

Mechanical Performance Evaluation of Hybrid Basalt–E-Glass Fiber Epoxy Composites Reinforced with Graphite Particles

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Abstract: The present study aims to examine the impact of 5g, 10g, and 15g of E-glass chopped mat and graphite powder on the tensile and flexural behavior of a basalt fiber-reinforced epoxy composite laminate reinforced with E-Glass fiber and graphite powder. The composites were made using the hand layup technique. The Basalt/E-glass/Graphite epoxy composite was subjected to tensile, flexural, impact, and hardness tests in compliance with ASTM guidelines. The results show that adding E-glass to the basalt/epoxy composite significantly improved its tensile strength, impact strength, and hardness. However, it was demonstrated that the basalt/E-glass/10% graphite epoxy composite had a higher flexural strength. The improved performance of the successfully produced laminates may be attributed to an efficient dispersion of the reinforcements in the polymeric matrix, which increased surface area for solid interfacial contact and effective load transmission.

1. Introduction

Anything created by blending particles or fibers with a matrix material to create a new material with characteristics different from the original material is referred to as a composite material. Composite materials are being employed in many applications because they are a promising option for engineers and material analysts. These materials are now the preferred choice for basic materials. It has been demonstrated that composites offer exceptional mechanical qualities, are lightweight, reasonably priced, and very adaptable. Basalt fiber is a high-tech fiber that is healthy, environmentally friendly, and green. From a theoretical and strategic perspective, it is crucial to further investigate and research the properties of basalt fiber and its composite materials. In terms of mechanical strength, acid-alkali resistance, electrical performance, high wave permeability, and sound insulation, basalt fiber performs better than glass, carbon, and aramid fibers, according to published studies. The mechanical characteristics of basalt fiber epoxy composites and the relationship between the effects of business coupling specialist heated de-estimating treatment and plasma polymerization measure on the fiber matrix interfacial strength were the main topics of Seghini et al.'s study [1]. FE-SEM perceptions and material organizations were used to shape FT-IR analysis of the surface morphology of the different basalt strands. After plasma polymerization, a uniform tetra-vinyl-silane (PP-TVS) Basalt fibres have a coating on their surface, which grows in fiber/matrix attachment. Both treated and untreated basalt's surface pain has been managed by the AFM.

Maria et al. [2] investigated the influence of waste basalt powder as a filler in rigid polyurethane foams. Their findings indicated that the incorporation of basalt powder enhanced the reactivity of the polyurethane system during the foaming process, which was further supported by dielectric polarization analysis. The study also highlighted the potential of polyurethane foams as an effective approach for waste management, with basalt powder acting as a waste-derived filler that promotes the formation process of the polyurethane matrix.

Danuta et al. [3] examined the mechanical characteristics of epoxy composites containing basalt powder. Their results demonstrated that the epoxy matrix reduced the degradation rate of the basalt powder, thereby contributing to increased stiffness and hardness. Furthermore, an increase in basalt powder content resulted in an improvement in the thermomechanical performance of the resulting composite.

Chen et al. [4] investigated the influence of strain rate on the mechanical behavior of basalt fiber-reinforced polymers. The study revealed that the composites exhibited increased stiffness with increasing strain rate, particularly at strain rates above 120 s^{-1} . The quasi-static stiffness of the basalt fiber-reinforced polymer was approximately 1642.2 MPa, which increased to 3383.3 MPa at a strain rate of 259 s^{-1} . Similarly, the elastic modulus increased from 77.9 GPa to 111.7 GPa, representing an improvement of approximately 43.4% at the strain rate of 259 s^{-1} .

Lopresto et al. [5] evaluated the mechanical performance of basalt fiber- and E-glass fiber-reinforced plastics fabricated using a vacuum bagging process. Their investigation provided a comparative assessment of the mechanical characteristics of composites reinforced with these two fiber types.

Dorigato et al. [6] investigated the fatigue resistance and mechanical behavior of basalt fiber-reinforced laminates. Epoxy-based laminates containing carbon, basalt, and E-glass fibers with different woven configurations were fabricated using the hand lay-up technique. The results indicated that basalt fiber composites exhibited a higher elastic modulus than comparable glass fiber laminates, while their stiffness was comparable to that of carbon fiber laminates. Basalt fiber laminates also demonstrated better fatigue performance at low fatigue loads and favorable damping characteristics compared with glass fiber laminates. Based on these findings, the authors suggested that basalt fibers could serve as a potential alternative to glass fibers for structural composite applications requiring good mechanical performance and energy-dissipation characteristics.

Benmokrane et al. [7] carried out a comparative characterization of glass/vinyl ester, basalt/vinyl ester, and basalt/epoxy fiber-reinforced polymer composites. Their work focused on evaluating the characteristics and durability of these different fiber-reinforced polymer systems.

Sakthivel et al. [8] investigated the drilling characteristics of basalt/sisal fiber-reinforced polymer composites. The experimental investigation was performed using a high-speed steel (HSS) drill, and statistical techniques such as analysis of variance (ANOVA) and regression analysis were employed to evaluate the influence of different parameters on the drilling performance. The experimental data obtained during the drilling operation were analyzed using Minitab 17 to establish the relevant relationships and trends.

Sabet et al. [9] examined the influence of thermal treatment on the tensile properties of basalt fibers. The mechanical behavior and stiffness of basalt filaments were evaluated at room temperature and after exposure to elevated temperatures of 300°C , 350°C , 400°C , 450°C , and 500°C for different durations. The investigation helped identify suitable thermal treatment conditions for the preparation and application of basalt fibers in composite materials.

Alexander et al. [10] studied the influence of combined thermal and microwave curing on the mechanical properties and surface hardness of basalt/epoxy composites. Their results demonstrated that microwave-assisted post-curing improved the surface characteristics of the composites. In addition, improvements in mechanical strength and hardness were observed following the microwave curing treatment.

Baheti et al. [11] investigated the thermomechanical behavior of glass-fiber-reinforced epoxy composites containing fly ash as a filler. The composites were fabricated using the hand lay-up method with a 50:50 proportion of fabric and epoxy resin. Different concentrations of dry fly ash, namely 1%, 3%, 5%, and 10%, were incorporated into the composite system, with the quantity of epoxy resin adjusted accordingly to maintain the required composition. The fabricated specimens were evaluated through tensile testing according to ASTM D638, flexural testing according to

ASTM D790, and Charpy impact testing in accordance with ASTM D256. Additional investigations included knife penetration resistance, dynamic mechanical analysis (DMA), and fracture surface characterization.

Srivastava and Pawar (2006) developed epoxy-based composites by incorporating fly ash particles at an epoxy-to-fly-ash ratio of 4:1, using fly ash particles of approximately 105 μm size. Their study demonstrated the potential of particulate-filled epoxy composites for achieving improved performance characteristics. The fatigue strength-to-weight ratio and resistance to fatigue damage were also identified as important characteristics of composite laminates.

Based on the findings of the above studies, the present investigation focuses on evaluating the influence of E-glass fiber and graphite powder on the mechanical performance of basalt fiber-reinforced epoxy composites. Graphite powder was incorporated at different levels of 5 g, 10 g, and 15 g, and the resulting hybrid composites were fabricated using the hand lay-up technique. The primary objective of the study is to examine the effect of graphite incorporation and E-glass hybridization on the tensile and flexural characteristics of basalt fiber-reinforced epoxy composite laminates.

2. Experimentation:

2.1. Materials Used

The present study employed LY556 epoxy resin and HY-951 hardener as the polymer matrix system for fabricating the composite specimens. Basalt fiber, E-glass fiber, and graphite powder were selected as the reinforcement and filler materials. These constituents were combined in different proportions and configurations to develop the required composite laminates.

2.1.1 Epoxy Resin

Epoxy is a thermosetting polymer widely utilized in aerospace, aircraft, and other engineering applications due to its favorable mechanical and chemical characteristics. In this investigation, LY556 epoxy resin was used as the matrix material for fabricating the fiber-reinforced composite laminates. The material was selected because of its good mechanical strength, low curing shrinkage, ease of processing, moisture resistance, chemical stability, and ability to effectively wet and bond with reinforcing fibers.

Epoxy resins are among the most extensively used thermosetting polymers in polymer matrix composites. During the curing process, they generally do not release significant reaction by-products, resulting in relatively low volumetric shrinkage. In addition, epoxy resins provide strong adhesion to a wide range of reinforcing materials and exhibit good resistance to environmental and chemical degradation. These characteristics make epoxy resin a suitable matrix for the development of fiber-reinforced composite structures.

2.1.2 Basalt Fiber

Basalt fiber is a mineral-based reinforcement produced from naturally occurring volcanic rocks. It possesses several desirable characteristics, particularly good mechanical strength and resistance to chemical environments [12–17]. As indicated in Table 1, the tensile properties of basalt fibers are comparable to those of glass fibers, while basalt fibers can withstand higher service temperatures than several conventional fiber reinforcements.

The combination of mechanical performance, thermal stability, and chemical resistance makes basalt fiber a promising reinforcement for structural composite applications. Its relatively high temperature resistance and resistance to aggressive chemical environments also make basalt-based composites suitable for demanding applications, including chemical storage systems and composite pipes used in the oil and gas industries [13]. Thus, basalt fiber provides a potential alternative to conventional glass-fiber reinforcement where improved environmental and thermal resistance is required.

2.1.3 E-Glass Fiber

E-glass fiber is one of the most commonly used reinforcement materials in polymer matrix composites (PMCs). It offers several advantages, including relatively low cost, good tensile strength, chemical resistance, and favorable electrical insulation properties. The commonly recognized categories of glass fibers include E-glass, high-strength (HS) glass, and corrosion-resistant (CR) glass.

E-glass was initially developed primarily for electrical insulation applications, which is reflected in the designation “E-glass.” The fiber is available in a range of filament sizes, with typical diameters reported in the range of 3–20 μm . The relevant properties of E-glass fiber used for comparison in this study are presented in Table 1. Although E-glass provides good tensile strength and chemical resistance, its elastic modulus is comparatively lower than that of some alternative high-performance reinforcement fibers. E-glass composites may also exhibit creep and stress-rupture behavior under prolonged loading conditions.

Table 1. Properties of Basalt and E-Glass Fiber

Material	Density (g/cm ³)	Tensile strength (GPa)	Specific strength	Elastic Modulus (GPa)	Specific Modulus
Epoxy	1.14	0.05-0.13	0.05-0.008	34.7	31
Basalt fiber	2.65	2.9–3.1	1.09–1.17	85-87	32.1–32.8
E- Glass	2.6	2.5	0.962	76	29.2

2.1.4 Graphite Powder

Graphite is a naturally occurring allotrope of carbon and represents one of the most stable crystalline forms of carbon. It is generally characterized by its black appearance, opaque nature, and metallic-like luster. At the atomic level, carbon atoms in graphite are arranged in a hexagonal layered structure, with successive layers stacked over one another.

Graphite can occur in different structural forms, including crystalline, amorphous, lump, and fiber forms. In the present investigation, graphite was incorporated in powder form as an additional filler material in the basalt/E-glass-reinforced epoxy composite system. Graphite is particularly notable for its high electrical conductivity, which makes it attractive functional filler for polymer composite applications.

3. Fabrication of Composite Specimens Using the Hand Lay-Up Method

3.1 Basalt–Epoxy Composite

The composite laminates were fabricated using the conventional hand lay-up technique. The specimens were prepared in accordance with the ASTM D790M-86 standard requirements for evaluating the mechanical properties of fiber-reinforced polymer composites. Initially, a suitable release gel was applied uniformly to the mold surface to facilitate easy removal of the cured laminate and prevent adhesion of the resin to the mold.

Thin plastic sheets were positioned over the upper and lower surfaces of the mold to obtain a smooth surface finish and facilitate demolding. The basalt fibers were cut according to the required mold dimensions and positioned uniformly in a straight configuration over the plastic sheet. LY556 epoxy resin was thoroughly mixed with the specified quantity of HY-951 hardener to initiate the curing process. The resin-hardener mixture was then applied uniformly over the fiber layer using a brush.

A subsequent layer of basalt fiber was placed over the resin-coated surface, followed by another uniform application of the epoxy mixture. The laminate was then covered with a thin plastic sheet. Gentle pressure was applied using a squeegee to distribute the resin uniformly and expel entrapped air from the laminate. The prepared mold assembly was subsequently maintained at room temperature for approximately 24 h to allow the composite to cure. After curing, the laminate was removed from the mold and prepared for further testing.

3.2 E-Glass–Epoxy Composite

E-glass-reinforced epoxy specimens were fabricated using a similar hand lay-up procedure. In the hybrid reinforcement configuration, basalt and E-glass fibers were incorporated in a 50:50 proportion. The required fiber layers were cut according to the dimensions of the mold and arranged uniformly over the thin plastic sheet placed on the mold surface.

For the fabrication process, 100 g of LY556 epoxy resin was used as the matrix material and mixed thoroughly with 10 g of HY-951 hardener. Eight sheets of 300 GSM E-glass chopped mat, each measuring 230×300 mm, were used as the reinforcement. The resin-hardener mixture was applied uniformly over the first fiber layer using a brush. Additional fiber reinforcement and resin layers were subsequently arranged to obtain the required laminate configuration.

After completing the lay-up, a thin plastic sheet was placed over the laminate. A squeegee was gently moved across the surface to remove trapped air and promote uniform distribution of the resin throughout the reinforcement. The assembled laminate was then allowed to cure at room temperature for 24 h before demolding and specimen preparation.

3.3 Basalt/E-Glass/Graphite–Epoxy Hybrid Composite

Basalt/E-glass/graphite-reinforced epoxy hybrid composites were fabricated by incorporating graphite powder into the epoxy matrix. The required quantity of graphite powder was added to the epoxy resin and thoroughly blended using a mechanical stirrer for a minimum of 10 min to obtain a relatively uniform mixture. Different graphite concentrations were considered to investigate their influence on the mechanical performance of the hybrid composite.

Three different graphite additions, namely 5%, 10%, and 15%, were incorporated into the basalt/E-glass fiber-reinforced epoxy system. The required quantities of the constituent materials were accurately measured before fabrication. The graphite–epoxy mixture was then used during the hand lay-up process together with the basalt and E-glass reinforcements.

The specimens intended for tensile testing were prepared with dimensions of $165 \text{ mm} \times 12.5 \text{ mm} \times 4 \text{ mm}$ in accordance with the applicable ASTM requirements. Specimens for flexural testing were fabricated with dimensions of $100 \text{ mm} \times 25 \text{ mm} \times 4 \text{ mm}$. For impact testing, specimens having dimensions of $63.5 \text{ mm} \times 12.36 \text{ mm} \times 6 \text{ mm}$ were prepared. The overall fabrication sequence is illustrated in Fig. 1.



Fig. 1. Sequential procedure of fabrication of the composites

4. Experimental Testing of Composite Specimens

4.1 Tensile Testing of Composites

The tensile strength of the fabricated composite specimens was evaluated using an electronic tensometer (METM 2000 ER-1) with a maximum load capacity of 2 tons. A 2-ton load cell was employed for the tensile testing. The electronic tensometer is equipped with load and displacement indicators having resolutions of 0.01 kg and 0.01 mm, respectively.

The composite specimens prepared for tensile testing had dimensions of 165 mm in length, 12.5 mm in width, and 4 mm in thickness. The specimens after completion of the tensile test are shown in Fig. 2.

4.2 Flexural Testing of Composites

Flexural strength was determined using a three-point bending test in accordance with the ASTM D790M-86 standard. The specimens used for the test were 100 mm long, 25 mm wide, and 4 mm thick.

Two identical specimens were tested for each composite configuration, and the corresponding results were considered for evaluation. The test was conducted at a crosshead speed of 0.2 mm/min, with a span of 70 mm between the outer rollers. The failed specimens obtained after the flexural test are presented in Fig. 3.



Fig. 2. Specimens after tensile test



Fig. 3. Specimens after flexural test

4.3 Impact Testing of Composites

The impact strength of the fabricated composite specimens was evaluated using the Charpy V-notch impact test. Three specimens from each composite category were tested, and the average value of the measured impact strength was reported. The specimens after completion of the impact test are shown in Fig. 4.

4.4 Hardness Testing

The hardness of the composite specimens was determined in accordance with the ASTM D2583 standard. A Brinell hardness tester (Model GYZJ-934-1) was used for evaluating the hardness of the fabricated composites. A Coleman BarcollImpressor was employed for determining the hardness in accordance with the specified testing procedure. The composite laminates were cut into specimens measuring $12.7 \times 12.7 \times 3$ mm in length, width, and thickness, respectively. The tested specimens are shown in Fig. 5.



Fig. 4. Specimens after impact test



Fig. 5. Specimens after hardness test

5. Results and Discussion

5.1 Tensile Strength

Table 2 presents the tensile strength results obtained for the different composite configurations tested in accordance with the ASTM D638 standard. Fig. 6 illustrates the comparison of load versus elongation for the following composite systems:

- Basalt (B)
- E-glass chopped mat (E)
- Basalt/E-glass chopped mat (B+E)
- Basalt/E-glass chopped mat with 5% graphite powder (B+E+5% G)
- Basalt/E-glass chopped mat with 10% graphite powder (B+E+10% G)
- Basalt/E-glass chopped mat with 15% graphite powder (B+E+15% G)

The results indicate that the B+E and B+E+10% G composites exhibited greater load-bearing capacity compared with the other composite configurations. In contrast, the pure basalt (B) and B+E+15% G composites exhibited comparatively lower tensile strength.

Higher elongation values were also observed for the B+E and B+E+10% G composites, indicating comparatively better ductile deformation behaviour. The pure basalt and B+E+15% G composites exhibited relatively lower elongation at failure.

The variations in tensile strength among the different composite systems can be attributed to several factors, including the uniformity of fiber and graphite-powder distribution within the resin matrix and the quality of interfacial bonding between the fibers and the polymer matrix [3]. A uniform distribution of reinforcement and strong fiber–matrix adhesion contribute to efficient stress transfer and consequently improve the tensile performance of the composite.

Table.2 Tensile strength for various composites

S.No.	Composite	Load (N)	Elongation (mm)	Tensile strength (N/mm ²)	Elongation (%)
1	B	6890	8.4	11.13	5.51
2	E	8720	16.1	13.90	10.20
3	B+E	9340	22.2	14.84	13.84
4	B+E+G5	4570	8.2	7.62	5.39
5	B+E+G10	9150	20.3	14.56	12.76
6	B+E+G15	8350	9.6	13.34	6.24

5.2 Flexural Strength

The flexural strength results for the various composite configurations are summarized in Table 3. Fig. 7 presents the variation in flexural strength for basalt, E-glass chopped mat, basalt/E-glass chopped mat, and basalt/E-glass chopped mat composites containing 5%, 10%, and 15% graphite powder.

The results demonstrate that the E-glass and B+E+10% G composites exhibited comparatively higher flexural strength than the other composite configurations. The basalt composite without graphite powder and the B+E composite without graphite powder showed comparatively lower flexural performance.

The incorporation of 10% graphite powder into the B+E composite resulted in a significant improvement in flexural strength compared with the corresponding composite without graphite reinforcement. However, a further increase in graphite content to 15% resulted in a reduction in flexural strength.

The decrease in flexural strength at higher graphite concentrations may be attributed to the increased brittleness of the composite. Excessive graphite content can adversely affect the continuity and integrity of the polymer matrix, thereby reducing its ability to withstand bending stresses [3].

Table 3. Flexural strength for various composites

S.No.	Composite	Load (N)	Elongation (mm)	Flexural strength (N/mm ²)
1	B	1170	6.8	307.125
2	E	1450	8.5	475.125
3	B+E	1810	8.0	380.625
4	B+E+G5	1400	7.0	367.5
5	B+E+G10	1960	8.6	514.5
6	B+E+G15	1550	7.3	406.875

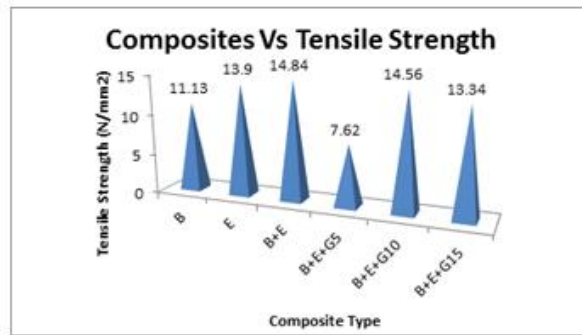


Fig. 6. Tensile strength variation

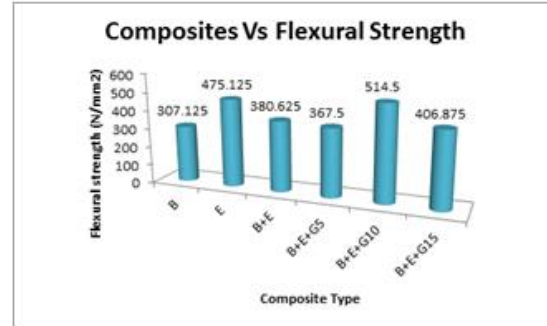


Fig. 7. Flexural strength variation

5.3 Impact Strength

The impact strength results obtained for the fabricated composites are summarized in Table 4. Fig. 8 illustrates the variation in impact strength among the different composite configurations, including plain-woven basalt, E-glass chopped mat, basalt/E-glass chopped mat, and basalt/E-glass chopped mat composites containing 5%, 10%, and 15% graphite powder. The results indicate that the pure E-glass and B+E composites exhibited comparatively higher impact strength than the other configurations. The addition of graphite powder generally resulted in a reduction in impact strength. This reduction can be attributed to the increased brittleness introduced by the graphite particles. The presence of graphite may disrupt the continuity of the polymer matrix and promote crack initiation and propagation during impact loading. Consequently, the energy-absorbing capability of the composite decreases, resulting in lower impact strength values [4].

5.4 Hardness Number

The hardness measurements obtained after testing are summarized in Table 5, while Fig. 9 presents the variation in hardness values for basalt, E-glass chopped mat, basalt/E-glass chopped mat, and basalt/E-glass chopped mat composites containing 5%, 10%, and 15% graphite powder. The results show that the pure E-glass and B+E composites exhibited higher hardness values compared with the other composite configurations. Since E-glass fibers generally possess higher hardness than basalt fibers, the incorporation of E-glass into the basalt composite resulted in an increased hardness value for the B+E system. Interestingly, the incorporation of graphite powder did not result in a corresponding improvement in hardness. This behavior may be associated with the presence of voids and entrapped air within the composite structure. The formation of air bubbles and voids is difficult to eliminate completely during composite fabrication. Voids act as stress-concentration regions and can initiate cracks under applied loading. They also reduce the effective load-bearing cross-sectional area of the composite, thereby adversely affecting its mechanical properties [3]. The variation in hardness observed among the different composite systems may therefore be related to differences in void content, reinforcement distribution, and matrix–reinforcement bonding.

Table 4. Impact strength for various composites

S.NO	COMPOSITE	JOULES/J/m
1	B	3.9
2	E	5.5
3	B+E	5.7
4	B+E+G5	3.7

5	B+E+G10	5.47
6	B+E+G15	5.4

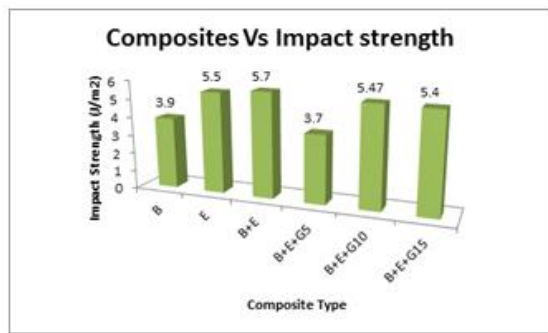


Fig. 8. Impact strength variation

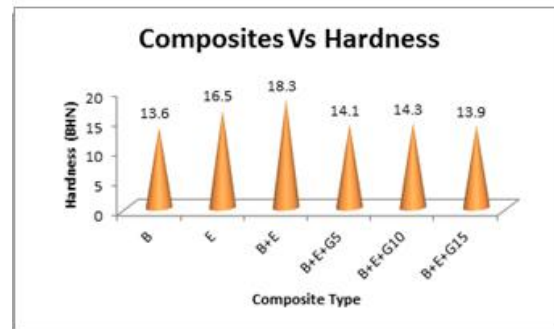


Fig. 9. Hardness variation

Table 5. Brinell hardness number

S.NO	COMPOSITE	BRINELL HARDNESS NUMBER
1	B	13.6
2	E	16.5
3	B+E	18.3
4	B+E+G5	14.1
5	B+E+G10	14.3
6	B+E+G15	13.9

6. Conclusion

Basalt/E-glass/graphite-reinforced epoxy composites were successfully fabricated using the conventional hand lay-up technique. Experimental investigations were conducted to evaluate the influence of E-glass reinforcement and graphite powder on the mechanical properties of basalt/epoxy composites. Based on the experimental results, the following conclusions were drawn:

1. The Basalt/E-glass chopped mat composite exhibited superior tensile strength compared with the pure basalt and pure E-glass epoxy composite specimens.
2. The Basalt/E-glass composite containing 10% graphite powder demonstrated the highest flexural strength among the investigated composite configurations, indicating that an optimum graphite content can enhance the bending performance of the composite.
3. With respect to impact strength, the pure E-glass, Basalt/E-glass + 10% graphite, and Basalt/E-glass + 15% graphite composites exhibited relatively comparable performance. Among the investigated configurations, the Basalt/E-glass chopped mat composite demonstrated comparatively better impact resistance.
4. The Basalt/E-glass composite exhibited the highest Brinell hardness number among the investigated composite systems. The addition of graphite powder did not produce a significant improvement in hardness,

which may be attributed to factors such as void formation, reinforcement distribution, and matrix–reinforcement interaction.

5. Overall, the experimental results indicate that the mechanical properties of basalt/E-glass/epoxy composites are strongly influenced by the type and proportion of reinforcement and graphite content. An optimum graphite concentration can improve specific mechanical properties, whereas excessive graphite addition may increase brittleness and adversely affect tensile, flexural, and impact performance.

References:

- [1] M.C.Seghini, F.Touchard, F.Sarasini, V.Cech, L.Chocinski-Arnault, D.Mellier, J.Tirillò, M.P.Bracciale, M.Zvonek, July 2019, “Engineering the interfacial adhesion in basalt/Epoxy composites by plasma polymerization”, vol.122, pp. 67-76,
- [2] MariaKurańska, July 2019, “Fabrication and Testing of chopped mate e glass and basalt fibers with iron ore powder using hand layup technique”vol.76, pp.90-100.
- [3] Danuta, Matykiewicz, MateuszBarczewski, SławomirMichałowski, May2019, “Basalt powder as an eco-friendly filler for epoxy composites: Thermal and thermo-mechanical properties assessment”, vol.164, pp.272-279.
- [4] Chen, Wensu, Hong Hao, Michael Jong, Jian Cui, YanchaoShi, Li Chen, and Thong M. Pham, September 2017, “ Quasi static and dynamic tensile properties of basalt fiber reinforced polymer”Composites Part B: Engineering, Vol. 125, pp.123-133.
- [5] V. Lopresto, C. Leone, and I. De Iorio, June 2011, “Mechanical characterisation of basalt fiber reinforced plastic,” Compos. Part B Eng., vol. 42, no. 4, pp. 717–723.
- [6] Dorigato and Pegoretti, April 11, 2013, “Flexural and impact behavior of carbon/basalt fibers hybrid laminates”, J. Compos. Mater. vol. 48, no. 9, pp. 1121–1130.
- [7] Benmokrane B, Elgabbas F, Ahmed E, et al. Dec 2015,“Characterization and comparative durability study of glass/vinylester, basalt/vinylester, and basalt/epoxy FRP bars”,*ASCE J Compos Construct*,doi: 10.1061/(ASCE)CC.1943-5614.0000564. pp. 04015008:1-12.
- [8] M. Sakthivel, 2015, “Drilling Analysis on Basalt / Sisal Reinforced Polymer Composites Using ANOVA and Regression Model,” vol. 9, no. 66, pp. 3285–3290.
- [9] S. M. M. Sabet and F. Akhlaghi, February 20, 2015, “The effect of thermal treatment on tensile properties of basalt fibers”, J.Ceram. Sci., vol. 248, pp. 245–248.
- [10] J. Alexander and B. S. M. Augustine, 2015, “The Effect of Combined Thermal and Microwave Curing on Mechanical Properties and Surface Hardness of Basalt / epoxy Composites,” vol. 23, no. 2, pp. 347–349.
- [11] Baheti, Vijay &Militky, Jiri & Mishra, Rajesh &Behera, B.K., (2015). “Thermo-mechanical properties of glass fabric/epoxy composites filled with fly ash”, *Composites Part B:Engineering*. 85. 268-276. 10.1016/j.compositesb.2015.09.049.
- [12] WeiB., CaoH., SongS., October 2010, “Tensilebehavior contrast of basaltand glass fibers after chemical treatment”, *Mater. Des, Vol. 31*, Issue 9, pp. 4244–4250.
- [13] Fiore V., Scalici T., Di Bella G., Valenza A., June 2015,“A review on basal fiber and its composites”, *Compos. Part B Eng.*;74:74–94.
- [14] Monaldo E., Nerilli F., Vairo G. 15 April, 2019, “ Basalt-based fiber- reinforced materials and structural

- applications in civil engineering”, *Compos. Struct.*; 214:246–263.
- [15] Kufel A., Praa S., Kuciel S., 25 Sep 2021, “Basalt/Glass Fiber Polypropylene Hybrid Composites: Mechanical Properties at Different Temperatures and under Cyclic Loading and Micromechanical Modelling”, *Materials*. 14:5574. doi: 10.3390/ma14195574.
- [16] Li Z., Ma J., Ma H., Xu X. 2018, “Properties and Applications of Basalt Fiber and Its Composites”, *IOP Conf. Ser. Earth Environ. Sci.*; 186:012052.
- [17] Technical Datasheet for Basalt Fibers. Lance Brown Import-Export (LBIE) [(accessed on 5 January 2021)].