

PAPER • OPEN ACCESS

Numerical Investigation of Hybrid of Eglass and Basalt Fiber Reinforced Epoxy Tube Pressurized Internally

To cite this article: Thamir A. D. M. S. Almula *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **638** 012012

View the [article online](#) for updates and enhancements.

You may also like

- [Preparation and characterization of alkali treated cocos nucifera var aurantiaca peduncle fibers reinforced epoxy composites](#)
K J Nagarajan, A N Balaji, N R Ramanujam *et al.*
- [Tribological investigation of alumina/graphene nanoplatelets reinforced epoxy nanocomposites](#)
A Kesavulu and Akash Mohanty
- [Experimental investigation on the mechanical properties and water absorption behavior of randomly oriented short pineapple/coir fiber-reinforced hybrid epoxy composites](#)
Mohit Mittal and Rajiv Chaudhary



240th ECS Meeting

Digital Meeting, Oct 10-14, 2021

We are going fully digital!

Attendees register for free!

REGISTER NOW



Numerical Investigation of Hybrid of Eglass and Basalt Fiber Reinforced Epoxy Tube Pressurized Internally

Thamir A. D. M. S. Almula^{1*}, Ahmad Hassan Khuder², Mohd Yazid Yahya³ and Amran Ayob³

¹Engineering Technical College/ Mosul, Northern Technical University NTU, 41002 Mosul, Iraq

²Electromechanical Engineering department /University of Technology, 10066 Baghdad, Iraq

³Center for Composites, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia

*Email: thamir_owen@yahoo.com; thamir_owen@ntu.edu.iq

Abstract. The composite hybrid pipe is a novel structure made of concentric composite multilayer possess improved thermal and mechanical properties better than its original components. At variance experimental analysis, the numerical studies on the structure and behavior of composite hybrid natural fiber reinforced epoxy pipe materials pressurized internally seem lacking. In this study, numerical analysis was carried out for three different stacking plies of composite hybrid natural fiber $\pm 55^\circ$ basalt and Eglass fiber reinforced epoxy tube which was tested under the subjection for three modes of applied load, the hoop and longitudinal tensile tested as well as subjection under biaxial internal pressures load in accordance to ASTM's standard to investigate the mechanical behavior and the optimal configuration among them. Also, analyzed the comparable three types of hybrid natural fiber (basalt)/ Eglass reinforced epoxy with pure $\pm 55^\circ$ Eglass reinforced epoxy and pure $\pm 55^\circ$ basalt reinforced epoxy numerically to predict the performance for the hybrid over the pure E-glass and basalt fiber reinforced epoxy composite pipe as a good replacement to meet the different demand of applications in the pressure pipelines. Also The three stacking plies types of hybrid composite pipes were compared with the pure E-glass and basalt fiber reinforced epoxy pipes. All samples were fabricated using a dry filament wound CNC machine with $\pm 55^\circ$ orientation angle, then infused with epoxy resin using vacuum infusion procedure (VIP). Numerical analysis was carried out using finite element commercial code ANSYS V14.

1. Introduction

Composite hybrid pressure pipes are advanced structures produced by concentric layers of wound fiber reinforced matrix possess better thermal and mechanical properties exceeds of their constituent materials. Large demands for composite pressure pipe products have been motivated by the satisfying for the requirements of erosion and corrosion, high stiffness properties with lighter weight and low price, especially for the composite natural fiber used for its abundance, cheap and healthy with environmental. Composite hybrid pipe investigation studies had been increasingly popular and attracted many researchers because of its important applications in many fields, especially cooling water pipeline, aerospace, oxygen pipeline usage in hospitals, manufacturing power plants, biomaterials and other applications. Various sectors can utilize basalt like marine [1], ballistic warfare and impact [2,3]. The beneficial properties of basalt include its tensile strength and modulus. Basalt



has proved itself as a viable option since it is a natural product with minimum environmental contamination, has light weight and fits well within the costs of the processing and hence can be used in different ways [4].

Usually, the process that yields a hybrid novel composition involves combining two foreign materials which are placed within a host matrix. Since, the combination of two materials produces an end product which has better properties like ductility, elasticity, resistance against fire and decreased weight [5-7]. New combinations can be developed by this method. Polyethylene (PE) fibers were incorporated with carbon fibers in the framework of an epoxy matrix by Park and Jang [8] and a hybrid laminated composite material was produced. The scientists decided to use PE fibers for this study since it has good stiffness and is a strong fiber that can withstand high degrees of stretching. This experiment showed that the position at which the reinforcing fiber is placed is the determining factor of the mechanical strength possessed by the compound produced by the combination process. The developed compound had a higher degree of strength when the position of CF was at the outermost layer. These findings reinforced the need to develop fibers that are lightweight yet strong, but are also long lasting and do not increase the cost of the production process. Basalt fibers are used most commonly in the present scenario since they are inorganic in nature, have good mechanical strength, can withstand high temperature and function in the presence of chemicals, retain their stability in different environments, require simple processing steps and cause less environmental pollution. The flowing lava which is produced from basalt based molten volcano rock is a rich source of basalt fibers [1,9]. Basalt stands out in comparison to E glass in terms of tensile strength and ability to withstand compression and costs quite less than fibers of carbon origin [10-12].

Replacing E-glass fiber by natural fibers as suitable substitutes can be recycled and comparable like flax, hemp, kenaf and sisal as well as renewability, abundant and cheap with contributes their high toughness, easy chapping, low density, capable of neutrality with CO₂ and simplest fabrication procedure and maintenance [13]. Moreover the important request for reducing the need of petroleum derivatives products by nature and friendly replacement products is an interesting for many researchers and in developing. Subsequently, the investigations for the new products of natural fiber mechanical behavior have a great deal of attention for many researchers recently [14]. Lately, a step forward had been developed polymer composite material by natural fiber usage to avoid human dangerous from glass fiber [15].

So, basalt fibers are being explored as a viable option to act as a reinforcement compound in the development of hybrid composites or laminates [16]. There are many instances in the literature that show the use of basalt fibers as reinforcements in CFRP based composites. Lopresto et al.[17] compared plastic polymers reinforced with basalt fibers (BFRP) and plastics reinforced with glass fibers (GFRP) on the basis of Young's modulus, compressive strength and flexural behavior and their findings favored the use of basalt over glass. Manikandan et al. [18] also conducted a study which provided similar conclusion. Such a combination would not only be financially attractive, but would also be long lasting and weigh less, thus increasing the scope of basalt in the hybrid composite sector [19]. According to Carmisciano et al. [10] composites reinforced by basalt fibers [BWFRC] had higher shear strength and flexural modulus. The construction sector has made use of basalt fibers in the recent past and it has also been utilized in concrete materials as an external or internal reinforcement [20, 21, and 3]. Both tensile and flexural strength showed an increase of 16% when laminates made of basalt or epoxy TM were used, the tensile modulus would have an increment of 27% and flexural modulus would have an increment of 153% [22].

For easy and fast biaxial strength predicting method of the filament winding E-glass/epoxy tube is by using "netting analysis". This process was defined by a study of Hull and was extensively used throughout the primary progression of filament wound method [23]. It has been getting to give an equally rupture strength respectable approaches of composite tubes. This conventional approach and its simplicity may be the motives for its current use. Figure.1 presents the principal stresses are (σ_1 and σ_2), whereas the reference stresses are (σ_y, σ_x and τ_{xy}). $\sigma_y = \sigma_2 \sin^2 \theta$, $\sigma_x = \sigma_1 \cos^2 \theta$;

$\tau_{xy} = \sigma_1 (\sin \theta \cos \theta)$; if $\sigma_H / \sigma_A = 2$; and $\sigma_y = \sigma_H, \sigma_x = \sigma_A$; then, within pipes case of closed ended with thin walls, $\sigma_H / \sigma_A = (\sigma_1 \sin^2 \theta) / (\sigma_1 \cos^2 \theta)$, then it will equal to $(\tan^2 \theta = 2)$ to give $\theta = \sqrt{2} = 54.7^\circ$

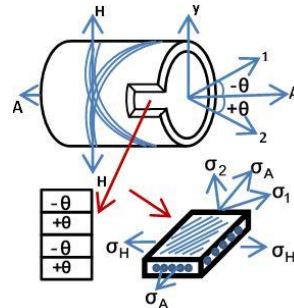


Figure 1. composite pipe Configuration {reference and principal axes (x, y) (1, 2) respectively}

The netting analyses can be used to predict the best angle that agrees with axial to hoop stress relative ratio. The best ratio of the glass/epoxy pipes is at twice of a hoop stresses to longitudinal stresses ratio, wound with $\pm 55^\circ$ orientation angle.

Xia et al [24] used an exact solution to study the different strain and stress in a tube that has many layers and has been pressurized internally; the basic presumption behind the model is that the tube has orthotropic for each layer. Later Xia et al [25] also used an exact technique in context of the sandwich tube with thick walls with internal pressure and thermo mechanical load and calculated the thermal stresses in such a system. Rosenow [26] developed an approach for calculating stresses and strain in case of composite cylinders composed of different layers in different angles varying from 15 degrees to 85 degrees. Accordingly, for thin layered composite tubes 55 degrees would be the best angle of orientation on the basis of comparison of actual and experimental data, but Xia et al [25] proposed 75 degrees as the best angle in case of internal pressure loading without axial.

The work done by Shultz's et al [27] showed that as far as thin pressure vessels that are manufactured from carbon fiber or epoxy are concerned the best winding angle was ± 50 degrees. Highton et al [28] conducted research on failure and concluded that in case of epoxy tubes reinforced with glass ± 75 degrees winding angle was sufficient to cause fracture under biaxial loads. Echold et al [29] has proposed the theory that it is not merely the anisotropic factors that dictate the chances of failure; it is also the type of raw materials used, the process of manufacturing and the testing conditions that play a very important role in deciding the failure limits. Carswell [30] has concluded that the leak pressure is directly proportional to resin flexibility. Spencer et al. [31] showed that when biaxial load was used to create a pressure and the axial negative strain that was used came out to be fewer than ± 35 degrees, then the maximum value of leak pressures was detected to be ± 55 degrees. The calculation of stresses and strain in the filament winding tube which were pressurized biaxially internal pressures and could work in different temperature was facilitated by the work of Bakaiyan et al [32]. Due to this work the structure of the pipe was pictured as an orthotropic cylinder form in 3 dimensions with reinforced layers with alternate pigment composition. The conventional designs are based on standard safety mechanisms that are based on non-predictable problems during manufacturing, loading or problems arising out of mechanical or material issues.

The work of Wang et al. [33] focused on developing an enhancement method for BFRP using hybridization and the design was structured in a manner that it was best suited for use in long span cable based bridge. According to the findings of the study, there was an increase in the mechanical strength, modulus and fatigue behavior, the increase was attributed to hybridization. Zhang et al [34] also conducted a similar study. Quartz content up to 20% of basalt make it with excellent mechanical properties [35]. With augmented requests for fiber hybridization of composite pipe, the mechanical behavior sound investigation knowledge subjected to internal pressure is being necessary; consequently this numerically analysis would inspect the mechanical performance for hybrid (basalt and Eglass) filament winding multilayer fiber $\pm 55^\circ$ reinforced epoxy subjected to internal pressure,

longitudinal and hoop tensile test load to verify the best hybrid structure among others. Also, compared with the pure wound $\pm 55^\circ$ Eglass and pure basalt fiber reinforced epoxy composite pipe to show the performance of hybridization over the conventional Eglass fiber reinforced epoxy and basalt fiber reinforced epoxy pipe.

2. Materials

In this numerical study the pipe profile and geometry used in the analysis can be shown in Figure 2. The five used materials were used, basalt/E-glass/basalt reinforced epoxy, E-glass/basalt/E-glass reinforced epoxy, hybrid (both of one E-glass strand and one basalt strand were wound altogether) reinforced epoxy, pure E-glass/epoxy and basalt/epoxy. All mentioned sample types were wound with the filament wound machine with three layers and 55° orientation angle of 2.5mm pipe thickness and infused with epoxy resin by the vacuum infusion process. Each sample dimensions followed the ASTM for each test that were subjected to. Three types of applied load were subjected to all mentioned sample types. The hoop and longitudinal tensile test and biaxial internal pressure test according to ASTM D2290[36], ASTM D2105[37] and ASTM D1599[38] respectively. The tubes were produced for experimentally tests, even though the investigation is numerical.

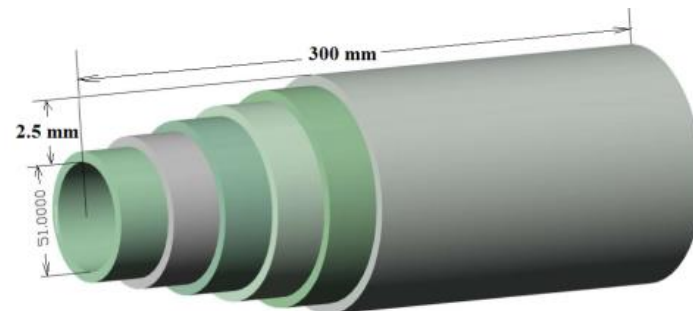


Figure 2. Dimensions and geometry of the composite tube.

According to ASTM D2584 [39] The volumetric fraction has been computed are by adopting ignition-loss of the cured strengthened resins, Following Jones [40-41]. The required parameters computed are by adopting the material mixture law (Equations.1). Table 1 presented the two fiber type's properties which were used for the different composite constituent fabrication.

Table 1. Fiber characteristics for components of composites structures

	E [GPa]	G [GPa]	ρ (kg/cm ³)	ν
Basalt	89.0	21.70	2.750	0.280
E-glass	72.4	29.70	2.540	0.330
Epoxy	3.60	1.440	1.20	0.280

Elements that were essential to simulate the hybrid tubes were: volume v in cm³, mass M in gm, volume fraction V and density ρ in g/cm³. The tube material mechanical properties that are computed are by adopting Eqns. 2-8 are: modulus of elasticity E , the density ρ , the Poisson ratio ν and shear moduli G . Table 2 displays the composite tube mechanical properties.

$$M_c = M_m + M_f ; v_m = M_m / \rho_m ; v_f = M_f / \rho_f ; v_c = v_m + v_f ; V_m = v_m / v_c ; V_f = v_f / v_c \quad (1)$$

$$\rho_c = V_f \cdot \rho_f + V_m \cdot \rho_m \quad (2)$$

$$E_{11} = E_f \cdot V_f + E_m \cdot V_m \quad (3)$$

$$\nu_{12} = \nu_{13} = \nu_f \cdot V_f + \nu_m \cdot V_m \quad (4)$$

$$E_{12} = (\xi \eta_c V_f + 1) / (1 - \eta_c V_f) ; \text{ where } \eta_c = \frac{(E_f / E_m) - 1}{(E_f / E_m) + \xi} ; \xi = 2 \text{ for } E_{12} \text{ computing} \quad (5)$$

$$G_{12} = \frac{1 + \xi \eta_g V_f}{1 - \eta_g V_f} ; \text{ where } \eta_g = \frac{(G_f / G_m) - 1}{(G_f / G_m) + \xi} ; \xi = 1 \text{ for } G_{12} \text{ computing} \quad (6)$$

$$G_f = E_f / 2(1 + \nu_f) ; \text{ and } G_m = E_m / 2(1 + \nu_m) ; \text{ assume } G_{12} = G_{13} . \quad (7)$$

$$\nu_{23} = \nu_f \cdot \nu_m / V_m \cdot \nu_f + V_f \cdot \nu_m \quad (8)$$

Table 2. Composite constituent material's characteristics

Composites	ρ [kg/m ³]	E_1 [GPa]	E_2 [GPa]	E_3 [GPa]	G_{12} [GPa]	G_{23} [GPa]	G_{13} [GPa]	ν_{12}	ν_{23}	ν_{13}
Eglass/Epo	2.54	45.8	10.1	10.1	3.46	3.46	3.46	0.308	0.31	0.308
Basalt/Epo	2.75	54.4	9.8	9.8	3.24	3.24	3.24	0.28	0.28	0.28
Hyb/Epoxy	2.645	50.2	9.99	9.99	3.35	3.35	3.35	0.29	0.29	0.29

3. A finite element simulation

Through utilizing a FEM-ANSYS V14 commercial software code, linearly and elastic composite properties investigation of the composite structure of the filament winding tube pressurized internally, axial tensile and hoop tensile test were implemented numerically. The hybrid of Eglass and Basalt fiber reinforced epoxy composite tube had been taken under consideration to be orthotropic. The fiber elastic property and ply angle were familiarized. The model with fine-meshed, linear 3D tetrahedral of thin wall thickness with 8 nodes were utilized for simulation for all load modes through divers of element numbers and node numbers for each load mode. For the internal pressure test mode, the element numbers were 416 and the nodes were 818, although for the hoop tensile testing, the elements were 4059 and the nodes were 16927, then for axial tensile testing the element numbers were 454 and the nodes were 465. The numerical analysis provided axial and hoop strain and stress for diverse fiber ply angle and for the three different types of hybrid composite selected material pipes. From the outcomes it can be assessed the behavior of the three different types of the novel hybrid basalt/E glass fiber reinforced epoxy to designate the optimal ply sequence among the three different types.

4. Results and discussions

The elastic and linear numerical investigations had been simulated utilizing three different modes of subsection load of biaxially pressurizing internally as well as longitudinal tensile and hoop tensile tests on three different kinds of composite hybrid stacking plies tubes of basalt/Eglass/basalt, Eglass/basalt/Eglass and hybrid contributed fibers of Eglass and basalt at the same time for the dry filament winding process assuming for all selected stacking hybrid plies of fiber materials wound with an angle of $\pm 55^\circ$ ply angles and six stacked layers. Figure.3 (a) displays the strain results contour of composite $\pm 55^\circ$ hybrid basalt/Eglass/basalt subjected to 18 MPa biaxial internally pressure. Hoop strain results contour can be shown in Figure.3 (b) for the subsection under hoop tensile load mode. According to ASTM D2105 standard that had been adopted so that there were no bend happened on the dogbone segment. Axial strain result contour shown in Figure.3 (c) under the subsection of axial tensile load mode.

Table 3. Shows the numerical results of longitudinal and hoop strains and stress against the diverse comparable three types of hybrids of basalt/Eglass/basalt, Eglass/basalt/Eglass and hybrid contributed fibers of Eglass as well as pure basalt and pure Eglass fiber reinforced epoxy tubes (a) under 18 MPa biaxial internally pressure, (b) under hoop tensile test and (c) under Longitudinal tensile test. The strain results of basalt/Eglass/basalt reinforced epoxy hybrid pipe type shows low differences in stress as much as strain under same internal pressure level. As well as the differences between the three different composite hybrid kinds for the simulated tube structures are because of their different stacking plies adhesive of fiber interface behavior.

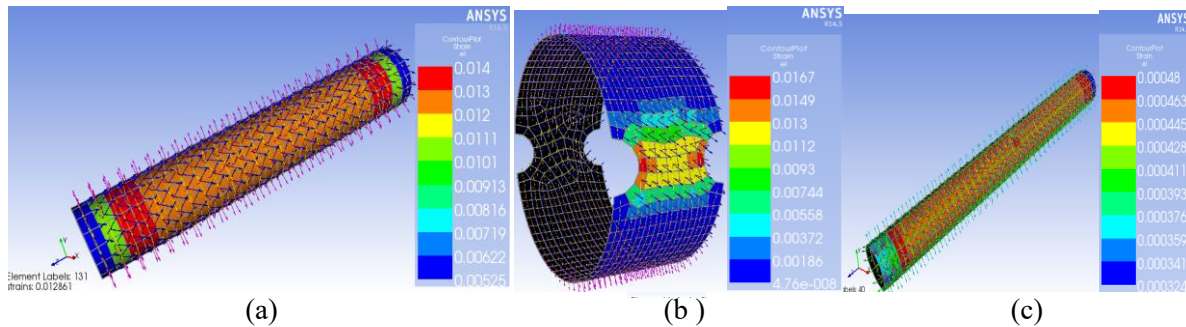


Figure 3. The contours of strain result for: (a) The result of hoop strain for $\pm 55^\circ$ basalt/Eglass/basalt type of composite hybrid pipe under 18 MPa biaxial internally pressure. (b) The Hoop strain of $\pm 55^\circ$ basalt/Eglass/basalt type of composite hybrid pipe under hoop tensile testing (c) Axial strain of $\pm 55^\circ$ basalt/Eglass/basalt type of composite hybrid pipe under longitudinal tensile testing

Table 3. Axial and hoop strain and stress for diverse pipe materials: (a) under 18 MPa biaxial internal pressure, (b) under 10918 N hoop tensile test and (c) under 3258 N Longitudinal tensile test

(a)					
Numerical results of different materials under const. internal pressure 18 MPa					
material type	Pr MPa	ϵ hoop	ϵ Long.	σ hoop MPa	σ Long MPa
3L Eglass 55	18	0.0134	-0.0082	178.03	89.8
3L Basalt 55	18	0.0132	-0.0089	178.3	89
3L BGB 55	18	0.012861	-0.0036	182.73	83
3L GBG 55	18	0.01297	-0.0038	193.8	85
3L HYBRID55	18	0.01317	-0.0021	194.23	87

(b)				
Numerical Hoop tensile test results, different Materials at selected const. load				
material type	ϵ_h	σ_h	Gauge.Length mm	Max.load
3L Eglass 55	0.0181	169	9.4	10918
3L Basalt 55	0.0177	178.46	9.4	10918
3L BGB 55	0.0167	184.427	9.4	10918
3L GBG 55	0.01897	173.448	9.4	10918
3L HYBRID 55	0.0204	177.21	9.4	10918

(c)				
Numerical longitudinal tens test results of different. materials at const. load				
material type	ϵ_L	σ_L	A	Max.load
3L Eglass 55	0.000486	9	480	3258
3L Basalt 55	0.000467	8.9	480	3258
3L BGB 55	0.000458	9.46	480	3258
3L GBG 55	0.000463	9.42	480	3258
3L HYBRID 55	0.000466	9.07	480	3258

Form the results, it can be detected that when the stacking plies is diverse within the subjection for the same level of internal pressure value, the value of hoop strain 0.012861 mm/mm occurred for $\pm 55^\circ$ with 3 layers basalt/Eglass/basalt hybrid pipe type is lower than the rest. The hoop tensile test results indicated that the hoop strain and for $\pm 55^\circ$ with 3 layers basalt/Eglass/basalt hybrid pipe type equal to 0.0167 mm/mm under the same hoop tensile load is lower than the rest. While for longitudinal tensile test the longitudinal strain for $\pm 55^\circ$ with 3 layers basalt/Eglass/basalt hybrid pipe type equal to 0.000458 mm/mm under the same longitudinal tensile load is lower than the rest. The results in the lower strain values for the pure of basalt and Eglass with the three hybrid types within the same load condition for the three different test modes subjection indicate that the hybrid shows optimal performances than pure of basat and Eglass, also among the three hybrid pipe type, the results indicated that stacking of basalt/Eglass/basalt hybrid type shows better performance more than the rest.

And the basalt/Eglass/basalt fiber reinforced epoxy hybrid pipe can carry more internal, hoop and longitudinal tensile load earlier the tube fails. For the basalt/Eglass/basalt tube, a lower strain has been detected due to the strength of basalt fiber that has a greater elastic modulus more than Eglass. The property of an adhesive for Eglass fiber enhances the stacking for the plies interface when it occupies the middle layer among the basalt plies which will be result in better mechanical behavior. Figure.4 shows the effect of different stacking plies fiber material on the hoop strain (a) under a biaxial of an internal pressure value equal to 18.0 MPa, (b) under the hoop tensile load of 10918.0 N and (c) under a axial tensile load of 3258.0 N. It can be detected that the lower hoop strains recorded value with basalt/Eglass/basalt hybrid type. A lesser axial strains values were noted for the basalt/Eglass/basalt hybrid type also.

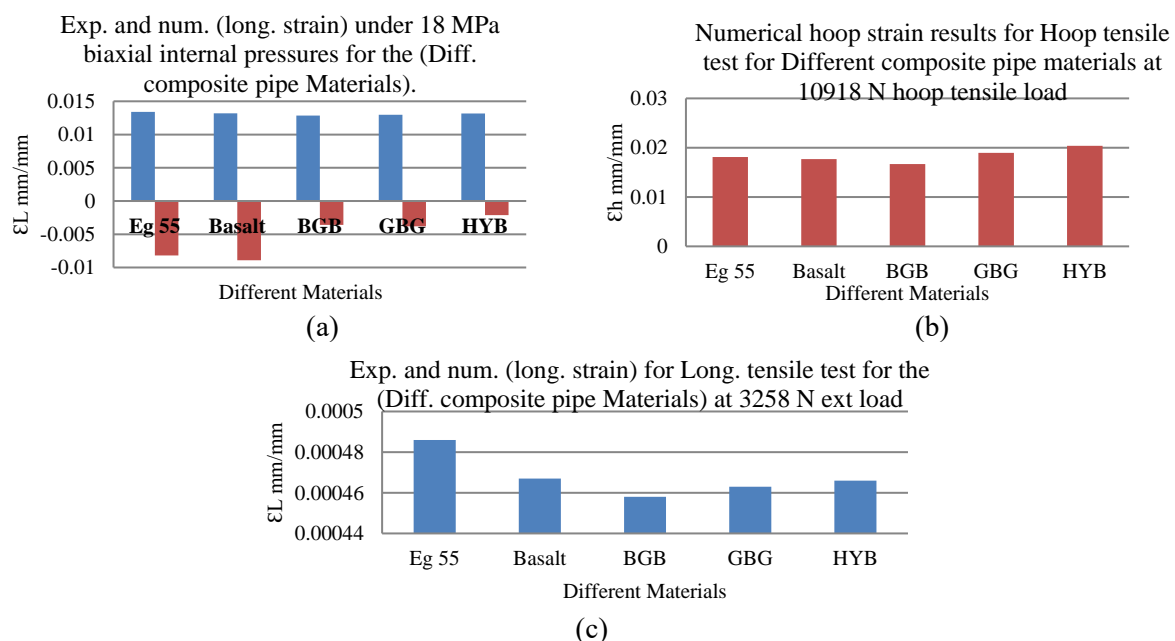


Figure 4. Effect different stacking plies fiber material on hoop and longitudinal strains (a) under 18 MPa biaxial internal pressures, (b) under 10918 N hoop tensile test and (c) under 3258 N axial tensile test

5. Conclusion

In this numerically elastic and linear stress and strain investigates of composite pipes of hybrid of Eglass and basalt fiber reinforced epoxy with different stacking sequence as well as the pure of Eglass and the pure of basalt ± 55 filament wound hollow cylinder were carried out under the subjection of internal pressures as well as longitudinal and hoop tensile test. A designated model of finite element was recognized to evaluate the performance for a new structure of hybrid of basalt and Eglass reinforced epoxy over the pure of Eglass/epoxy and the pure of basalt/epoxy composite tube. Also to show the optimal stacking plies among all of hybrid different plies stacking composite pipe that has been utilized within different application. From the analysis results it concluded that:

- The basalt/epoxy showed better mechanical behavior than Eglass/epoxy composite pipe.
- Basalt/epoxy filament wound composite tube can be replaced by Eglass/epoxy tube within many healthy pressurized pipelines applications successfully as a better replacement with good mechanical performances than Eglass/epoxy.
- The hybrid basalt fiber and Eglass fiber reinforced composite pipe structure showed enhanced mechanical performances than the pure of each one.
- Basalt/Eglass/basalt fiber reinforced epoxy hybrid composite pipe has been seen as an optimal stacking plies among the three different stacking plies of hybrid composite pipe.

Based on this study, hybridization of basalt with Eglass fiber augmented the mechanical behavior, increased the mechanical strength, modulus and fatigue behavior, made costs less, excellent and has desired mechanical properties.

Acknowledgment

A gratefully acknowledged has been appreciated for the supporting of Universiti Teknologi Malaysia through the research grant No. (Q.J130000.2524.07H19).

References

- [1] Fiore V, Bella GD, Valenza A. Glass-basalt/epoxy hybrid composites for marine applications. *Mater Des* 2011;32(4):2091–9.
- [2] Dehkordi MT, Nosraty H, Shokrieh MM, Minak G, Ghelli D. Low velocity impact properties of intra-ply hybrid composites based on basalt and nylon woven fabrics. *Mater Des* 2010;31(8):3835–44.
- [3] Sarasini F, Tirillo J, Valente M, Ferrante L, Cioffi S, Iannace S, et al. Hybrid composites based on aramid and basalt woven fabrics: impact damage modes and residual properties. *Mater Des* 2013;49:290–302.
- [4] Saravanan D. Spinning the rocks – basalt fibres. *J Inst Eng India – Part TX* 2006;86:39–45.
- [5] Ary Subagia IDG, Kim Y, Tijing LD, Kim CS, Shon HK. Effect of stacking sequence on the flexural properties of hybrid composites reinforced with carbon and basalt fibers. *Compos Part B – Eng* 2014;58:251–8.
- [6] Dehkordi MT, Nosraty H, Shokrieh MM, Minak G, Ghelli D. Low velocity impact properties of intra-ply hybrid composites based on basalt and nylon woven fabrics. *Mater Des* 2010;31(8):3835–44.
- [7] Han SH, Oh HJ, Lee HC, Su SS. The effect of post-processing of carbon fibers on the mechanical properties of epoxy-based composites. *Compos Part B – Eng* 2012;45(1):172–7.
- [8] Park R, Jang J. Performance improvement of carbon fiber polyethylene fiber hybrid composites. *J Mater Sci* 1999;34(12):2903–10.
- [9] Banibayat P, Patnaik A. Variability of mechanical properties of basalt fiber reinforced polymer bars manufactured by wet-layup method. *Mater Des* 2014;56:898–906.
- [10] Carmisciano S, Rosa IMD, Sarasini F, Tamburrano A, Valente M. Basalt woven fiber reinforced vinylester composites: flexural and electrical properties. *Mater Des* 2011;32:337–42.
- [11] Liu Q, Shaw MT, Parnas RS, McDonnell AM. Investigation of basalt fiber composite mechanical properties for applications in transportation. *Polym Compos* 2006;27(1):41–8.
- [12] Szabo JS, Czigany T. Static fracture and failure behavior of aligned discontinuous mineral fiber reinforced polypropylene composites. *Polym Test* 2003;22(6):711–9.
- [13] Mohanty AK., Misra M., Hinrichsen G., Biofibres biodegradable polymers and biocomposites: An overview, *Macromol Mater Eng.* 276/277 (2000) 1–24.
- [14] Mohanty AK., Drzal LT., Misra M., Novel hybrid coupling agent as an adhesion promoter in natural fiber reinforced powder polypropylene composites, *J Mater Sci Lett.* 21 (2002)1885–1888.
- [15] Misri S., Leman Z., Sapuan S., and Ishak M., Mechanical properties and fabrication of small boat using woven glass/sugar palm fibres reinforced unsaturated polyester hybrid composite, *IOP Conference Series: Materials Science and Engineering.* 11 (2010) 12-15.
- [16] Das S. The cost of automotive polymer composites: a review and assessment of DOE's lightweight materials composites research. Oak Ridge National Laboratory; 2001. p. 1–49.
- [17] Lopresto V, Leone C, Iorio ID. Mechanical characterisation of basalt fibre reinforced plastic. *Compos Part B – Eng* 2011;42(4):717–23.
- [18] Manikandan V, Jappes JTW, Kumar SMS, Amuthakkannan P. Investigation of the effect of surface modifications on the mechanical properties of basalt fibre reinforced polymer composites. *Compos Part B – Eng* 2012;43(2):812–8.

- [19] Artemenko SE, Kadykova YA. Polymer composite materials based on carbon, basalt and glass fibres. *Fibre Chem* 2008;40(1):37–9.
- [20] Larrinaga P, Chastre C, Biscaia HC, San-Jose JT. Experimental and numerical modeling of basalt textile reinforced mortar behavior under uniaxial tensile stress. *Mater Des* 2014;55:66–74.
- [21] Sim J, Park C, Moon DY. Characteristics of basalt fiber as a strengthening material for concrete structures. *Compos Part B – Eng* 2005;36(6–7):504–12.
- [22] Ary Subagia IDG, Tijing LD, Kim Y, Kim CS, Vista FG-IV, Shon HK. Mechanical performance of multiscale basalt fiber–epoxy laminates containing tourmaline micro/nano particles. *Compos Part B – Eng* 2014;58:611–7.
- [23] Foulk JD., Akin DE., Dodd RB., New low cost flax fibers for composites. SAE 2000 World Congress. (2000) 6–9.
- [24] Xia M., Takayanagi H., and Kemmochi K., Analysis of multi-layered filament-wound composite pipes under internal pressure, *Composite Structures*. 53 (2001) 483-491.
- [25] Xia M., Kemmochi K., and Takayanagi H., Analysis of filament-wound fiber-reinforced sandwich pipe under combined internal pressure and thermomechanical loading, *Composite structures*. 51(2001) 273-283.
- [26] Rosenow M. W. K., Wind angle effects in glass fibre-reinforced polyester filament wound pipes, *Composites*. 15(1984), 144-152.
- [27] Shultz, M., and Smith, L. V., Optimal fiber orientation for fiber reinforced pressure vessels, *Applied Mechanics*. (2004) 7-10.
- [28] Highton, J., Adeoye, A. B., and Soden, P. D., Fracture stresses for ± 75 degree filament wound grp tubes under biaxial loads, *The Journal of Strain Analysis for Engineering Design*. 20(1985)139-150.
- [29] Eckold, G. C., D. Leadbetter, Lamination theory in the prediction of failure envelopes for filament wound materials subjected to biaxial loading, *Composites*. 9 (1978) 243-246.
- [30] Carswell, W. S., An atlas of polymer damage: Lothar Engel, Herman Klingele, Gottfried W. Ehrenstein and Helmut Schaper (Eds.), Wolfe Science Books, *International Journal of Fatigue* 3 (1981) 218.
- [31] Spencer, B. and D. Hull, Effect of winding angle on the failure of filament wound pipe. *Composites*, 9 (1978) 263-271.
- [32] Bakaiyan H., Hosseini H., and Ameri E., Analysis of multi-layered filament-wound composite pipes under combined internal pressure and thermomechanical loading with thermal variations, *Composite Structures*. 88 (2009) 532–541.
- [33] Wang X, Wu Z, Wu G, Zhu H, Zen F. Enhancement of basalt FRP by hybridization for long-span cable-stayed bridge. *Compos Part B – Eng* 2013;44(1):184–92.
- [34] Zhang Y, Yu C, Chu PK, Lv F, Zhang C, Ji J, et al. Mechanical and thermal properties of basalt fiber reinforced poly(butylene succinate) composites. *Mater Chem Phys* 2012;133:845–9.
- [35] Kunel S., A short review on Basalt fiber, *International Journal of Textile Science*. 1 (2012) 19-28.
- [36] ASTM D2290-00, Standard Test Method for Apparent Hoop Tensile Strength of Plastic or Reinforced Plastic Pipe by Split Disk Method, ASTM International, West Conshohocken, PA, (2000), www.astm.org.
- [37] ASTM D2105-01, Standard Test Method for Longitudinal Tensile Properties of “Fiberglass” (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Tube, ASTM International, West Conshohocken, PA, (2014), www.astm.org.
- [38] ASTM D1599-14, Standard Test Method for Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing, and Fittings, ASTM International, West Conshohocken, PA, (2014), www.astm.org.
- [39] ASTM D2584-11, Standard Test Method for Ignition Loss of Cured Reinforced Resins, ASTM International, West Conshohocken, PA, (2011), www.astm.org.
- [40] Jones, M.L.C. and D. Hull, Microscopy of failure mechanisms in filament-wound pipe, *Journal of Materials Science*. 14 (1979) 165-174.
- [41] Almula, T. A. D. M. S., M. Y. Yahya, et al., Mechanical Behavior of Functionally Graded Sandwich Hollow Cylinders under Internal Pressure, *Advanced Materials Research* 845 (2014) 360-366