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NATURAL FIBER COMPOSITE FOR UAV: MATERIAL CHARACTERIZATION

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ABSTRACT

Composites with natural fiber reinforcement, such as Basalt Fibers, are gaining increasing popularity as replacement for traditional fibers in various engineering applications. Understanding the behavior and performance of Basalt Fiber-Reinforced Polymers (BFRPs) requires detailed material characterization. This paper studies the mechanical properties of Basalt Fiber composite in an epoxy matrix through tensile and compression testing. The main objective is to fully characterize the BFRP as a potential candidate for the use in Unmanned Aerial Vehicle (UAV) industry.
A testing program is developed to characterize BFRP mechanical properties in tension and compression according to ASTM D3039 and ASTM D6641 standards, respectively. The program includes 32 BFRP testing coupons with fiber orientation 0° and 90°. The study concluded mechanical properties characterization utilizing full-field 3D Digital Image Correlation (DIC) strain measurements. This work provides a comprehensive evaluation of the BFRP, employing full-field strain measurements.

1 INTRODUCTION

Basalt Fibers Reinforced Polymers (BFRPs) are becoming a potential alternative for traditional fibres in various industries. They offer potential advantages over carbon fibers in terms of their low cost, and posse higher strength compared to glass fibers [1]. In fact, they provided a viable alternative material for the main landing gear (MLG) design of UAVs when compared to carbon and glass fibres [2].
To understand the behaviour and performance of BFRPs under different mechanical loading scenarios, a detailed material characterization is necessary. This study focuses on investigating the mechanical properties of a basalt-fibre composite embedded in an epoxy matrix through tensile and compression testing.
The obtained results are compared with published BFRP mechanical properties used in designing a MLG for an UAV [2]. Comparisons also included published mechanical properties of carbon and glass epoxy systems [3,4,5]. Therefore, this comparison enables further justification for the suitability of BFRPs for UAV structures and other engineering applications.

2 MATERIALS AND METHODS

Unidirectional basalt fibers, provided by Jiangsu Hanovo New Material Co. in Jiangsu, China, are used in this study. According to the manufacturer datasheet, these fibers have a filament diameter of 18 µm, and a Young's modulus of 90 GPa which was obtained based on ASTM-D2101 Standard.
For the composite manufacturing, Ampreg 21 resin, produced by Gurit in Zurich, Switzerland, was used. Vacuum bagging technique was employed to manufacture the BFRP composite.

To conduct the mechanical testing, a square-shaped composite panel measuring 80×80 cm was manufactured. The density of the manufactured BFRP panel was measured to be 2.02 (g/cm^3). The panel is manufactured with 10 unidirectional layers of Basalt fibers with approximately 90% fiber volume fraction. All samples tested and compression at different orientations are prepared from the same panel to guarantee consistency in manufacturing quality.

Specimens are prepared according to ASTM D3039 [6] and ASTM D6641 [7], resulting in four different categories of samples: Tension-0°, Tension-90°, Compression-0°, and Compression-90°. Eight samples are manufactured within each category.

The nominal geometry of tested specimens, shown in Figure 1, are provided in Table 1. To ensure reliable testing, the specimens are carefully made with a smooth edge surface finish. Tabs made of glass fiber reinforced polymer are attached at both ends of the specimens using Cyanoacrylate glue to ensure excellent bonding during testing.

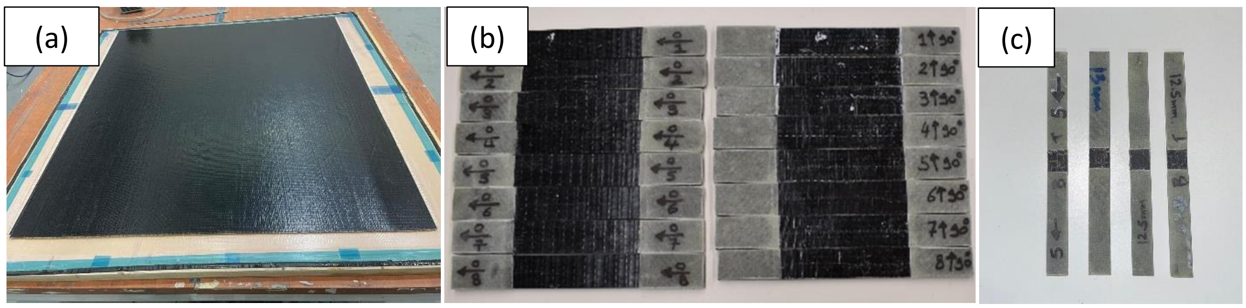

Figure 1: (a) BFRP composite panel, (b) BFRP tension specimens, (c) BFRP compression specimens

Digital Image Correlation (DIC) method is used for full-field strain measurements. Deformation is monitored by a random speckle pattern applied to the samples, as shown in Figure 2 (a, b). DIC enabled non-contactly measurement of localized small-scale and strain concentrations in a 3D volume. GOM software [8] is used to track and analyze the speckle pattern during load application and specimen deformation.

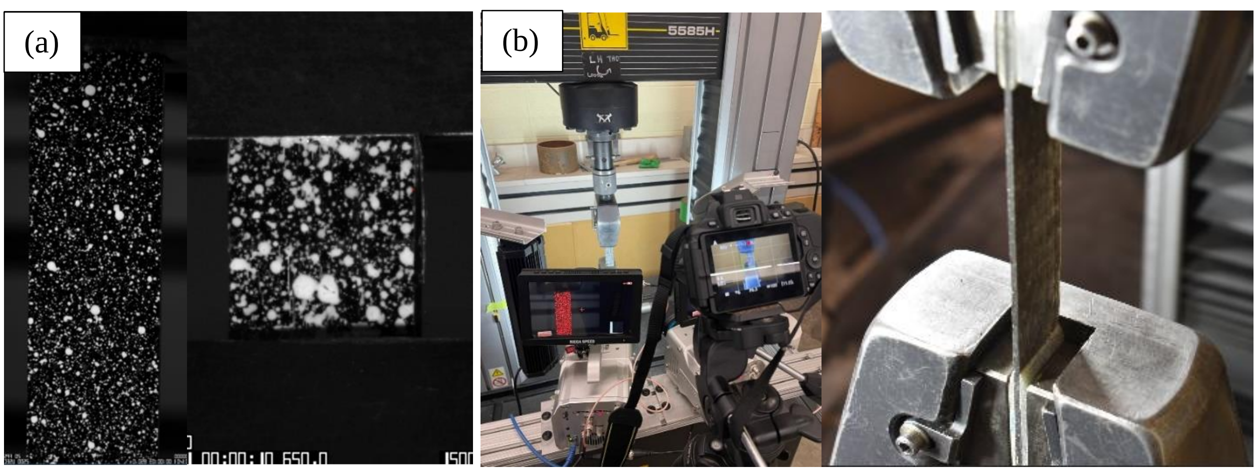

Figure 2. (a) Speckled tension specimens, (b) Test set up

Quasistatic tests are conducted using a load frame, Instron 5585H, with strain rates of 2 mm/min and 1.3 mm/min for the tensile and compression tests, respectively. A high-speed camera system for 3D-DIC measurements is installed, and all tests continued until the sample failure.

Table 1: Specimen dimensions (all dimensions are in mm)

Category	Width	Overall Length	Thickness	Tab Length	Tab Thickness
Tension	25	200	2	50	2
Compression	12	140	2	63.5	2

3 TESTING RESULTS AND DISCUSSION

The tensile test specimens are tested following the ASTM D3039 standard. The stress is calculated based on loading values report by the load cell, while the full-field strain is obtained from the DIC using GOM software. For each test, the mechanical properties are evaluated from the obtained stress-strain curve. Detailed test results are provided in Table 2. The main fracture modes observed are ‘Edge Delamination Gage Middle (DGM)’ or ‘eXplosive Gage Middle (XGM)’. Stress-strain curves of three tensile specimens with 0° stacking are shown in Figure 3. Images from DIC are superimposed to stress strain curves to show localized strains within samples during their testing; localized strain zones are highlighted in these images.

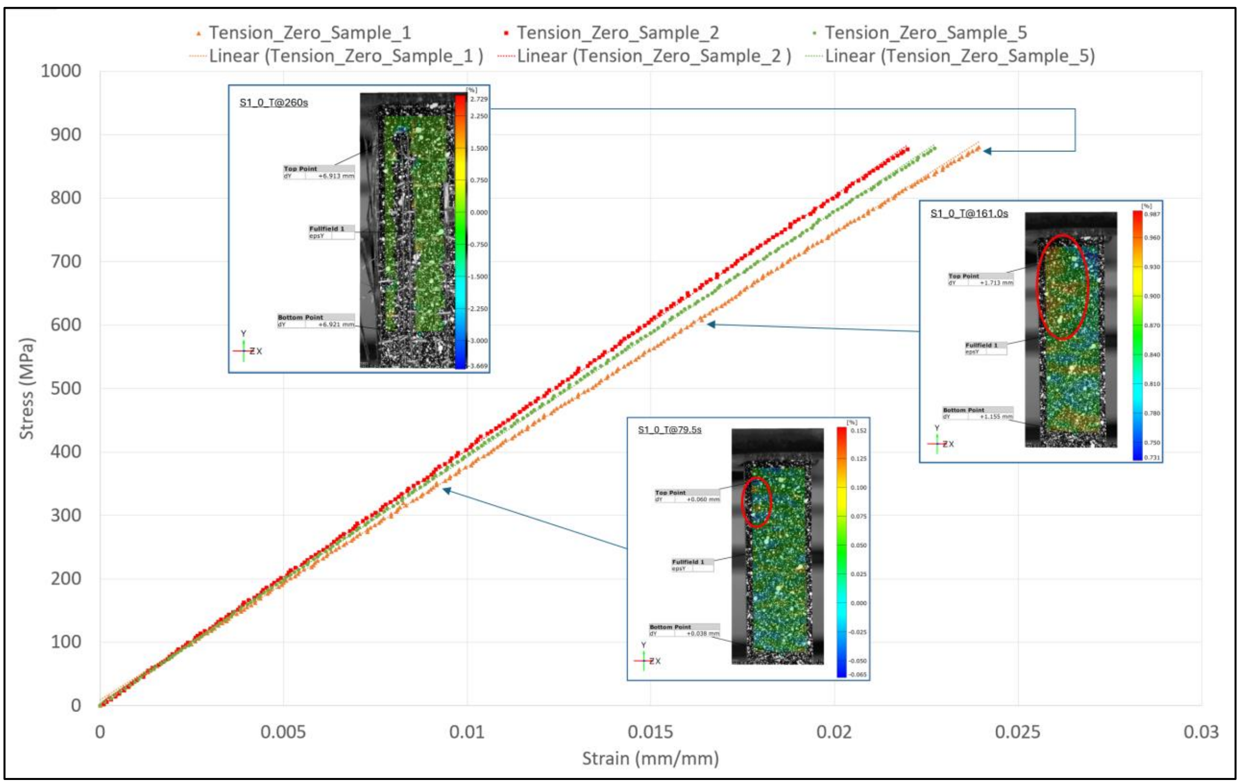

Figure 3: Tensile stress-strain curve of three selected Tension-0° basalt composite samples

Similarly, tensile stress and strain are obtained for 90° stacking with fibers oriented along the transversal loading direction. Corresponding test results are presented in Table 2. The main fracture modes observed are ‘Lateral Gage Middle (LGM)’ or ‘Lateral Gage Bottom (LGT)’. Stress-strain curves of three tensile specimens with 90° stacking are illustrated in Figure 4. DIC Images are overlaid to stress strain curves to demonstrate localized strains within the samples during testing; highlighted areas indicate localized strain zones.

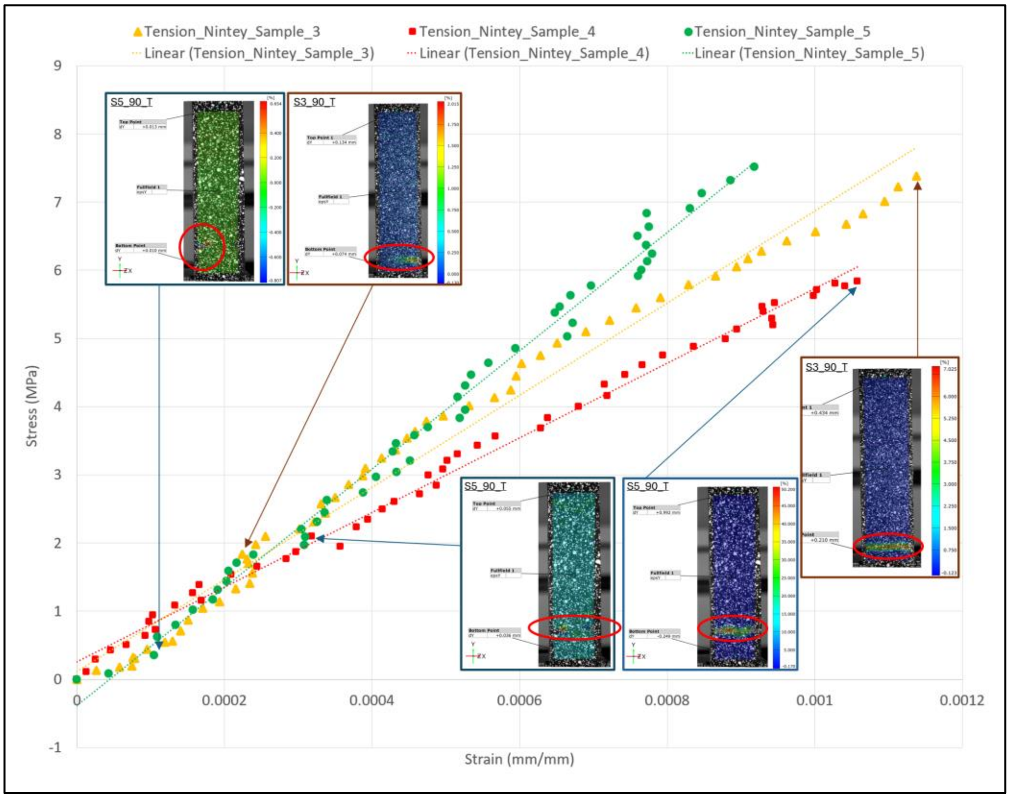

Figure 4: Tensile stress-strain curves of three selected Tension-90° basalt composite samples

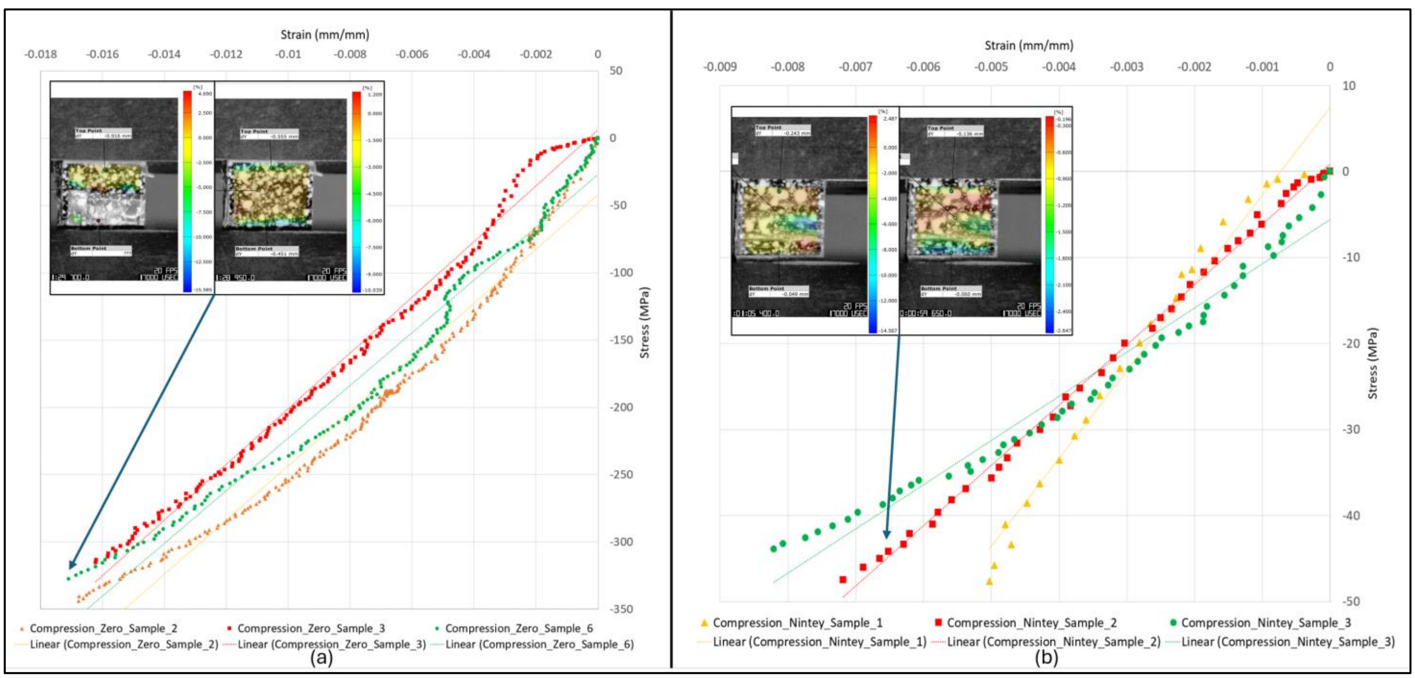

Figure 5: Compression stress-strain curve of UD basalt composite with fibers oriented, (a) along the loading direction (b) along the transverse direction

The compressive test specimens are tested following ASTM D6641 standard. Loading from load cell is used to calculate compressive stress, while the strain is obtained from GOM software. Stress-strain curves of three samples in are compression of UD basalt composite with fibers oriented, along the loading direction 0°, Figure 5 (a), and along the transverse direction 90°, Figure 5(b). Some DIC images are illustrated in the figure to show localized strains and failure. The main fracture mode observed is 'Brooming Gage Middle (BGM)'.

Furthermore, the major Poisson's ratio of the material is determined through the use of 3D-DIC, utilizing two directional strains as illustrated in Figure 6. The obtained value for the major Poisson's ratio is 0.2814 using 0° samples.

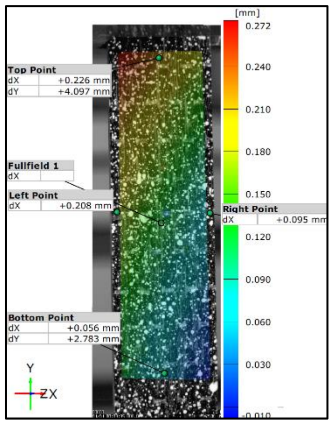

Figure 6: Measurements of strain in both the axial and lateral directions to obtain the Poisson's ratio using 3D-DIC.

Table 2: Different material properties taken from several references compared to the obtained material properties:

Material	Carbon /Epoxy [3]	E-Glass /Epoxy [4]	Basalt/Epoxy [5]	This Basalt/ Epoxy
Density (g.cm^3)	1.53	2.08	2.10	2.02
Fiber volume ratio	0.6	0.6	0.6	0.9
Longitudinal Tensile Modulus (GPa)	134	45	44.3	38.27
Transverse Tensile Modulus (GPa)	7	12	11.9	7.527
Longitudinal Tensile Strength (MPa)	1270	1250	1310	866.31
Transverse Tensile Strength (MPa)	42	35	49.8	6.92
Longitudinal Tensile Strain (%)	1.67	2.95	3.1	2.218
Transverse Tensile Strain (%)	0.6	0.5	0.47	0.104
Major Poisson's Ratio	0.25	0.3	0.27	0.2814
Longitudinal Compressive Modulus (GPa)	38.3	41.2	46.2	19.67
Transverse Compressive Modulus (GPa)	12.3	14	15.2	6.072
Longitudinal Compressive Strength (MPa)	1130	600	776	337.10
Transverse Compressive Strength (MPa)	141	141	135	46.83
Longitudinal Compressive Strain (%)	- 1. 08	-1.5	- 1.7	-1.712
Transverse Compressive Strain (%)	-1.72	-1.2	- 1.6	-0.662

The tensile properties of the composite align with the published trends of BFRPs, indicating that they are comparable to the properties of glass fiber reinforced polymers (GFRP) [4]. The longitudinal tensile ultimate stress of 866 MPa is a highly reliable indicator of the mechanical properties of basalt fibers. The slight difference in the results could be attributed to the use of 3D-DIC analysis which was not utilized in existing/published work. Meanwhile, larger differences are observed in comparison to published compression properties. The longitudinal modulus of 19.67 GPa is 42.6 % lower compared to the values reported in other publications [5]. This difference can be due to the difference in fiber volume fraction and the type of resin used between current and published work. The compression properties were about half the GFRP [4].
It should be noted that determining the transverse compressive strain and characterizing transverse behavior proved challenging due to the rapid localized failure observed through (DIC) within a relatively short time.

4 CONCLUSION

The study concluded characterization of Basalt Fiber Reinforced Polymers (BFRP) mechanical properties utilizing full-field 3D Digital Image Correlation (DIC) strain measurements. Tensile and testing demonstrated high stiffness along the fiber direction, as indicated by high longitudinal modulus and longitudinal tensile strength. These findings suggest that basalt fibers offer valuable advantages. Using DIC and full-field strain measurements enabled examining localized strains and accurate identification of failure modes across all tested specimens in tension and compression. The combination of mechanical performance of BFRP together with their environmental advantages make them an appealing solution when compared to traditional fibers. Further research and development in this field has the potential to drive the widespread adoption of BFRP across various industries.

5 REFERENCES

[1] V. Fiorea, T. Scalicia, G.Di Bellab, A. Valenzaa. "*A review on basalt fibre and its composites*". *Composites Part B*: Engineering, Vol 74, pp 74-94. 2015.

[2] Alzaid A and Nakhla S. "*Natural Fiber Composite for UAV Landing Gear*", *CANCOM2022 - Canadian International Conference on Composite Materials*, Fredericton-Moncton, NB, Canada, 2022.

[3] IM. Daniel, and O. Ishai. "*Engineering mechanics of composite materials*". 2nd edition, *Oxford university* press, 2006.

[4] D. Gay and S.V. Hoa. "*Composite materials: design and applications*". CRC press, 2007.

[5] D. Plappert, G.C. Ganzenmüller, M. May, and S. Beisel. "*Mechanical properties of a unidirectional basalt-fiber/epoxy composite*". *Journal of composites science* Vol. 4.3, pp101, 2020.

[6] ASTM D3039 "Standard Test Method For Tensile Properties Of Polymer Matrix Composite Materials". *ASTM International*, 2017.

[7] ASTM D6641/D6641M–16e1 "Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials Using a Combined Loading Compression (CLC) Test Fixture". *ASTM International,* 2016.

[8] GOM Metrology. https://www.gom.com/en, Accessed 11 May 2023.