried out with the machine based on the ASTM D790 standard (Campbell, 2010). This was carried out by placing the pipe specimen between two forming rollers (or specimen stops) while applying load at a constant rate from the upper roller assembly at the halfway point of the specimen. The Instron machine can be operated manually and automatically while taking its reading using a load cell mechanism of 150 kN. For this experiment, the cross-head speed used was 1 mm/min and result plots were done at 2 pts/s. The test was conducted in a laboratory at a temperature of 21 ^{o}C.

To carry out the test, a number of procedures were adhered to in ensuring the integrity of the results. This is shown below:

1. Visual inspection of the pipe to ensure no damage has been done to it prior to testing was done and the Instron machine was cleaned.
2. The specimen was prepared by cutting it into 230 mm using an electric saw.
3. Diameter and thickness measurements of the pipe were carried out using vernier calipers.
4. The lower roller assembly and the 3-point upper roller assembly were mounted on the machine.
5. Flexural test method was selected on the machine while dimensions and measurement parameters of test specimen were equally inputted.
6. The specimen was placed between the two forming rollers.
7. The top assembly was manually lowered till it touched the face of the pipe without any load.
8. Loading parameter was reset to zero loads on the machine.
9. Protective glass shield was placed and goggles were worn.

10. Bending test was commenced.

Test results were computed by the machine during the test period. After the test was completed, results were saved and extracted while the machine was safely turned off.

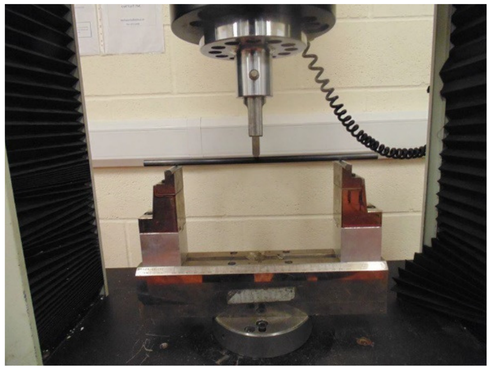

Plate 1: Three-point flexural tests showing the composite pipe placed between the end rollers just before the commencement of the bending test

3. RESULTS AND DISCUSSION

3.1. Bending Test Result

The composite pipe was subjected to increasing loading and began to deflect. The speed of the crosshead was at 1 mm/min. The pipe was subjected to compressive force at the top and tensile force at the bottom. It was noticed that as the load increased, the deflection of the pipe increased. The maximum deflection of the pipe was 3.36 mm experienced at the midpoint of the pipe.

Table 1: Bending test results

Description	Value
Machine used	Instron
Pipe material used	Carbon fibre
Temperature	21 ^{o}C
Number of specimens	1
Data rate	2.0 pts/sec
Crosshead speed	1 mm/min
Outer diameter	9.93 mm
Thickness	0.001 m
Length	0.23 m
Load at break point	0.2336 kN
Maximum displacement at break point	0.0036
Maximum strain	0.015 mm/mm
Maximum bending stress	0.94 kN/mm

Figure 1 shows the load-deflection relationship plotted after a compilation of the data from the machine. The topmost point in the graph (A) shows the fracture load (0.2336 kN). To estimate Young's modulus, a slope of stress and strain can be taken from the graph. The stress and strain calculated (Figure 2) have a linear relationship until point A. This was an expected trend as composites do not yield or undergo plastic deformation. Point A shows the maximum bending stress of the pipe under bending before initial fracture. The fracture at point A shows the first fibre fracture of the pipe. However, continuous fracture proceeds across other fibres as seen in the progression of the graph until point B where complete fracture is experienced in the pipe. This further goes to show that the composite pipe will not fail in a catastrophic manner unlike monolithic steel pipes (Laney, 2002). In oil and gas applications, this shows that a composite pipe can withstand high bending loads without losing its shape or deforming completely under loading. Unlike conventional steel pipe which would deform significantly before catastrophic failure or rupture, a carbon fibre pipe will keep its elastic nature with the matrix spreading loads across other fibres to ensure it does not fail completely (Etchevenry and Barbos, 2012).

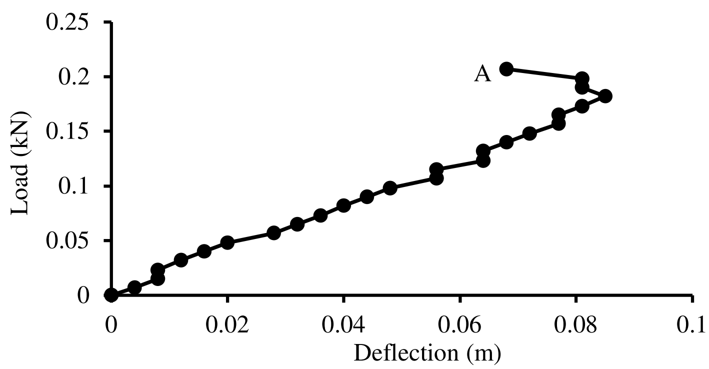

Figure 1: Graph of load against deflection

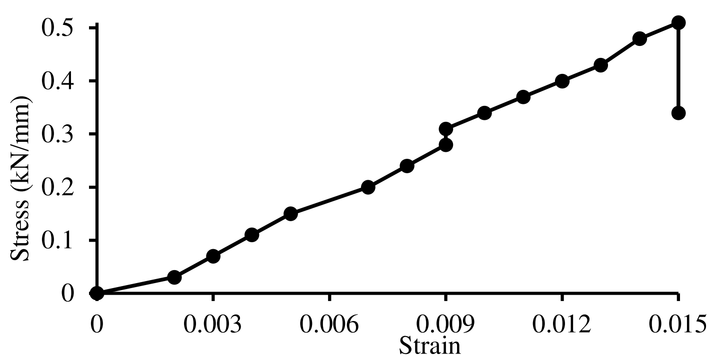

Figure 2: Graph of bending stress and strain

4. CONCLUSION

The understanding of the carbon fibre pipe under bending stress is important. In this study, the behaviour of a thin-walled carbon fibre reinforced composite pipe subjected to bending test was investigated. The results of this work revealed the maximum deflection of the pipe to be 3.36 mm and was experienced at the midpoint of the pipe. The implication is that a composite pipe can withstand high bending loads without losing its shape or deforming completely under loading. The results obtained will help to understand the strength capabilities of the pipe. From the findings of the test conducted, it can be concluded that the results and pattern of the plots agreed with the results of other researchers on composite material under bending stress.

The tensile as well as shear tests conducted on the composite pipes gave further understanding on the characteristic material properties and behavior of composite pipes under shear and tension. The composite pipe did not deform plastically and withstood high loads and stress. Based on the findings from this study, it is recommended that several other types of composite pipes be tested in future studies to compare results and properties of the various composite materials and to understand the best applications for them.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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