Investigation Experimentally the Effect of Thermal Stresses on the Straight and Curved Natural Composite Material Pipes

Riyadh Fakher Jassim and Fadhel Abbas Abdulla
College of Engineering, Al-Mustansiriayah University, Baghdad, Iraq

Corresponding Author: rdh.fakher80@gmail.com

Abstract

This paper study experimentally the effect of changing the angle of curvature pipe made from natural composite materials (eggshell powder with polyester) under thermal load. This work involves the design and fabricate of straight and curved pipe samples with difference angle of curvatures (34° and 48°) at 50 % weight fraction. Three composite pipes were tested (straight pipe, curved pipe with angle 34°, and curved pipe with angle 48°). Tensile and thermo-mechanical test were performing to find the mechanical properties of the specimens. Experimental work included design and manufacturing test rig to simulate thermal stress. The experimental results revealed that a maximum hoop strain and longitudinal strain increased with increasing the temperature for all test pipes. The longitudinal stresses at crown and intrados positions were more than the longitudinal stress at extrados position by 258 % and 199 % respectively and the von mises stresses at crown and intrados positions were more than the von mises stress at extrados position by 180 % and 165 % respectively. In the curved pipe with angle 48°, the hoop strains at intrados and crown positions were more than the hoop strain at extrados position by 78 % and 37 % respectively.

Introduction

In many industries, such as refineries, power plants, and chemical plants, piping systems are important components where their primary function is to move fluid from one piece of equipment to another. The fluid pipe material is normally dry, the fluid content of the pipe is hot, and because the piping system was originally constructed at the reference temperature [1]. There are many studies that dealt with the topic of pipes exposed to different stresses, and here a review of the researches that dealt with straight or curved pipes and their exposure to stresses and the use of natural composite materials. A. Kandil, et al; (1995) [2] contemplated hypothetically the thermal stress investigation of a thick-walled cylinder subject to inclination of transient temperatures with different circumstances of working using finite difference approach. The
Analysis shows that the maximum stress happened each time in the inward surface of the cylinder, and the greatest magnitude was in the working temperature starting. A. Kandil (1996) [3] investigated stresses in the cylindrical pressure vessel wall that are exposed to periodic temperature and internal pressure. Time-dependent stress distribution was obtained by finite element method using a numerical model. I.T. Al-Zaharnah, et al; (2000)[4] calculated theoretically the thermal stresses in a pipe with uniform heating and fully developed flow, the properties of thermal fluid and the influence of material pipe on the resulting heat transfer and stresses, the pipe materials and fluids used were mercury, coolanol 25 and water as fluid, steel and copper as pipe material. C. Miki et al, 2000 [5] studied the elbow strain and deformation subject to permanent ground offsets. The test material was steel pipe bend. Mechanical assembly for both opening and closing mode bending tests was investigated, the experimental results showed that the steel bends pipe were wrinkled deformed and highly before started of the crack, in the closure bending mode case, while in the case of open bending mode, in the case of intrados-extrados direction it is ovalized. Z.S. Nazirah et al, 2016 [6] studied the hoop and longitudinal stresses of epoxy resin-reinforced fiberglass (GRE) undergoing internal pressure due to its performance at different temperatures were. The analysis was carried out to determine composite pipes failed. Fiber reinforcements are the principal contributors of a composite structure's strength and rigidity. At elevated temperatures, the failure stress is reduced. For addition, the mechanical properties may also be influenced by an increase in temperature, the Young's modulus decreases as temperature increases as the resin matrix at high temperatures softens itself. Qasim S M (2015 [7] studied composite and Nano composite pipes conduct under bending moment and internal pressure. The results showed that the maximum stresses for woven roving carbon are approximately four times equivalent to glass fiber (woven roving), but carbon (roving) is nearly twice equivalent to glass fiber (roving). Carbon and glass fiber (roving woven) specimens were also more tolerant to stress, deformation of the hoops and strain of the hoops than roving specimens. İ.Y. Sülü, (2016) [8] studied the analysis of stress for (carbon / epoxy) and (fiber glass / epoxy) hybrid composite pipes with different pressure and angles of orientation. From results, the stresses of (-45/45) are bigger than other orientations angles. Hybrid composite pipes were also compared and shown to be used under high internal pressure and are critical for pipe systems in industry. W.J. Habubi and Hamdi N.F. (2017) [9] investigated the composite preparation of epoxy /eggshell as an insulation. The results showed a good thermal (stability and conductivity) for 4 percent eggshell / epoxy composite, and can be used as insulation. Abdulla F A (2018) [10] studied the behavior of straight and curved composite pipes under bending moment and internal pressure. The results showed that the maximum carbon fiber stress at (4 mm) curved pipe thickness was significantly higher from the curved pipe fiber glass by (362%). The curved pipe with internal pressure only has stresses greater than curved pipe with in-plane bending and internal pressure. S. Z. Tariq (2020) [11] studied the behavior of pipes made of natural hybrid composite materials under the influence of thermal load. The results showed that the pipe made of firewood ash had a higher temperature, lowest longitudinal strain, lowest longitudinal stress, lowest hoop stress. This study focused experimentally to analysis of straight and curved natural composite pipes made from eggshell powder with polyester under thermal loads.

1- Experimental Work

The materials used in this research are eggshell powder and polyester with 50% volume fraction
2.1 Preparation of Materials

Fresh egg shells are prepared after being thoroughly washed with water, cleaned and left to dry at room temperature and then grounded by an industrial mill. The process of preparing materials is shown in the figure (1).

![Preparation of materials](image1)

**Figure (1) Preparation of materials**

2.2 Preparation of Tensile Test and Coefficient of Thermal Expansion Samples

The mechanical properties have been found using ASTM D 638 standard [12]. A composite plate (20cm*30cm*0.5cm) was casted using resin casting method as shown in figure (2). The CNC cutting machine was used to desired the sample of tensile test (see in figure (3)). Thermo Mechanical Analyzer (TMA) is the tool used to determine the thermal expansion coefficient, as shown in figure (4). The required TMA unit sample measurements are (2cm*0.5cm *0.4cm). From the previously cast rectangular shaped composites shown in figure (2), the samples are cut using a platform CNC cutting machine.

![Casting Process of a Rectangular Composite Form](image2)

**Figure (2) Casting Process of a Rectangular Composite Form**
2.3 Preparation of Natural Composite Straight and Curved Pipes

Three molds are used for casting with are three angles of the pipes. The angles are (0°, 34° and 48°) as shown in figure (5). Each mold is made of iron. After bending the pipe according to the required angle, the curved pipe is cut longitudinally into two halves, and then links are welded for the purpose of the two halves forming after cutting, and the base is welded which is a circular disk with the same diameter as the outer diameter of the iron mold and divided into two halves in the form of a half disk in which a hole has been made in the disk before cutting, then these halves welded with each part of the iron mold to form the base [13,14]. The mold also contains a curved serrated iron rod with the same angle of curvature of the mold used for the purpose of stabilizing and balancing the core of the mold. It also contains the filling [as shown in figure (6)] which is a sponge material used to cover the artificial limbs, used in this work for the purpose of making a gap in the mold; This gap is the thickness of the pipe to be manufactured later and the two halves of the mold are fixed by the joints on the sides of each end using screws.
2.3.1 The Casting Process

The process of manufacturing the pipes to be examined undergoes two stages, namely:

A- Pouring the heart

It is the stage of the work of the heart required to manufacture the cavity of the pipe to be manufactured and is done as follow:

- preparing the mold and placing a filling inside the mold, then fixing the serrated iron bar with one half of the main mold, after that, gathering the main mold through the connections on the body of the mold and the necessary screws for that, and putting a kazkit for the purpose of preventing material leakage out of the mold through the holes in the mold [15,16].
- Mixing the plaster material with water and pouring it inside the main iron mold, then left until it completely
solidifies and then it is removed from the main mold and hence the first stage is complete as shown in figure (7).

![Figure (7) the stage of pouring the heart](image)

**B- Casting the composite materials**

In this stage, manufacturing of the pipe from the natural composite materials according to the required percentage is done, this work also includes several steps:

- cleaning the mold from dirt and impurities, and covering the plaster that was poured with transparent adhesive for the purpose of easily flow of the composite materials and prevent its adhesion to the plaster, after that, the plaster is coated with an insulating material (wax) to prevent the adhesion of composite materials to the body of the heart [17,18]. Then painting the main mold with the insulation material (wax) for preventing the sticking the materials with its walls, then reach to installing the core made of plaster inside the main mold as shown in figure (8), assembling the main mold by connecting the two halves, and then fastening of the mold, after all that is done, Mixing the (natural) fiber with the bonding material (polyester) well using the mixing machine and according to the mixing ratios required in the mixing bowl to reach the best homogeneity while adding the hardener to the mixture, then manually pour the mixture into the main mold and leave it to solidify for a whole day, after which the mold opens and the product is removed as shown in figure (9).
2.4 The Test Rig

A test rig was manufacturing to applied thermal loads on the specimens as shown in figure (10). Within the pipe specimen, the thermal load was applied in the composite pipe using hot air [19]. From three components, the test rig was consisting:

1. Boundary conditions system  
2. Thermal system  
3. Data acquisition system
2.4.1 Boundary Conditions System

Two iron jaws were used at both ends of the pipe specimen for the purpose of fixing the X and Y directions, a toothed shaft with two iron plates was used for the Z direction, that plate has some holes which allow air to flow through the pipe and two iron stands were also used to hold the pipe specimen, jaws and shafts with its caps, all these shown in figure (11).

2.4.2 Thermal System

The temperature device designed to provide thermal charge on the pipe specimen in the test rig. Temperature device consists of a hot air supplier (heat gun), eight thermocouples (type K) (four mounted on the top side and four on the bottom side of the pipe specimen) and a 12-channel thermocouple reader connected to the 8 thermocouples mounted on the pipe as shown in figure (12).
2.4.3 Strain Gauge Set-up

In each test the connecting strain gauge procedure is repeated. Strain gage is an instrument with an electrical resistance that varies according to the change in strain. Thus, two rectangular strain gages for straight pipe and six for curved pipe (R=120B, GF=2.2) are used for the recording of strain data. The figure (13) is showing number of strain gauges, their position on straight and curved pipes and the Universal Data Logger system. The strain gage was placed in the center of the pipe for reading the hoop and longitudinal strain.

![Figure (12) Thermal System](image)

![Figure (13) Data Acquisition System (Strain Gauge and Strain Data Logger)](image)

2.5 Experimental Procedures
Thermal charge application was performed when heat air was applied from the heat piston and increased uniformly and continuously to the pipe specimen, as temperature reader readings were the same for all thermocouples, this means that the temperature reached on the device was reported at the steady state and strain data logger readings. The temperature and strain gage data were analyzed at the end of the test in order to obtain the mechanical parameters required. The readings of the Strain data logger's computer program will be in (mA). The values of stresses were obtained through equations (1), (2), and (3). [20]

\[
\sigma_L = \frac{E}{1 - \nu^2} (\varepsilon_H + \varepsilon_L) \quad (1)
\]

\[
\sigma_H = \frac{E}{1 - \nu^2} (\varepsilon_H + \varepsilon_L) \quad (2)
\]

\[
\sigma_{\text{von.}} = \sqrt{\left(\sigma_H\right)^2 + \left(\sigma_L\right)^2 - \sigma_H \sigma_L} \quad (3)
\]

3 Results and Discussion

In this section, the tensile test, coefficient of thermal expansion and the effect of temperature on the strains and stresses, as well as the change in the angle of curvature of the manufactured pipe are shown and discussed for three pipes (the first pipe is a straight pipe, the second pipe is a 34-degree curved pipe and the third pipe is a curved pipe at an angle of 48) all made of eggshell powder (fibers) with polyester (matrix) and 50% by weight fraction.

3.1 Results of Tensile Test and Coefficient of Thermal Expansion Test

The properties of material (modulus of elasticity, coefficient of thermal expansion, poisson ratio and yield stress) resulted from the tensile test and coefficient of thermal expansion test are shown in table (3-1).

| No. | Fiber            | Matrix | Symbol | Weight Fraction % | E (Gpa) | α (m/mk) | ν   | σy (Mpa) |
|-----|------------------|--------|--------|-------------------|---------|----------|-----|----------|
| 1   | Egg Shell Powder | Polyester | E50 | 50 | 16.41 | 2.96E-06 | 0.42 | 29.75   |

3.2 Effect of Temperature on the straight pipe

Figure (3-1) for the straight pipe shows the relationship of temperature to hoop and longitudinal strain. From the figure it can be seen that increasing temperature causes increase in hoop and longitudinal strain. It can also be seen from the figure that the highest temperature tolerated by the sample was (230 ° C). However, the sample had the highest hoop strain reached (1.3E-03) and the
highest longitudinal strain reached (1.04E-03). Also, it was clear that the hoop strain was more than of longitudinal strain by 25% because the increase in the deformation of the hoop (δH) relative to longitudinal deformation (δL).

Figure (3-2) for the straight pipe shows the temperature relation with hoop stress, longitudinal stress and von mises stress. It can also be seen from the figure that the model’s highest tolerated hoop stress was (34.605Mpa), highest tolerated longitudinal stress was (31.6Mpa) and highest von mises stress was (33.205Mpa). All stresses increase with the heightened temperature. It was also found that the hoop stress (σH) is significantly higher than von mises (σVon) by 4.21% while the longitudinal stress (σL) is lower than von mises stress (σVon) by 5.079 %. This is due to the disparity in the hoop and longitudinal stress caused by the rise in strain.

Table (3-1) Maximum Stresses, Strains and Temperature for the Straight pipe

| Symbol of Composite Material | T(°C) | εH    | εL    | σH (MPa) | σL (MPa) | σVon (MPa) |
|-----------------------------|-------|-------|-------|----------|----------|------------|
| SE50                        | 230   | 1.3E-03 | 1.04E-03 | 34.605   | 31.6     | 33.205     |

3.2 Effect of Temperature on the Curved pipe with angle 34°

Figure (3-3) shows the relationship between temperature and hoop strain (εH) for curved pipe with angle 34°, at three angles [Φ= 90°, Φ= -90°, Φ= 0°]. In angle (Φ= -90°) the increasing in the hoop strain (εH) with increasing temperature was very obvious. In the intrados and crown position, hoop strain is more than in extrados position by 128 % and 50 % respectively. This increase came as a result of the increasing in hoop deformation (δH) in angles (Φ= -90°, Φ= 0°). The figure (3-4) shows the relationship between temperature and longitudinal strain (εL) for curved pipe with angle 34°, at three angles [Φ= 90°, Φ= -90°, Φ= 0°]. In angle (Φ= 0°) the increasing in the longitudinal strain (εL) with increasing temperature was very obvious. In the crown and intrados position [21], longitudinal strain is more than in extrados position by 433 % and 260 % respectively. This increase came as a result of the increasing in longitudinal deformation (δL) in angles (Φ= 0°and Φ= -90°).
Figures (3-5), (3-6) and (3-7) give the influence of temperature increasing on the stresses [h hoop stress ($\sigma_H$), longitudinal stress ($\sigma_L$) and von mises stress ($\sigma_{Von}$)] for curved pipe with angle 34, at three angles [$\Phi= 90^\circ$, $\Phi= -90^\circ$, $\Phi= 0^\circ$]. It is showed that all stresses increased with the increasing in temperature [22]. Also, show that the hoop stress ($\sigma_H$) in angle ($\Phi= -90^\circ$) and ($\Phi=0^\circ$) in figure (3-5) are more than ($\sigma_H$) in angle ($\Phi=90^\circ$) by 151 % and 116 % respectively. The longitudinal stress ($\sigma_L$) in angle ($\Phi=0^\circ$) and ($\Phi= -90^\circ$) in figure (3-6) are more than ($\sigma_L$) in angle ($\Phi=90^\circ$) by 258 % and 199 % respectively. The von mises stress ($\sigma_{Von}$) in angle ($\Phi=0^\circ$) and ($\Phi= -90^\circ$) in figure (3-7) are more than ($\sigma_{Von}$) in angle ($\Phi=90^\circ$) by 180 % and 165 % respectively.
Figure (3-3) Hoop strain for Curved pipe with angle $34^\circ$ at different angle $\Phi$ ($90^\circ$, $0^\circ$, $90^\circ$)

Figure (3-4) Longitudinal strain for Curved pipe with angle $34^\circ$ at different angle $\Phi$ ($90^\circ$, $0^\circ$, $90^\circ$)

Figure (3-5) Hoop Stress for Curved pipe with angle $34^\circ$ at different angle $\Phi$ ($90^\circ$, $0^\circ$, $90^\circ$)

Figure (3-6) Longitudinal Stress for Curved pipe with angle $34^\circ$ at different angle $\Phi$ ($90^\circ$, $0^\circ$, $90^\circ$)

Figure (3-7) Von Mises stress for Curved pipe with angle $34^\circ$, at different angle $\Phi$ ($90^\circ$, $0^\circ$, $90^\circ$)
3.3 Effect of Temperature on the curved pipe with angle 48°

Figures (3-8) to (3-12) show the effect of temperature increasing on the strains and stresses for the curved pipe with angle 48°. The curved pipe with angle 48° consist eggshell powder/polyester resin. The figure (3-8) shows the relationship between temperature and hoop strain (εH) for curved pipe with angle 48°, at three angles [Φ= 90°, Φ= -90°, Φ= 0°]. In angle (Φ= -90°) the increasing in the hoop strain (εH) with increasing temperature was very obvious. In the intrados and crown position, hoop strain is more than in extrados position by 78 % and 37 % respectively, this increase came as a result of the increasing in hoop deformation (δH) in angle (Φ= -90° and Φ= 0°). The figure (3-9) shows the relationship between temperature and longitudinal strain (εL) for curved pipe with angle 48°, at three angles [Φ= 90°, Φ= -90°, Φ= 0°]. In angle (Φ= 0°) the increasing in the longitudinal strain (εL) with increasing temperature was very obvious. In the crown and intrados positions, longitudinal strain is more than in extrados position by 345 % and 202 % respectively, this increase came as a result of the increasing in longitudinal deformation (δL) in angle (Φ= 0° and Φ= -90°) [23].

Figures (3-10), (3-11) and (3-12) give the influence of temperature increasing on the stresses [hoop stress (σH), longitudinal stress (σL) and von mises stress (σVon)] for curved pipe with angle 48°, at three angles [Φ= 90°, Φ= -90°, Φ= 0°]. It is showed that all stresses increased with the increasing in temperature. Also, show that the hoop stress (σH) in angle (Φ= -90°) and (Φ=0°) in figure (3-5) are more than (σH) in angle (Φ=90°) by 98 % and 87 % respectively, the longitudinal stress (σL) in angle (Φ=0°) and (Φ= -90°) in figure (3-6) are more than (σL) in angle (Φ=90°) by 199 % and 143 % respectively, the von mises stress (σVon) in angle (Φ= -90°) and (Φ=0°) in figure (3-7) are more than (σVon) in angle (Φ=90°) by 129% and 111 % respectively.
4- Conclusions

1- The maximum stress for curved pipes was greater than the maximum stress for straight pipe.
2- In curved pipes, the stresses and the strains at intrados and crown positions were more than the stresses and strains at extrados position.
3- For all pipes, when the temperature is increasing the hoop and longitudinal are increasing.
4- The hoop strain and hoop stress for straight pipe were more than longitudinal strain and longitudinal stress.

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