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Effect of Fiber Orientation on Tensile Property of Basalt Reinforced Epoxy Composite

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Abstract: Because of higher strength/stiffness, lower density and good chemical stability, basalt fiber-reinforced polymeric composites (BFRPs) have found many applications in various areas like aircraft, automotive, ship and packing industry. Purpose of study is to find out the fiber orientation's effect for tensile property of BFRPs, produced by Temperature-Controlled Vacuum Resin Infusion Transfer (VARTIM) method. Standard tensile testing samples are prepared. Tensile tests are conducted at various fiber directions such as 0^{o}, 45^{o}, 0/90^{o}, respectively, and a comparison is made among these composites. The results indicated that fiber arrangement affected the tensile behavior, especially for angle-ply samples. There are some differences occurred between longitudinal direction and orthogonal direction of tensile strengths around 460 MPa and 480 MPa, respectively. In 45^{o} direction, tensile strength was around 82 MPa average but strain reached to 1.1%. In addition, analysis of variance results showed that orientation effects were statistically significant for 5%. Fisher's Least Significant Difference Tests also confirmed that significant differences occurred among A, B and C factors.

Keywords: VARTIM, Basalt fiber, Plain fiber, Fiber direction, Tensile strength, Strain rate

Introduction

Fiber-reinforced polymeric composites (FRPCs) have increasingly used in many applications like airplane/airspace, ship and automotive industry due to higher specific stiffness/strength, lightweight, lower cost, easy production as compared with conventional metal structures and concreates (Sahin, 2022; Sahin&Patrick, 2018). The composites compose of matrix with soft continuous phase while reinforcing phase can be in form of fibers, particles, whisker, flake or fabrics. There are varieties of fibers such as glass, carbon, basalt, aluminium oxide, kevlar, as reinforcements that can be achieved the enhanced mechanical properties. Along with different fiber reinforcements, basalt has excellent chemical, physical, thermal stability, excellent strength, environmental cost associated with non-toxic and non-combustible characteristics. Thus, basalt fibers are adopted an increasing attention in replacement of glass ones (Deak and Czigány, 2009; Routray et al. 2015). They can be widely used for numbers of high temperature-insulation applications. Due to high strength, lighter and appropriate construction, basalt-reinforced epoxy composites (BFRPs) are used to repair and strengthening concrete and steel structures (Dhand et al. 2015). Some mechanical properties like tensile, bending, fatigue using E glass, and basalt are investigated. It is reported that higher performances of laminates were provided through basalt fabrics in comparison to glass fiber composite (Lopresto, et al. 2011; Yang et al. 2019; Wang et al. 2020).

Fiber arrangement in any composite plays an important role on mechanical property of composite (Sahin, 2022). For instances, Vinay et al. (2022) studied the effect of orientation of bi-directional basalt fiber under mechanical testing. The tensile fracture study was investigated for 45^{o}, 60^{o} and 90^{o} orientation of bidirectional mat-basalt-reinforced composite. The result revealed that 90^{o} orientation fiber gives the maximum mechanical properties compared with other orientations. Kumar & Singh (2021) studied the mechanical property/fracture surfaces of basalt bidirectional mat fiber polymers tested at three orientations with molding method. The properties such as tensile strength, flexural strength, impact, hardness searched experimentally. Result indicated that maximum properties provided in 90° orientation in comparison to other produced samples. Abdua et al.(2025) studied the mechanical behaviour of basalt fibre-reinforced epoxy composites produced one-ply, two-plies and three-plies with vaious angles. Density of composites decreased as number of basalt fiber plies increased to two and three because of the presence of voids, trapping of air between the layers during the process. Further, higher strength and modulus were obtained in one-ply composites with 0/90 orientation exhibited due to fiber alignment with the loading axis, but higher strain was observed in angle-ply orientation.

He et al. (2018) studied the BF/EP composite with various mixing rates/orientations. After the completing the matrix solidification, experiments are conducted at its cutting angles of 0°,15°,30°and 45°of tensile samples. The results exhibited that the tensile, modulus, and limiting strain of BF/EP composites all decreased with angle. Seshaiah&Reddy (2018) results revealed that the tensile strength/modulus of the unidirectional glass fiber/epoxy [0°]s is higher and compared to other orientations. The density of the unidirectional glass fiber is lower than others while the compressive strength of the samples is higher. Kumaresan et al. (2015) reported that sisal fibre-reinforced composites with 90° orientation had better mechanical behavior, whereas, Lasikun et al. (2018) reported that the highest tensile is obtained for fibre axis. Rao et al. (2020) reported that impact strength was maximum in 0° orientation for bamboo fibre-reinforced composites.

Fiber orientations also affected the mechanical properties of carbon fiber composites (Agarwal et al. 2014; Rahmani et al. 2014; Kaleemulla &Siddeswarappa, 2010). Highest mechanical properties were obtained in the longitudinal direction (Ozsoy, 2015; Sahin 2024; Çecen & Sarıkanat 2008). Mohameda et al. (2023) focused on to repair structure of composites by gluing it with various orientations. The composite plates are made from 8-layer of graphite/epoxy, glass/epoxy and boron/epoxy in various orientations. Tensile strength was better for the longitudinal direction of the fibers. Further, Agarwal et al. (2021) indicated that higher tensile and flexural property of CFRP were achieved for 0° and 0/90° configurations. However, Guru Raja et al. (2013) reported that for 0/90° orientation, considerable increase in elasticity modulus of composites, followed by 60/30° orientations for hybrid composites.

From the literature review above, large numbers of studies carried out over mechanical behavior of FRPs. But limited numbers of studies for tensile properties of CFRPs/BFRPs produced through VARTM were studied (Sahin 2021, 2022; Sanchez et al., 2013; Bodaghi et al., 2016; Cecen&Sarıkanat, 2008) and BFRP (Vinay et al. 2022, Kumara Singh, 2021, Nur Fatin Abdua, 2025, He et al. 2018). Therefore, purpose of study is to characterize the tensile property of BFRP composites fabricated using VARTIM with different orientations such as 0°, 45°, 0/90° subjected to tensile loading.

Material ve Method

Materials Basalt

To produce BFRP composites, Vacuum Assisted Resin Infusion Transfer (VARTIM) approach was adopted. Plain-weave type (K3P) dry basalt was selected while CR-80-A epoxy resin and CH-80-2 (B) was hardener. Areal weight of woven Basalt is 900 g/m^2, selected as reinforcement, average diameter is about 20 µm. The properties of basalt fabrics used for VARTIM approach are indicated in Table 1. In manufacturing the composites, total of three plies of plain basalt fabrics were stacked on release film of aluminum mold.

Table 1. Some properties of the woven basalt fabrics and epoxy

Materials	Plain Basalt Fabric (BF)	Epoxy resin (EP)
Fabric weight (g/m2)	900	CR-80-(A)
Fabric thickness (mm)	0.19	CH-80-2(B)
Warp construction/fill	22/26	-
Monofilament diameter (µm)	10-17	-
Density (g/cm3)	2.70	1.15
Modulus of elasticity (GPa)	80-90	30-50
Tensile strength (MPa)	1350-4600	73

The composite sample's size is about 500 mm × 500 mm × 0.8 mm fabricated with square laminate. A releasing agent was applied on mold for providing quality surface roughness and removing the laminate easily. Sealant tape, peel ply, vacuum bag was used for completing process. Preform was prepared using fabrics of basalt. Vacuum will be continued until the resin has run out. 1 at pressure was applied at inlet port to remove the resin-rich layer. Flow direction should be along the flow media. The assembly was allowed to cure to the ambient temperature. Finally, post curing was done at 50 °C for 24 hours. Volume fraction (vol.%) of the composites were 39%.

Tensile tests were performed according to ASTM D3039 using universal mechanical testing machine with 100 kN load cell capacity. Specimens were prepared for tensile tests by cutting from the epoxy laminate panels with CNC-router. Samples were cut from the plate according to 0°-45°-0/90° direction with rectangle shape. Specimen was measured about 18 mm in width, 179 mm in length, 1.0 mm in thickness. Five tests for each condition were repeated for the whole composites.

Results and Discussion

Tensile Strength of Composites

Typical stress vs. strain rate curves for the BFRPs when loaded in tension load is indicated in Figs. 2, 3 and Fig. 4 for 0° (longitudinal), 45° (angle- ply) orientation, 90° cross-ply, respectively. Total five samples are tested from each orientation. Tensile stress is provided by getting maximum load as failure of all tested samples. 3 layers of BFRPs showed the following mechanical properties. Figure 2 exhibits the results of stress vs. strain rate of BFRPs, tested at 10 mm/min head-speed in 0° direction. This figure exhibited almost linear behavior to failure before the load reached its maximum point because of higher mechanical properties. Three layers of fiber reinforced composites showed at about maximum stress of 460 MPa, except trial one while for trial five, average strain to failure is to be increased slightly more, but no significant difference was observed among the others. This also indication of fiber loaded in the fiber axis by carrying it in addition to enough interface bonding between the fibers and resin while fiber was. Moreover, average strain rate was about 0.60 except for trial one. Similar conclusions were reported that better behavior was provided in the 0° orientation for other previous studies (Lasikun et al. 2018; Çecen& Sarıkanat 2018; Rao et al.2020; Ozsoy 2015; Sahin 2024). It can be seen that not full agreements were achieved, as indicated in the following orthogonal orientation.

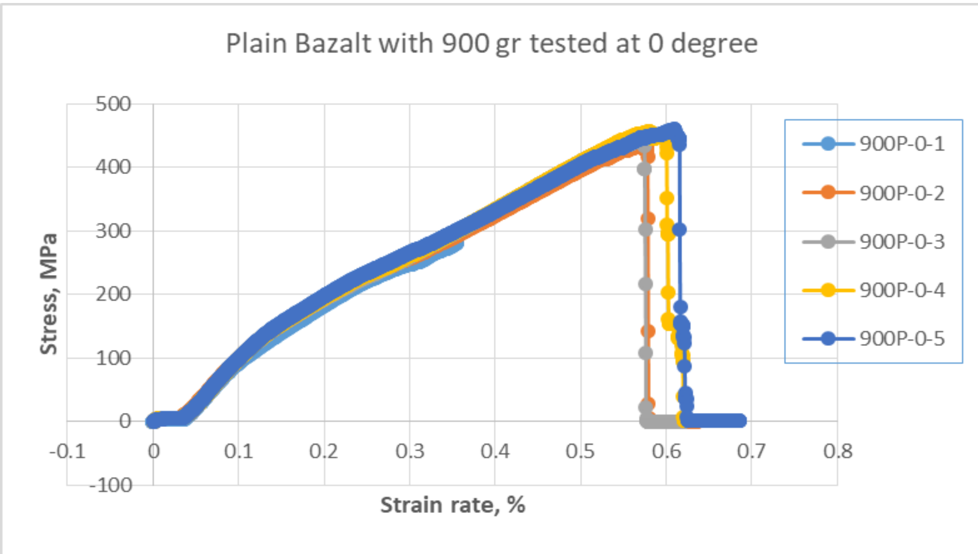

Figure 2. Stress vs. strain rate curve for BFRPs using three layers at 0° orientation

Figure 3 shows the typical stress-strain rate of woven BFRPs subjected to tensile tests at 10 mm/min speed. This is obvious that more linear behavior was observed to failure before the load reachin its maximum level. The maximum strength was around 480 MPa due to introducing more stiffness basalt fibers while average failure time was 0.62 for the samples including 3 layers. The tensile strength increased slightly more in 0/90° direction. This might be due to application of vacuum in this method or formation of enough interface bonding between the fiber/resin, whereas, loading the fiber axis did not show significant difference between the longitudinal and orthogonal design of the samples. Both ones of these samples behavior are stable here. Tensile modulus behavior of hybrid composites (Carbon+Glass) indicated that higher tensile modulus were achieved for 0-90° oriented samples than those of 30-60°,±45° oriented samples (GuruRaja and HariRao, 2013; Kumaresan et al. 2015; Vinay et al.2022). Similar results were also obtained for other studies (Kumar&Sing, 2021; Abdua et al.2025). The carbon fabrics epoxy composite laminates showed the highest tensile strength and highest elastic modulus for F584/PW sample and for F584/8HS sample, respectively (Paive et al. 2006).

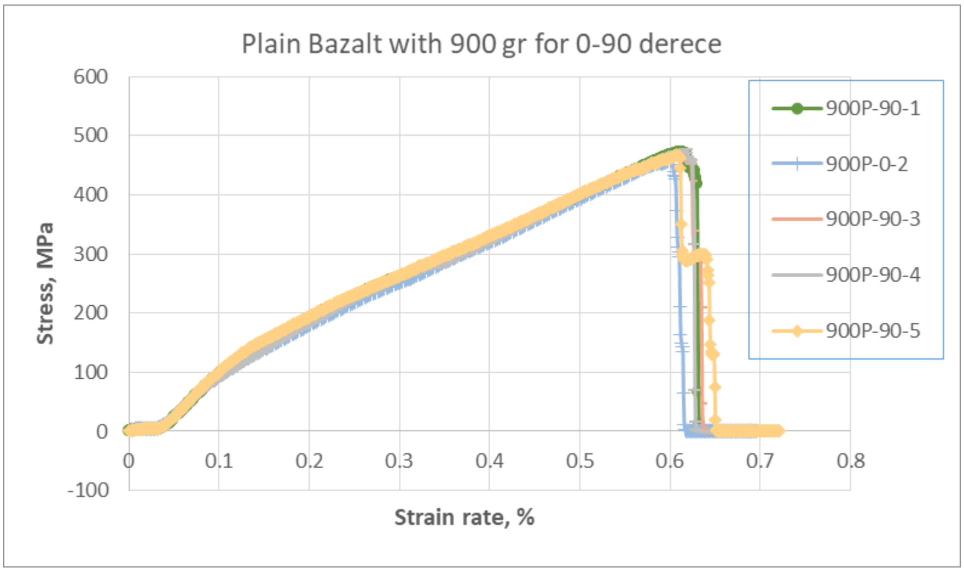

Figure 3. Stress vs. strain rate curves for BFRCs with 3 layers tested along 90° orientation.

Figure 4 reveals stress vs. strain rates for BFRPs as tested along 30° orientation. The behavior was fully different from the previous two orientations. First indication is that non-linear behavior was observed with gradual increase, indicating elastic-plastic region after reaching to peak point of 90 MPa, and then dropped to about 83 MPa. Second indication was that the layers are subjected to change of angle at aligning their selves in application of load direction. As the load applied, it was limited to bending and shear force, and finally this resulted in debonding of adhesion and fracture of samples, as reported in the prevous study (Korkmaz et al. 2016). When the average stresses of 0° sample and 0/90° sample compared with 30° oriented samples improvements were around 477% and 500%, respectively. In terms of strain rate, the improvements in 30° angle-ply orientation in comparison to other orientations is about 83.3 and 77.7%, respectively.

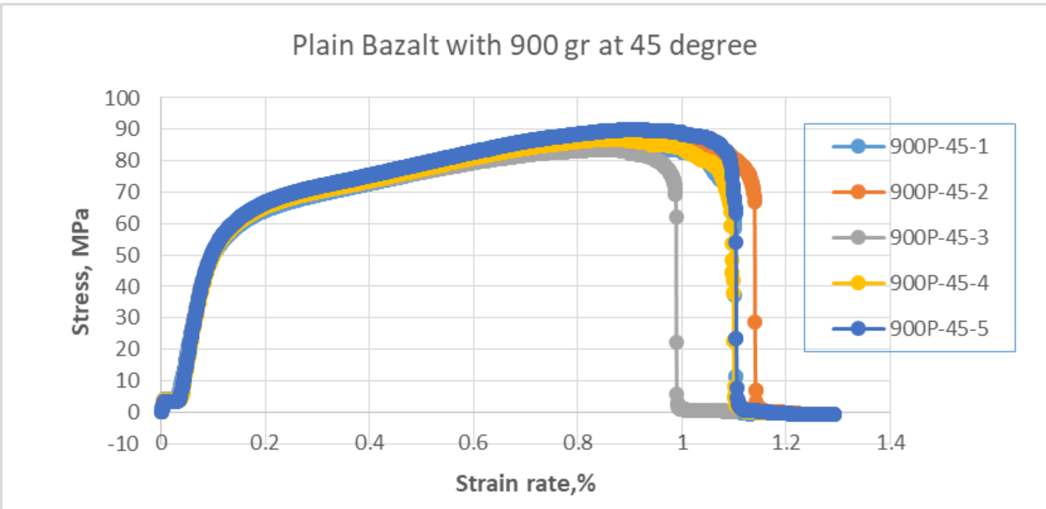

Figure 4. Stress vs. strain rate curves for BFRCs with 3 layers tested along 45° orientation

Other reason in this case is that the load transfer was achieved through resin instead of fibers. Third point is to obtain higher strain rate, which is about 1.1% that is twice higher than those of other composites because of subjecting to fibers distortion along the warp and weft direction. Other reason was that fibers propagated through zigzag way along the 45° fibers/matrix interface that resulted in higher crack propagation energies. Another finding is that elastic modulus is smaller than others. Thus, due to generating more energy, these oriented composites were to be tougher than those of others be because of selecting 900 gr fiber in making these composites.

Analysis of Variance (ANOVA)

The data collected from the experiments is shown in Table 2. Hypotheses are as follows:
$H0$: $T1 = T2 = \ldots = T3 = 0$
$H1$: *Ti is not equal to* 0, at least for one *i.*

Table 2. The data collected from the experimental observations

Source	Observations					Ti	Ȳ
A(0° orientation)	460	478	450	445	468	2301	460.2
B(90°orientation)	492	475	478	482	473	2400	480
C(45° orientation)	82	85	84	76	83	410	82
						ΣTi=5111	-

$T_{..}$ = grand total of all observations/response, N = total number of observations, n = number of observations under the ith treatment, SS = sum of squares, CF = correction factor, $T_{i.}$ = ith treatment total

$$Correction\ factor,\ CF = Ti^{2} / \mathrm{N} \quad (1)$$

$$SS_{Total} = \Sigma i\ \Sigma j\ Yij^{2} - CF \quad (2)$$

$$SS_{T} = \Sigma\ Ti^{2} / n - CF \quad (3)$$

$$SS_{e} = SS_{Total} - \mathrm{SS_T} \quad (4)$$

Table 3 indicates the ANOVA carried out for the tensile strength of the tested samples. Orientation effects are found to be statistical significant at 5% significant level because F calculation value is larger than that of F-table value.

Table 3. ANOVA result for the tensile strength of composite samples.

Source of variation	Sum of squares	Degree of freedom	Mean variance	Fo	F-table
Between treatments (Ori. angles)	503 052	2	251 526	3052	3.89
Error	988.9	12	82.408		
Total	504 041	14			

$F_{0.05,\,2,12}$ = 3.89 (Krishnaiah & Shahabudeen, 2012). Since Fo is bigger than that of F_{α} (table value) Ho is rejected. It means that that treatments differ significantly.

Fisher's Least Significant Difference (LSD) Test

LSD is carried out to determine the differences among the orientation effects. For this purpose, the following formula will be used.

$$\mathrm{LSD} = t^{*}_{\alpha/2,\,N\text{-}a}\,(2{*}\mathrm{MSerr} / n)^{1/2} \quad (5)$$

$t_{0.025,12}$ = 2.179 (Krishnaiah & Shahabudeen, 2012). As all required values put into the Eq.(5), LSD = 12.509.

Mean values of Y1, Y2 and Y3 are given in the following. The pair-wise comparisons are shown below.

Ȳ1 = 480; Ȳ2 = 460.2; Ȳ3 = 82;
Ȳ1- Ȳ2 = 19.8 > 12.50 Significant
Ȳ1- Ȳ3 = 398 > 12.50 Significant
Ȳ2- Ȳ3 = 378 > 12.50 Significant

As a result, significant differences appeared among the A, B and C factors.

Conclusion

The basalt-fiber reinforced epoxy composites (BFRPs) are manufactured by Vacuum Controlled Resin Transfer (VARTIM) method to determine the effect of fiber orientation on tensile property. The following conclusions were drawn out from present study of the composites.

1. Among the orientation effects, the 90º oriented samples indicated slightly higher tensile stresses than that of the 0º oriented samples, respectively. However, there are considerable differences between angle-ply orientation and other two orientation.
2. Based on tensile stresses, improvements in 90º and 0º orientation in BFRP composite were about 500%, 477% compared to 45º orientation, respectively.
3. Strain rate of the 0º tested samples and 0/90º samples was found to be around 0.60, 0.62 while the toughness energy of samples of 45º were the highest about 1.1%. The improvements in angle-ply orientation in comparison to other orientations is about 83.3 and 77.7%. The reason was that fibers propagated through zigzag way along the 45º fibers/matrix interface that resulted in higher crack propagation energies.
4. Analysis of variance results indicated that three treatments of orientation angles differ from each other. Orientation effects are found to be statistically significant at 5% significant level. Moreover, Fisher's Least Significant Difference Tests confirmed that significant differences occurred among the A, B and C factors.

Recommendations

Finite Element Method (FEM) should be applied on tensile/compressive behavior of the similar reinforced composites and compared to the experimental data for the future study.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* The authors declare that there is no conflicts of interest

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