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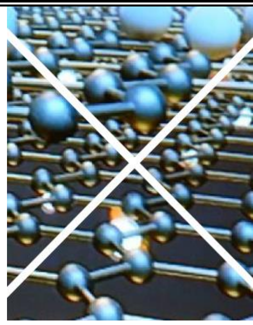

THE INFLUENCE OF FIBER ORIENTATION ANGLE ON HOOP TENSILE CHARACTERISTICS OF BASALT FIBER REINFORCED COMPOSITE PIPES

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Abstract

This paper aimed to investigate the effect of fiber orientation angle on hoop tensile properties of basalt/epoxy fiber reinforced composites (BFRP). The filament wound ring-shaped samples having six layers were prepared with three different fiber orientations (±40º, ±55º and ±70º) and subjected to tensile loading in hoop direction with respect to the split disk method. Furthermore, failure modes and fracture mechanisms of damaged samples were examined to establish the influence of fiber orientation angles. The results showed that fiber orientation had significant influences on the hoop tensile properties of BFRP samples. It was seen that remarkable increases were achieved in apparent hoop tensile strength and modulus for higher fiber orientation angles. The samples with ±70º fiber orientation angle exhibiting 411.36 MPa strength and 21.06 GPa modulus values showed 5.3 and 4.8 times of the sample with ±40º (77.74 MPa and 4.39 GPa) for apparent hoop tensile strength and modulus, respectively. This was attributed to more load bearing capacity as a result of fiber alignment along the load axis at higher fiber orientations. Matrix cracking, delamination and fiber debonding were seen as common failure modes for all samples and fiber pull-outs were observed for samples with higher fiber orientations.

Keyword: Basalt fiber, Fiber orientation, Hoop tensile, Filament winding, Composite pipe

1. Introduction

The use of eco-friendly materials in the field of polymer composites is getting attention from researchers in the scientific world due to sustainable life policies to provide a safe world in the future.

These kinds of materials providing the opportunity to eliminate the negative impacts of consumer products are a great choice to meet requirements as an alternative material. Hemp, jute, kenaf, basalt are some of the natural fibers that recently utilized in polymer matrix fiber reinforced composites within the environmental sustainability focused on natural resources. Among them, with its remarkable features such as high resistance to chemical attacks, biological stability, non-flammable structure, high-temperature resistance, and low water absorption, basalt has become one of the promising fiber for various industrial applications in the last years [1].

Basalt obtained from volcanic rocks formed by molten lavas has easy availability all over the world. It is a non-hazardous material and has no toxic impurities [2]. Recently, several studies owing to basalt fiber in polymer composite laminates are present in the literature due to its popularity [3-7]. Bulut [8] has investigated the effects of nanographene particles on the mechanical behaviors of basalt fiber reinforced composite laminates. It was reported that 0.1 wt.% nanographene addition providing better bonding ability at the interphase between nanoparticle-epoxy-basalt fiber interactions significantly increased the behaviors of tensile, flexural and impact resistance of the laminates. Özbek et al. [9] has examined the influences of fiber orientation angle on the Charpy impact behaviors of basalt fiber reinforced composites. Higher orientation angle resulted with remarkable increases in impact properties. The samples having (45/-45) orientation showed the best values as 3.07 J and 34.82 kJ/m2 for energy and toughness, respectively. However, limited studies related to basalt fiber application in composite pipes are seen in the literature because it is a relatively new subject in filament winding area [10-11]. Demirci et al. [12] investigated the low velocity impact behaviors of filament wound arc-shaped composite samples. The basalt and glass fiber reinforced samples at different notch-depth ratios were tested on a Charpy impact test machine. Glass samples showed more dominant delamination failures than basalt samples. Roslan et al. [13] performed a study on the energy absorption capabilities of basalt sandwich composite cylinders having foam in core. The fiber cracking, pipe’s wall folding and crumping were observed as failure modes in a progressive manner.

Determination of hoop tensile behavior of a material plays an important role in engineering applications that exposed to high hoop stresses such as pressurized pipes [14]. Split disk method which presents a practical and simple way for making reliable evaluations on hoop tensile properties of materials is a well-known, and popular technique [15]. The apparent hoop tensile strength instead of true one is achieved in this technique due to bending moment imposition to ring-shaped samples. Several studies devoted to determine hoop tensile characteristics of the samples using split disk application are present in the literature [16-19]. Vacher et al. [20] applied the split disk technique on the glass/epoxy and carbon/epoxy fiber reinforced composite tubes fabricated by filament winding method. The strength and modulus properties of the pipe samples in fiber direction were evaluated in experimental studies. Furthermore, failure analysis and the results were compared with the Puck’s failure theory. Kaynak et al. [16] performed an experimental study on the apparent hoop tensile characteristics of the carbon and glass fiber reinforced samples having different fiber reinforcement, resin type, winding angles.

The samples were fabricated via wet filament winding technique and tested in accordance with the split disk method. It was stated that carbon fiber usage has 60% higher performance compared to glass fibers, and no significant effects were reported for different resin applications. Lapena et al. [21] carried out a comparative study on the mechanical characterization of basalt fiber reinforced and glass fiber reinforced composite tubes. Basalt fiber reinforced tubes showed 45% and 11% higher results in terms of apparent hoop tensile and interlaminar shear strength, respectively, due to less debonding behavior of basalt fiber in fracture characteristics.

The current work deals with the influence of fiber orientation angle on the hoop tensile characteristics of basalt/epoxy fiber reinforced composite pipes and aims to contribute the literature to shed light on future research studies especially for industrial applications. The filament wound pipe samples having six layers were fabricated with different fiber orientation angles (±40º, ±55º and ±70º) and tested in accordance with the split disk method. Also, detailed examinations on the damaged sections of the specimens have been performed to understand failure modes and fracture mechanisms.

2. Materials and Methods

2.1. Materials

The basalt roving fiber with a linear density of 2400tex and 13 μm filament diameter procured from Tila Kompozit A.Ş., Turkey, was used as reinforcement of the composite pipes. For the preparation of the matrix phase, the epoxy (EPIKOTE MGS L160) and hardener (EPIKURE Curing Agent MGS H260S) supplied from Dost Kimya Company, Turkey, were mixed with a mechanical stirrer in the stoichiometric weight ratio of 100:36, respectively. The physical and mechanical properties of those of raw materials were given in Table 1.

Table 1. The physical and mechanical properties of raw materials

Material	**Tensile strength (MPa)**	**Tensile modulus (GPa)**	**Elongation at break (%)**	**Specific density (g/cm^3)**
Basalt fiber	3200	90	3.1	2.78
Epoxy (neat)	70-80	3.2-3.5	5.0-6.5	1.18-1.20

2.2. Sample Preparations

Basalt fiber reinforced composite pipes were fabricated by the filament winding method shown in Figure 1. The filament winding is one of the most efficient technique to obtain composite pipes due to its advantages such as low cost production, use of continuous fiber, providing different design parameters. The technique is mainly depended on the relationship between axes velocities and fiber orientation angle as indicated in Eqn. (1).

$$\tan\alpha = (2\pi R N_m)/(60 V_c) \quad (1)$$

where R represents the mandrel radius, N_m and V_c are the speeds of the rotational mandrel and translational carriage, respectively.

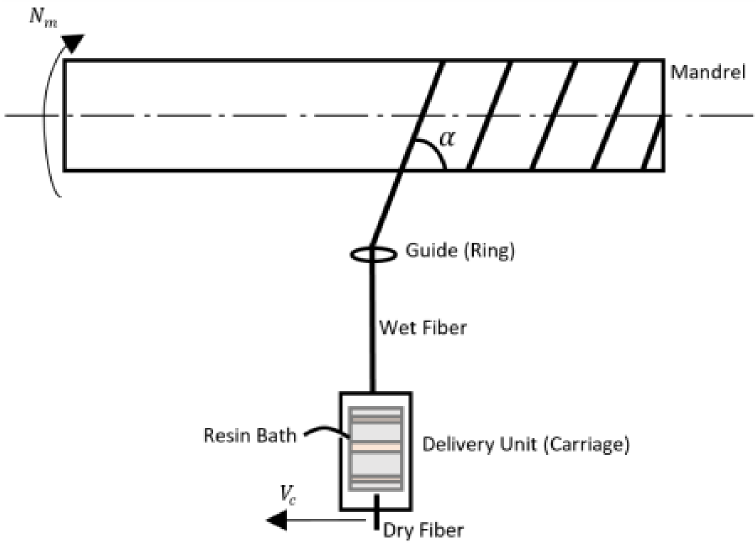


Figure 1. Schematic illustration of the filament winding technique [22]

The fabrication of composite pipes can be classified into three distinct steps as preliminary preparations, winding process and post-processing. In the first stage, the application of release wax and release agent film on the mandrel was performed to provide easy extraction of the pipes after the manufacturing process. Afterward, glass wool was wrapped to supply smooth surface quality on inner surface of the pipes. Then, the prepared resin mixture was deposited into the resin bath which has rollers to guide fiber tensions. Then, winding process was performed by the derived motion codes. After total of six layers were wrapped on mandrel, the pipes were left to initial curing process which takes 24 hours at room temperature. Following the initial curing, the pipes rotated along longitudinal axis were exposed to air blown at 40ºC for 2 hours to perform post-curing. The inner diameter of the pipes was measured as 46.3 mm within the tolerance of ±0.2 mm.

Ignition loss experiments in accordance with ASTM D 2584 standard [23] were performed to determine fiber mass fractions of the samples. After measuring the initial mass of samples, they were exposed to the burning process at 650ºC temperature for 1.5 hours in a high capacity furnace to find the final mass of samples which specifies the only fiber weight information. Then, fiber mass fractions of each sample were calculated by applying the Eqn. (2);

$$\%wt = 100(W_2/ W_1) \quad (2)$$

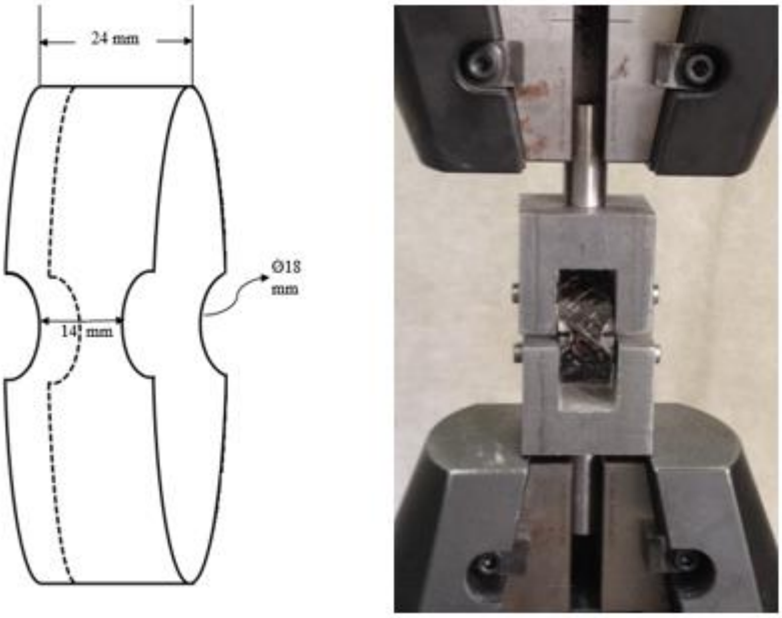
where W_1 and W_2 represent the weight of samples before and after burning, respectively. The naming, thickness and fiber mass fraction information of the BFRP samples were given in Table 2.

Table 2. The naming, thickness and fiber mass fractions of the BFRP samples

Fiber Orientation Angle (º)	Naming	Thickness (mm)	Fiber Mass Fraction (wt.%)
40	B40	4.00	59.95
55	B55	3.90	63.40
70	B70	3.85	66.01

2.2. Split Disk Experiments

The split disk method was used to determine the hoop tensile behaviors of BFRP samples. The ring-shaped specimens for tensile experiments, shown in Figure 2(a), were prepared according to ASTM D 2290 standard [24] which explains how to find hoop tensile characteristics of composite pipes. To minimize bending imposition occurring on the ring-shaped samples, semi-cylindrical metal based structures were placed inside the samples. All tests were conducted on a computerized servo controlled universal testing machine (Shimadzu AG-X Series) having 300 kN loading capacity as shown in Figure 2(b).



a) b)

Figure 2. Hoop tensile experiments; a) The geometry of the ring-shaped sample, b) Split disk test

The apparent hoop tensile strength, σ_a of the BFRP samples are calculated by Eqn. (3);

$$\sigma_a = P/2A \quad (3)$$

where P and A are the maximum load and the area of reduced section. Hoop tensile modulus of elasticity, E_m is obtained from the following equation [25];

$$E_m = P(0.1257 r_{mean}^3) / ((\Delta y) w t^3) \quad (4)$$

where r_{mean}, w and t represent the mean radius, width and thickness of the BFRP samples. Δy is the displacement value of the sample at maximum load. Four numbers of samples for each configuration were loaded in tensile direction at a cross-head speed of 5 mm/min. The example images of samples with different fiber orientation angles were given in Figure 3.

Figure 3. The BFRP ring-shaped samples for split disk experiments

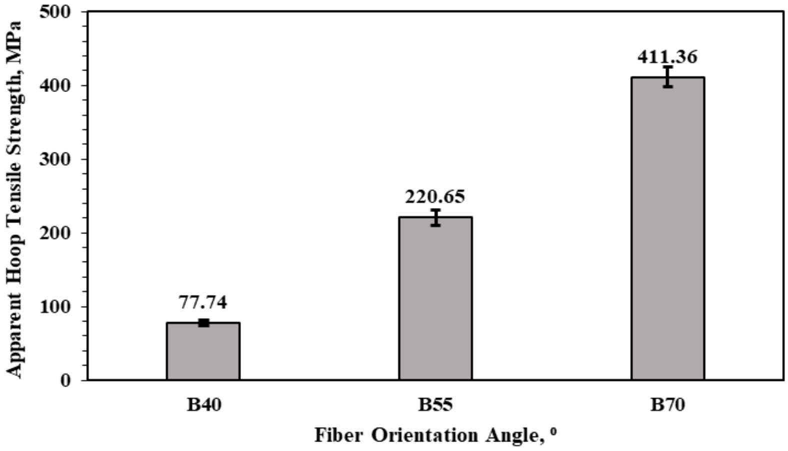
3. Results and Discussion

The apparent hoop tensile strength and modulus values of the BFRP samples according to different fiber orientation angles were exhibited in Figure 4(a) and 4(b), respectively. The B70 sample was exhibited maximum apparent hoop tensile strength as 411.36 MPa which was 2.84 and 5.3 times of B55 (220.65 MPa) and B40 (77.74 MPa) samples, respectively. The highest apparent hoop tensile modulus was also provided by B70 samples as 21.06 GPa which is approximately 1.42 and 4.80 times of hoop tensile modulus of B55 (14.79 MPa) and B70 (4.39 MPa) samples, respectively. Thus, it was clearly seen that higher fiber orientation angle had positive influences on

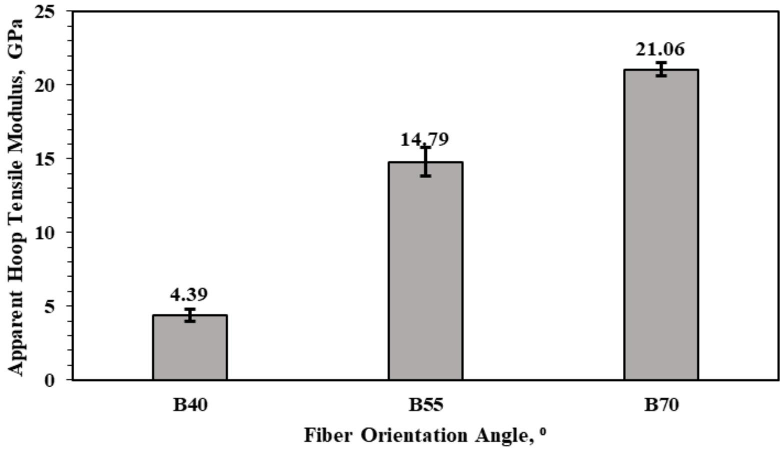
The load-displacement responses of BFRP samples for different fiber orientation angles were given in Figure 5. The steep rise in strength for an equal intervals of displacement can be seen for B70 samples. However, B40 samples showed more ductile behavior because of fiber effect was less in small orientation angles. It can be said that the load bearing capability of samples was increased when the fiber orientation was higher. This situation resulted with the higher load bearing capacity as a result of

the samples. This can be attributed to more load bearing capacity as a result of fiber alignment along the load axis at higher fiber orientations. Similar findings are also seen in the literature [26-27]. Kaynak et al. [16] reported the much higher values in hoop tensile strength and hoop tensile modulus values when winding angle was higher. It was also stated that winding angle is a major variable in composite pipes and tensile characteristics of filament wound composite strongly depend on it. Furthermore, Naseva et al. [28] stated that the maximum values for tensile strength were obtained from higher winding angles, examining the effect of winding angle on the glass fiber reinforced composite pipes subjected to hoop tensile loading.

the more effective contribution of fiber reinforcements against tensile loads when fiber was approaching to load direction as reported in Almeida’s study [29]. Furthermore, Zhu et al. [30] declared that reduction in load bearing capacity is related to increasing of distance between fiber alignment and loading direction in a study devoted to the crushing behaviors of carbon fiber reinforced composite tubes fabricated by filament winding technique.



a)



b)

Figure 4. BFRP samples; a) Apparent hoop tensile strength, b) Apparent hoop tensile modulus

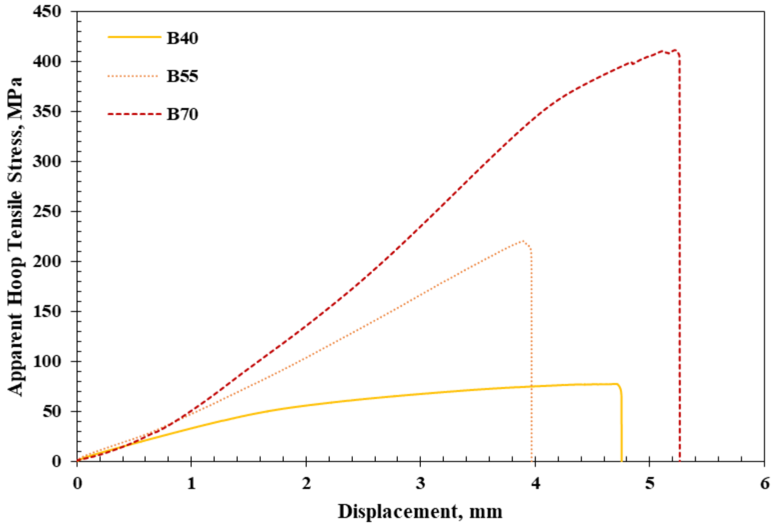


Figure 5. The load-displacement response of the BFRP samples

The macro views of the damaged samples were presented in Figure 6. As a result of reduction in load bearing capability at circumferential direction caused by reduction in stiffness of samples, the separation between layers (delamination) was seen as interlaminar damages for smaller fiber orientations [31]. Also, B40 samples showed fiber debonding failures due to the formation of high-stress concentrations between layers. However, increases in fiber orientation angle were resulted with more catastrophic failures due to higher load bearing. Even though delamination was seen as a major failure mode, remarkable fiber pull out was also observed at higher fiber orientations. Shortly, it can be stated that failure modes were seen as matrix cracking, delamination, fiber debonding for all samples, and finally fiber pull outs except for B40 samples.

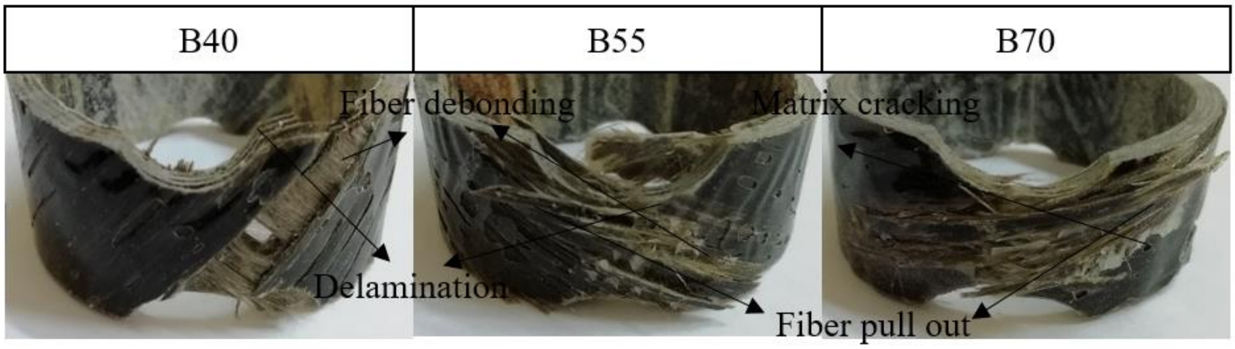


Figure 6. Failure modes of the BFRP ring-shaped samples

4. Conclusions

In this study, the effects of fiber orientation angle on the hoop tensile behaviors of basalt fiber reinforced composite pipes were investigated. The ring-shaped samples fabricated by filament winding technique were prepared with different fiber orientation angles (±(40º), ±(55º) and (±70º)) were exposed to hoop tensile loading in accordance with split disk method. According to the results, BFRP samples with ±70º fiber orientation angle exhibited the highest apparent hoop tensile strength and modulus having the values of 411.36 MPa and 21.06 GPa, respectively. It was 5.3 and 4.8 times of B40 sample strength and modulus. Furthermore, brittle characteristics of samples were increased in a higher fiber orientation angle. Matrix cracking, delamination and fiber debonding failures were seen for all samples and fiber pull outs failures for higher fiber orientated samples. Higher fiber orientation angles providing a more effective contribution of fibers that resulted with the increased brittle behaviors in the application had better tensile characteristics in terms of apparent hoop tensile strength, modulus and failure modes. The results obtained from this study showed that the fiber orientation angle was a crucial parameter that directly affects the tensile characteristics of BFRP samples.

Acknowledgements

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References

1. Bozkurt, ÖY, Hybridization effects on tensile and bending behavior of aramid/basalt fiber reinforced epoxy composites, Polymer Composites, 2017, 38(6), 1144-1150.

2. Jamshaid, H, Basalt fiber and its applications, Journal of Textile Engineering & Fashion Technology, 2017, 1(6), 254-255.
3. Bozkurt, ÖY, Bulut, M, Özbek, Ö, Effect of fibre orientations on damping and vibration characteristics of basalt epoxy composite laminates. In Proceedings of the World Congress on Civil, Structural, and Environmental Engineering (CSEE'16), 2016.
4. Li, W, Xu, J, Mechanical properties of basalt fiber reinforced geopolymeric concrete under impact loading, Materials Science and Engineering: A, 2009, 505(1-2), 178-186.
5. Banibayat, P, Patnaik, A, Variability of mechanical properties of basalt fiber reinforced polymer bars manufactured by wet-layup method, Materials & Design (1980-2015), 2014, 56, 898-906.
6. Özbek, Ö, Bozkurt, ÖY, Erkliğ, A, Effect of glass fiber hybridization on low velocity impact behaviors of basalt fiber reinforced composite laminates, The International Journal of Materials and Engineering Technology, 2020, 3(1), 21-29.
7. Bulut, M, Mechanical characterization of Basalt/epoxy composite laminates containing graphene nanopellets, Composites Part B: Engineering, 2017, 122, 71-78.
8. Erkliğ, A, Doğan, NF, Nanographene inclusion effect on the mechanical and low velocity impact response of glass/basalt reinforced epoxy hybrid nanocomposites. Journal of the Brazilian Society of Mechanical Sciences and Engineering, 2020, 42(2), 83.
9. Özbek, Ö, Bozkurt, ÖY, Erkliğ, A, Low velocity impact behaviors of basalt/epoxy reinforced composite laminates with different fiber orientations, Turkish Journal of Engineering, 2020, 4(4), 197-202.
10. Özbek, Ö, Bozkurt, ÖY, Erkliğ, A, An experimental study on intraply fiber hybridization of filament wound composite pipes subjected to quasi-static compression loading, Polymer Testing, 2019, 79, 106082.
11. Demirci, MT, Low velocity impact and fracture characterization of SiO2 nanoparticles filled basalt fiber reinforced composite tubes, Journal of Composite Materials, 2020, 0021998320915952.
12. Demirci, MT, Tarakçıoğlu, N, Avcı, A, Erkendirci, ÖF, Fracture toughness of filament wound BFR and GFR arc shaped specimens with Charpy impact test method, Composites Part B: Engineering, 2014, 66, 7-14.
13. Roslan, MN, Yahya, MY, Ahmad, Z, Abdul Rashid, AH, Wang, WX, Energy absorption capacity of basalt sandwich composite cylinder subjected to axial compression loadings, In Materials Science Forum (Vol. 917, pp. 7-11). Trans Tech Publications Ltd, 2018.
14. Özbek, Ö, & Bozkurt, ÖY, Hoop tensile and compression behavior of glass-carbon intraply hybrid fiber reinforced filament wound composite pipes, Materials Testing, 2019, 61(8), 763-769.

15. Wang, H, Bouchard, R, Eagleson, R, Martin, P, Tyson, WR, Ring hoop tension test (RHTT): A test for transverse tensile properties of tubular materials, Journal of Testing and Evaluation, 2002, 30(5), 382-391.
16. Kaynak, C, Erdiller, ES, Parnas, L, Senel, F, Use of split-disk tests for the process parameters of filament wound epoxy composite tubes, Polymer testing, 2005, 24(5), 648-655.
17. Srebrenkoska, V, Risteska, S, Mijajlovikj, M,. Thermal stability and hoop tensile properties of glass fiber composite pipes, International Journal of Engineering Research & Technology (IJERT), 2015, 4(12), 297-302.
18. Rafiee, R, Apparent hoop tensile strength prediction of glass fiber-reinforced polyester pipes, Journal of composite materials, 2013, 47(11), 1377-1386.
19. Chen, JF, Li, SQ, Bisby, LA, Ai, J, FRP rupture strains in the split-disk test. Composites Part B: Engineering, 2011, 42(4), 962-972.
20. Perillo, G., Vacher, R., Grytten, F., Sørbø, S., & Delhaye, V. (2014). Material characterisation and failure envelope evaluation of filament wound GFRP and CFRP composite tubes, Polymer testing, 40, 54-62.
21. Lapena, MH, Marinucci, G, Mechanical characterization of basalt and glass fiber epoxy composite tube, Materials Research, 2018, 21(1).
22. Özbek, Ö, Bozkurt, ÖY, The Influence of Fiber Orientation on Crashworthiness Behavior of Carbon Fiber Reinforced Composite Pipes, European Journal of Engineering Science and Technology, 2019, 2(3), 53-63.
23. ASTM D2584, Standard test method for ignition loss of cured reinforced resins. In American Society for Testing and Materials (Vol. 100), 2002.
24. ASTM, A, D2290-00: Standard Test Method for Apparent Hoop Tensile Strength of Plastic or Reinforced Plastic Pipe by Split Disk Method 2000. ASTM: West Conshohocken, PA, USA, 2000.
25. Kinna, MA, NOL Ring Test Methods, Naval Ordnance Lab White Oak MD, 1964.
26. Soden, PD, Kitching, R, Tse, PC, Tsavalas, Y, Hinton, MJ, Influence of winding angle on the strength and deformation of filament-wound composite tubes subjected to uniaxial and biaxial loads, Composites Science and Technology, 1993, 46(4), 363-378.
27. Erdiller, ES, Experimental investigation for mechanical properties of filament wound composite tubes, Master's thesis-METU, 2004.
28. Naseva, S, Srebrenkoska, V, Risteska, S, Stefanoska, M, Srebrenkoska, S, Mechanical properties of filament wound pipes: effects of winding angles, Quality of Life, 2015, 6(1-2), 10-15.
29. Almeida Jr, JHS, Ribeiro, ML, Tita, V, Amico, SC, Damage and failure in carbon/epoxy filament wound composite tubes under external pressure: Experimental and numerical approaches, Materials & Design, 2016, 96, 431-438.
30. Zhu, J, Li, W, Yang, G, Jia, X, Yang, X, Crushing characteristics of filament wound carbon fiber/epoxy tube under quasi-static compression condition, Journal of Wuhan University of Technology-Mater. Sci. Ed., 2015, 30(6), 1225-1228.
31. Maleki, S, Rafiee, R, Hasannia, A, Habibagahi, MR, Investigating the influence of delamination on the stiffness of composite pipes under compressive transverse loading using cohesive zone method, Frontiers of Structural and Civil Engineering, 2019, 13(6), 1316-1323.