Effect of wood ash additive on the thermal stresses of random fiberglass/polyester composite pipes

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Abstract. Experimental and numerical investigations of the effect of wood ash additive on the thermal stresses of random fiberglass/polyester composite pipes were presented in this work. The experimental work includes manufacturing of pipe specimens (50% Vf wood ash/polyester composite pipe, 50% Vf random fiberglass (Mat)/polyester composite pipe and 25% Vf wood ash and 25% Vf random fiberglass (Mat)/polyester composite pipe) by resin casting method and building a test rig to study the behaviour of these pipe specimens under thermal loads. Pipe specimens had inner diameter of 90mm and 400mm in length. The wall thickness is 5mm. The current work includes also manufacturing tensile test specimens which were examined by tensile device and manufacturing thermo mechanical test specimens which were examined by thermo mechanical analyser (TMA) to determine the coefficient of thermal expansion of the specimens. In numerical work, ANSYS was used as mechanical simulation software with SHELL63 element type. The results showed that adding wood ash to the random fiberglass/polyester composite pipe leads to decrease in its longitudinal stress, hoop stress and von mises stress, however increases the element temperature withstand. The numerical solution gave a good agreement results with the experimental work with maximum difference between experimental and numerical strain ranging was between (9.3%) to (17.7%) and maximum difference between experimental and numerical stress was ranging between (14.1%) to (17.75%).

1. Introduction
An important area of mechanical engineering is the materials mechanically behaviour when exposed to heat source. Finding materials requirements that enable them to work properly at different temperatures is a common problem facing materials technology. There are several different applications in which there are the flow of high temperature working fluid flows through the pipes. Thus thermal stresses and non-uniform deformations are generated when a pipe undergoes a change in temperature. Structures of nuclear engineering, military industry, gun tubes and turbines are typical examples for such a situation that subjected to the thermal stresses Zaharnah, 2002 [1]. Various acts had been accomplished on the fabrication of polymer matrix composites such as addition of different additives and fillers. Wood ash is considered an additive which is cheap and available modifier for the properties of polymer matrix composite Sanusi et. al., 2013[2].

Zaharnah et. al., 2000 [3] investigated theoretically the thermal stresses developed in a pipe with a fully developed flow and uniform heating. The influence of pipe material and fluid thermal properties on the resulting stresses and the heat transfer were studied. The working fluids were mercury, COOLANOL 25 and water, while the pipe materials were steel and copper. The results showed that,
the influence of the conductivity ratio and Prandtl number on distribution of temperature in solid and fluid was investigated. Wei Su, 2007[4], studied the thermal stresses in composite beams with tubular cross-sections area using modified lamination theory and parallel axis theorem. Three-dimensional finite element models for computing thermal stresses were developed using commercial software package ANSYS 10. For cantilevered composite beams with tubular cross-section area, the results showed that the fiber orientation of the plies plays an important role on the thermal induced in-plane stresses. Abdullah, 2011 [5], investigated theoretically and experimentally the use of natural composite materials as thermal insulator which consist of natural fiber such as jute, white feathers, black feather and egg shells. Method of Lee disc was used to measure the thermal conductivity of various types of natural composite materials. The result showed that Jute based composite material gave better result as composite thermal insulator as compared with that for other natural materials. Sanusi et. al., 2013[2], studied the effect of adding wood ash on the mechanical properties of a fiber glass/epoxy composite. X-ray florescence spectrometry was used to carry out the chemical analysis which defined the wood ash chemical composition. The results of adding wood ash to the fabrication of the polymer matrix composite showed a considerable increase in tensile and impact strength. I. Y. Süli, 2016 [6], investigated the stress analysis of multi-layered hybrid composite pipes with symmetrical orientation angles, under internal pressure, hybrid composite pipes were made of E-glass fiber/ epoxy and carbon/epoxy(AS4/3501-6), with different orientation angles. The code for a numerical model was created using ANSYS software for numerical analysis. The results showed that the stresses of [45/-45] for both material orientations were the greatest from the inner surface to the outer surface of the pipes than other. Sanusi et. al., 2016 [7], developed a polymer matrix composite (PMC) for the application of body armor using hand lay-up processing method in the fabrication of the epoxy/wood ash composite. The results showed that adding of wood ash of 2.3% resulted in increase in tensile strength and hardness against neat reinforced resin. Lemos et. al., 2017 [8], investigated the mechanical and thermal behavior of polypropylene (PP) composite with various natural fibers. The used fibers were wood, bamboo, sugarcane, coconut, babassu and kenaf with and without coupling agent. The thermal, mechanical and morphological properties were determined. The results showed that the mechanical and thermal performances of the natural fibers reinforced composites were lower than that of the glass fiber reinforced composite. However, in some situations the difference was not insignificant. Hamdi and Habubi, 2017 [9], studied the eggshell/epoxy composite preparation as thermal insulation. Epoxy resin was used as the matrix and eggshell powder was used as the reinforcement to improve the thermal conductivity and thermal stability of matrix. The epoxy was mixed with the eggshell powder at various volume fractions , namely; 1, 2, 3, 4, and 5% by hand lay-up technique. Glass mold with disk shape of a radius of 25 mm and thickness of 3 mm were used to cast the samples for the thermal conductivity test. The mold was left for 6 days of cure period at room temperature. The results showed that the 4% eggshell/epoxy composite showed a good thermal conductivity and thermal stability, which means the ability to utilize these composites as thermal insulation. Chandramohan and JohnPresinKumar, 2017 [10] studied experimentally the properties of natural fiber particle reinforced polymer composite material. Hybrid composite specimens were fabricated from epoxy resin as matrix and walnut shells, powdered coconut shell and rice husk as reinforcements. Each specimen had a fiber composition of (1:1), however, resin and hardener composition was (10:1) respectively. The fabricated composite specimens were tested according to ASTM standards to determine the mechanical properties like flexural strength, tensile strength, shear strength and impact strength. The results showed that the properties of hybrid composite were much better than the composite reinforced with a single fiber glass under mechanical loads. The results also showed that the incorporation of coconut shell and walnut shell fiber could improve the properties.

This work focuses on the experimental and numerical study of the effect of wood ash additive on the thermal stresses of random fiberglass/polyester composite pipes manufactured by resin casting method, and study the behaviour of these pipes when its subjected to thermal load that results in thermal stresses by building test rig to study the effect of thermal stresses, also a numerical study using ANSYS software was done to compare the results with the experimental work.
2. Experimental work

This section describes the experimental work conducted in the present work. The work contains manufacturing of the test specimens used and the development of the dedicated test rig. Fabrication of the composite pipe was done using resin casting method. The test rig was built so that it is capable of performing test under various thermal loads. This work includes also manufacturing tensile test specimens which were examined by tensile device and also thermo-mechanical test specimens were manufactured and examined by thermo-mechanical analyser device.

2.1. Test specimens

Three various composite materials were used in present work. Each composite has different volume fraction while the matrix volume fraction was fixed at about 50%, therefore it was divided to 25%+25% for wood ash and fiberglass in A25F25 specimen. Table (1) shows the specifications of each composite.

| Composite material symbol | Fiber                  | Matrix      | Volume fraction (%) |
|---------------------------|------------------------|-------------|---------------------|
| A50                       | Wood ash               | Polyester   | 50                  |
| F50                       | Fiberglass             | Polyester   | 50                  |
| A25F25                    | Wood ash + Fiberglass  | Polyester   | 25+25               |

2.2. Tensile Test

The mechanical properties of all specimens were determined according to the ASTM D 638 standard [11]. A rectangular shape composites of dimensions of 200×300×5mm were casted by resin casting method, then the tensile test sample desired shape was cut using a CNC cutting machine as shown in Figure 1.

![Figure 1. Tensile test sample](image)

Nine tensile test samples were cut, 3 samples for each composite with original length of 50mm, width of 13mm and 5mm thickness. The tensile test had been accomplished in University of technology / Production Engineering and Metallurgy Department. Nine tensile tests were done (3 tests for each specimen). Two strain gauges were fixed on the tensile test specimen, one in the longitudinal direction and the other one in the width direction in order to determine the strain in both directions which is necessary to calculate the Poisson ratio of the specimens. Tensile tests were done in one direction for all specimens due to that all test specimens were isotropic. WDW-200E device was used to achieve the tensile tests.
2.3. Coefficient of Thermal Expansion (α)
The coefficient of thermal expansion test had been accomplished in the Ministry of Science and Technology/ Polymer Department. (TMA) analyser was used to determine the coefficient of expansion. Thermo-Mechanical Analysing can be defined as a scale of change in engineering dimensions or mechanical properties change when the sample is subjected to a heat system with or without subjecting the sample to a mechanical load. The TMA device consists of the sample chamber, sample holder, oven, sensors and controller. The device is connected to a computer with screen to show the results and a printer to print the results. The dimensions of the desired TMA device sample were (20mm*5mm*5mm). The samples were cut from the previously casted rectangular shaped composites using a CNC cutting machine. The TMA test samples are shown in Figure 2.

![Figure 2. TMA test samples](image)

2.4. Manufacturing of pipe specimen
Various techniques are used for manufacturing composite pipes. Filament winding and vacuum bagging are the most common techniques used in the manufacturing of composite pipes. However resin casting technique is used for the purpose of the composite pipes manufacturing in this work due to the materials nature. Three pipe specimens were casted with specifications as shown in table (1). The dimensions of the pipe specimens were (400mm) length, (90mm) internal diameter and (5mm) thickness. The mold used in the resin casting process consists of two plastic pipes with different dimensions. The external pipe referred to as the shell has a 100mm internal diameter and a 400mm length. The internal pipe referred to as the core has a 90mm external diameter and 500mm length. The core is inserted inside the shell and both are centred and fixed as shown in Figure 3. The difference in diameter between the shell and core makes a hollow cavity of a pipe shape with the desired dimensions. The first step in the casting process was the lubrication of the mold to prevent the casted pipe from adhesion with mold. Petroleum jelly was used as a lubricant agent. The wood ash was mixed with polyester resin and hardener by hand until the mixture reached to a homogenous state. The mixture was then injected into the mold, using a medical feeding syringe, and left to solidify. After 5 hours the pipe specimen was fully solidified and ready to be extracted from the mold. This process was repeated for the casting of the remaining composite pipes. Figure 4. shows the type A50 pipe specimen casted by resin casting.

2.5. Test rig of the experimental work
A special test rig was made capable of applying thermal loads on the test specimens. In principle, the thermal stress in composite pipe can be achieved by hot air flowing inside the pipe specimen. The test rig consists of three main part, mechanism system, heating system, data acquisition system. The mechanism system in this study was fixing the X and Y directions in the both ends of the pipe specimen and fixing the Z direction along the pipe. For the purpose of fixing the X and Y directions two iron jaws were used in both ends of the pipe specimen. For the Z direction a toothed shaft with two iron plates were used, where the two plates were installed on the two ends of the pipe with the toothed shaft using bolts. Also two iron stands were used to carry the pipe specimen, jaws and the shafts with its plates. The heating system in test rig designed so that it can provide thermal load on the
The pipe specimen. The thermal system consist of a hot air gun that can provide hot air with temperature up to 600 °C, which is connected to the iron jaw, four thermocouples type K were installed on the top side of the pipe specimen, another four thermocouples were installed at the bottom of the pipe specimen. A 12 channels data acquisition is connected to the 8 thermocouples that installed on the pipe. When the heat gun is turned on it provides hot air with different temperatures which can be controlled manually through a regulator dial that built in the heat gun, when hot air flow through the pipe the thermocouples sense the change in temperature which can be read by the temperature recorder and recorded with time on SD card that installed in the temperature recorder. Data acquisition system consists of two strain gauges installed on the pipe specimen and data logger which is connected to strain gauges and also it is connected to a computer to view the readings in each test.

The strain gauge converts the strain applied to a proportional change of resistance, and this small change in resistance can be change to a voltage drop in mV or to a current in mA as an output value. By the end of the test the temperature and strain gauge data were studied in order to obtain the desired mechanical parameters. The current reads by the computer software of the strain data logger in mA, therefore calibration was done for it. The stress values were obtained from equations (1), (2) and (3).

\[ \sigma_L = \frac{E}{(1-\nu^2)} (\varepsilon_H + \varepsilon_L) \]  
\[ \sigma_H = \frac{E}{(1-\nu^2)} (\varepsilon_H + \varepsilon_L, \nu) \]  
\[ \sigma_{VON} = \sqrt{\left(\sigma_H\right)^2 + \left(\sigma_L\right)^2 - \sigma_H \sigma_L} \]

3. Numerical Work
A detailed process of the finite elements analysis (FEA) of the pipe is discussed through different situations in order to figure the stresses and strains with various loading conditions. The calculation of the mechanical stresses of the pipe is of great significance in research. Therefore, the finite element is the perfect solution to determine the stresses. ANSYS package software version 11 was used to calculate both strains and stresses for three cases. The SHELL63 element type was used in this work, in-plane and normal loads are both permitted. SHELL63 element has six degree of freedom (DOF) in each single node: motions in the nodal x, y and z directions and rotations about the nodal x, y and z.
axes. Meshing is an important step which is required for the FEA of the pipe prototype. The number of elements of the pipe model used in this work was 2000 elements, while the number of nodes was 2091 nodes, as shown in Figure 6. One of the important steps required for the FEA of the pipe model is applying the boundary condition for the model, a special procedure had been used to present the boundary conditions for the model during the normal daily activities, simply supported boundary condition had been applied for the pipe model used in this work. This condition was applied by selecting the circumference nodes on both sides of the pipe and set all DOF as shown in figure 7. The thermal load was applied on the internal surface of the pipe.

![Test Rig of the Experimental Work](image1)

**Figure 5.** Test Rig of the Experimental Work

![Meshing of the Pipe](image2)

**Figure 6.** Meshing of the Pipe

![Boundary Conditions of the Pipe](image3)

**Figure 7.** Boundary Conditions of the Pipe
4. Results and discussion

In this section, the temperature versus the stresses and strain behaviour and the effect of adding wood ash to the fiberglass composite pipe were presented. Also, the properties of materials resulted from the tensile test and thermo-mechanical test for all three specimens were presented. These results were recorded with the pipe specimens that have dimensions of 90mm internal diameter, 400mm length and wall thickness of 5mm.

4.1. Tensile Test and Thermo-Mechanical Test Results

The properties of the isotropic specimens (modulus of elasticity, poisson ratio, coefficient of thermal expansion, yield stress and ultimate stress) resulted from the tensile test and thermo-mechanical test are shown in table 2. It can be seen from the table that specimen F50 shows the highest modulus of elasticity of 21 GPa, while specimen A50 shows the lowest modulus of elasticity of 9 GPa) and the poisson ratio magnitudes are ranging from 0.47 to 0.48, as for the coefficient of thermal expansion (α), yield stress (σy) and ultimate stress (σult), it can be seen from the figures that the specimen F50 shows the highest coefficient of thermal expansion and ultimate stress of 8.5e⁻⁶ m/mk and 205 MPa respectively, while the specimen A25F25 shows the highest yield stress of 135 MPa. However, the specimen A50 shows the lowest coefficient of thermal expansion, yield stress and ultimate stress of 2.1e⁻⁶ m/mk, 22 MPa and 25 MPa respectively.

| Composite material symbol | E (GPa) | α (m/mk) | ν | σy (MPa) | σult (MPa) |
|---------------------------|---------|----------|---|-----------|------------|
| A50                       | 9       | 2.10e⁻⁶  | 0.48 | 22        | 25         |
| F50                       | 21      | 8.50e⁻⁶  | 0.47 | 101       | 205        |
| A25F25                    | 12.7    | 5.50e⁻⁶  | 0.47 | 135       | 190        |

4.2. Effect of temperature increment on strain and stress of the specimens A50, F50 and A25F25

Figures 8. to 12 show the effect of increasing temperature on the strain and stress for the specimens A50, F50 and A25F25. Figure 8. gives the relation of temperature with longitudinal strain, it can be seen from the figure that specimen A50 is the one with the highest temperature withstand of 275°C followed by specimen A25F25 with temperature withstand of 150°C, as for specimen F50, it has the lowest temperature withstand in this group with temperature withstand of 110°C. However, the specimen F50 showed the highest longitudinal strain in this group compared to the specimens A50 and A25F25 with difference of 42 and 11% respectively, this is due to the highest coefficient of thermal expansion. Figure 9. gives the relation of temperature with hoop strain, it can be noticed that the same results discussed in Figure 8. Shows a highest strain are shown in Figure 9. the hoop strain difference between specimens F50, A50 and (A25F25) is 40 and 19% respectively. Figure 10. gives the relation of temperature with longitudinal stress, it can be noticed that specimen F50 gives the highest longitudinal stress of 62.2 MPa compared to 32.5 MPa of the specimen A25F25 and 15.8 MPa of the specimen A50, this is due to that specimen F50 have the highest longitudinal strain and modulus of elasticity. Figure 11. gives the relation of temperature with hoop stress, it can be noticed that specimen F50 shows the highest hoop stress of 61.1 MPa followed by the specimen A25F25 which shows 30.9 MPa, as for the specimen A50, it shows the lowest hoop stress in this group of 15.73 MPa. Figure 12. gives the relation of temperature with von mises stress, it can be noticed that as a result of specimen F50 having the highest longitudinal and hoop stresses as shown and discussed in Figure 10. and Figure 11. the specimen F50 shows the highest von mises stress in this group of 61.77 MPa compared to the 31.8 MPa of specimen A25F25 and 15.8 MPa of specimen A50.

4.3. Comparison between numerical and experimental results of strain and stress

Figures 13. to 18. show the relationship between temperature increment and numerical longitudinal strain, experimental longitudinal strain, experimental hoop strain numerical von mises stress, experimental von mises stress, experimental longitudinal stress and experimental hoop stress for all three specimens. From the mentioned figures, it can be noticed that there is a reasonable maximum
The difference between experimental and numerical strain ranging between 9.3 to 17.7%. This difference is due to that numerical results were gained from the numerical solution with ideal circumstances as it shown as straight line in figures, while the experimental results were gained from the experimental work where error percentage is very common. Also, it can be noticed that there is a reasonable maximum difference between experimental and numerical stress ranging between 14.1 to 17.75% which considered acceptable due to error percentage in experimental work compared to the numerical solution.

**Figure 8.** Effect of Temperature Increment on Longitudinal Strain (Experimental)  
**Figure 9.** Effect of Temperature Increment on Hoop Strain (Experimental)  
**Figure 10.** Effect of Temperature Increment on Longitudinal Stress (Experimental)  
**Figure 11.** Effect of Temperature Increment on Hoop Stress (Experimental)
Figure 12. Effect of Temperature Increment on Von Mises Stress (Experimental)

Figure 13. Comparison between Numerical and Experimental Strain for A50

Figure 14. Comparison between Numerical and Experimental Strain for F50

Figure 15. Comparison between Numerical and Experimental Strain for A25F25

Figure 16. Comparison between Numerical and Experimental Stress for A50

Figure 17. Comparison between Numerical and Experimental Stress for F50
Figure 18. Comparison between Numerical and Experimental Stress for A25F25

5. Conclusion
Several conclusions can be drawn from this study:
Regarding temperature withstand, the specimen A50 composite had the highest temperature withstand of 275°C while the specimen F50 composite showed the lowest temperature withstand of 110°C. Adding wood ash to the fiberglass composite resulted in increasing its temperature withstand from 110 to 150°C. The specimen F50 composite had the highest longitudinal strain, while the specimen A50 composite showed the lowest longitudinal strain. Hoop strain of specimen F50 was reduced after the addition of wood ash. The specimen F50 composite had the highest longitudinal stress of 62.2 MPa while the specimen A50 composite showed the lowest longitudinal stress of 15.84 MPa. The specimen F50 composite had the highest hoop stress of 61.1 MPa, while the specimen A50 composite showed the lowest hoop stress of 15.73 MPa. The specimen F50 composite had the highest von mises stress of 61.7 MPa, while the specimen A50 composite showed the lowest von mises stress of 15.8 MPa.

Nomenclature
E: Modulus of elasticity (GPa)
M: Mass (kg)
Vf: Volume fraction
V: Volume (m^3)
V_{fb}.: Volume of fiber (m^3)
V_t: Total volume (m^3)

Greek letters
ρ: Density (kg/m^3)
σ_L: Longitudinal stress (MPa)
σ_H: Hoop stress (MPa)
σ_{VON}: Von Mises Stress (MPa)
ε_L: Longitudinal strain
ε_H: Hoop strain
ν: Poisson ratio
α: Coefficient of thermal expansion (m/mk)
σ_y: Yield stress (MPa)
σ_{ult}: Ultimate stress (Mpa)
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