

Research Article

The Effect of Micro Granite on Barcol Hardness, Flexural and Compression Strength of Basalt and Glass Fiber Reinforced Composites using Industrial Polyester

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Abstract: Micro granite, a variety of fine-grained particles derived from granite, has shown significant potential as a filler material in advancing composite materials. Integrating micro granite fillers into different matrix materials can enhance mechanical characteristics. This study aims to develop a new composite filled with micro granite in basalt and glass fibre-reinforced composite. The fabrication of this new composite using hand lay-up and vacuum silicon mould from the industry. Materials involved were basalt and glass fibre as the matrix, micro granite as filler and industrial polyester as resin. The performance of the composites was measured by conducting the Barcol Hardness, flexural and compression tests. The Barcol hardness value of BFRC is 54.60, increasing 30.6% from unmodified BFRC. Meanwhile, the highest Barcol hardness value of GFRC is 52.40, increasing 54.12% from unmodified GFRC. The flexural value for GFRC from 223.64MPa to 268.69MPa (the highest value), with an increasing value of 20.14%. The flexural value for BFRC went from 244.20MPa to the highest value at 3wt.%, 282.08MPa, with an increasing value of 15.51%. The compressive strength value also increased for maximum value in GFRC from 99.78MPa to 151.69MPa with an increasing percentage of 52%. The compressive strength value also increased in BFRC 125.76MPa to 137.67MPa and 149.04Mpa with an increasing percentage of 9.5% and 8.25%. This is because micro granite has a wide surface area to fill in the polyester until a certain amount of wt.%, in this experiment, until 3wt%. The surface morphological analysis was also carried out and discussed.

Keywords: micro granite; basalt; polyester; glass fibre



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1. INTRODUCTION

Fibre-reinforced composites have emerged as a notable category of materials, significantly transforming multiple industries due to their exceptional mechanical properties and lightweight nature. Fibre-reinforced composites are widely utilised in various industries, such as aerospace,

automotive, construction, and sporting goods, among others. This is primarily attributed to their capacity to improve performance while reducing overall weight. assert that fibre-reinforced composites possess a distinctive array of benefits, resulting in extensive utilisation across diverse domains. According to the authors (Bahiyah Baba et al., 2020; Chen et al., 2019), these materials demonstrate remarkable specific strength and stiffness, a high level of resistance to fatigue and corrosion, and exceptional thermal and electrical properties.

Basalt fibre, a relatively unique diversity within the field of fibre-reinforced composites, has garnered considerable interest within the discipline of material science and engineering. This particular fibre is sourced from basalt rock found in nature, and it exhibits remarkable mechanical properties, thermal stability, and chemical resistance. The distinctive amalgamation of these attributes renders basalt fibre a compelling substitute for conventional reinforcement materials, namely glass and carbon fibres. (Emi Nor Ain Mohammad et al., 2018; Rajawat et al., 2022) have reported that basalt fibre demonstrates notable tensile strength and modulus, which are comparable to those observed in glass fibre. Additionally, basalt fibre offers improved resistance to elevated temperatures. According to the authors, basalt fibre presents a potential solution for various industries, including construction, automotive, and aerospace, where there is a demand for materials with both high strength and fire resistance.

Polyester resin, an adaptable synthetic substance, has garnered considerable recognition across diverse industries owing to its exceptional characteristics and an extensive array of uses. The utilisation of this particular resin as a matrix substance in fibre-reinforced composites is prevalent, as it serves to bolster structural integrity and augment mechanical capabilities. Polyester resin is classified as a thermosetting polymer, which exhibits the process of crosslinking during the curing stage. This transformative reaction leads to the formation of a sturdy and long-lasting substance, characterised by its remarkable resistance to various chemical agents. As per the findings of (Nasution et al., 2020; Phani Sushma et al., 2018), polyester resin demonstrates a distinctive amalgamation of mechanical robustness, minimal shrinkage, and favourable affinity towards various reinforcing fibres. According to the authors, polyester resin has been widely employed in various industries, including marine, construction, automotive, and electrical, owing to its exceptional attributes such as corrosion resistance, dimensional stability, and cost-effectiveness.

Fillers are of utmost importance in the advancement and refinement of composite materials, as they provide a variety of advantageous characteristics and improvements in performance. Incorporating particles or fibres into the matrix material is a common practice to enhance specific properties, including mechanical strength, thermal stability, electrical conductivity, and flame resistance. Fillers can be obtained from a diverse range of sources, encompassing minerals, polymers, metals, or materials based on carbon. (Abdul Halim et al., 2022; Marycheva et al., 2019) have demonstrated that the inclusion of fillers in composite materials has a substantial impact on their microstructure and mechanical characteristics. According to the authors, the incorporation of fillers can potentially augment the tensile strength, stiffness, and impact resistance of composites, while also altering their thermal and electrical conductivity. Fillers can additionally function as reinforcement components, establishing an interconnected structure within the matrix that aids in the dispersion and mitigation of stress.

Micro granite, a variety of fine-grained particles derived from granite, has shown significant potential as a filler material in advancing composite materials. The integration of micro granite fillers into different matrix materials has the potential to enhance mechanical, thermal, and electrical characteristics. (Karimi et al., 2020) have reported that micro granite fillers exhibit remarkable

compatibility with various matrix materials, resulting in enhanced interfacial adhesion and overall composite performance. According to the authors (Karimi et al., 2020), including micro granite fillers in composites results in enhanced stiffness, strength, and abrasion resistance, rendering them well-suited for applications that demand superior durability. Moreover, using micro granite from natural sources confers environmental advantages and diminishes the dependence on synthetic fillers.

2. MATERIAL & METHOD

2.1 Material

The fabrication process involved the production of basalt and glass composites, wherein varying weight percentages (1, 3, and 5wt.%) of micro granite were utilised as filler material. The matrix material utilised in this study comprised woven glass fibres, woven basalt fibres, and polyester resin, specifically CRYSTIC® 272E Isophthalic Polyester Resin. The resin and hardener, provided by Carbon Tech Global Sdn Bhd in Rawang Selangor, were combined in a proportion of 2:1, where the resin quantity was twice that of the hardener. The woven basalt and glass fibres were procured from Vistec Technology, a company located in Puchong, Malaysia. The Department of Public Works in Malaysia provided the micro granite filler used in this study. The selection of these materials was based on attaining distinct mechanical and performance characteristics within the composite structure—all the materials used as in Figure 1.

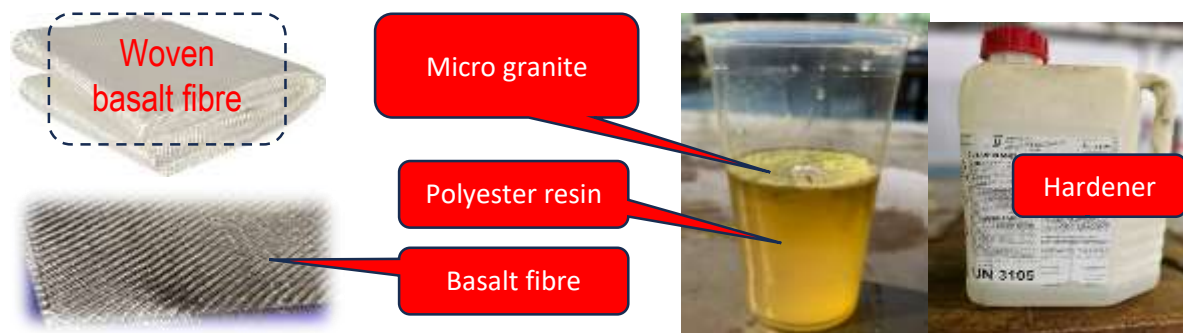


Figure 1. Material: matrix, resin, filler and hardener

2.2 Method

The initial step in the fabrication process of basalt and glass composites involves the preparation of the fibre layers. The woven glass and basalt fibre are precisely cut and accurately measured according to the desired specifications. Subsequently, the polyester resin is combined with the micro granite filler. The mixing process was conducted using weight percentage, which ensured the effective dispersion of the filler material within the resin. To achieve a comprehensive mixing, a mechanical stirrer was utilised for approximately 60 minutes at a rotational speed of 400 rpm. The recommended weight ratio for mixing the polyester resin with the hardener is 2:1. The resin mixture, comprising the filler and hardener, is subsequently poured onto the fibre layers that have been stacked. To promote the amalgamation of the composite, the specimen is enclosed using a silicon mould. Vacuum is utilised to eliminate any trapped air within the specimen, thereby facilitating the optimal consolidation of the composite structure. Following the sealing process, the FRP (fibre-reinforced polymer) specimen is extracted from the mould and allowed to undergo a curing period of approximately 8 hours at ambient temperature. Upon the completion of the curing process, the

composite specimens undergo precise measurements following the standards set by the American Society for Testing and Materials (ASTM). The task is accomplished by utilising a circular saw apparatus, thereby guaranteeing meticulousness and compliance with established protocols for testing—these prepared specimens, as shown in Figure 2.



Figure 2. Fabrication process

2.3 Barcol hardness

Barcol hardness is a commonly used method for measuring the hardness of composite materials. The Barcol hardness test involves using a handheld instrument called a Barcol impressor or Barcol hardness tester. The Barcol impressor consists of a pointed indenter attached to a spring-loaded mechanism. The indenter is pushed into the material, and the hardness value is displayed on a dial or digital readout. Cut or shape a representative sample of the composite material and ensure that the surface is clean and free from any contaminants. Before performing the test, it's essential to calibrate the Barcol hardness tester. This calibration ensures accurate and consistent results. Place the Barcol impressor perpendicular to the surface of the composite material. Make sure the indenter is in contact with the material but not applying any pressure. Gradually apply pressure on the indenter by pressing down on the instrument. Maintain a steady and consistent rate of pressure application. The indenter should penetrate the material. Once the indenter has penetrated the material to a specific depth, the hardness value can be read from the dial or digital display on the Barcol hardness tester. This value indicates the material's hardness based on the depth of penetration. To obtain reliable results, it's recommended to take multiple readings at different locations on the specimen's surface. This helps account for any variations in the composite material's properties. Calculate the average hardness value from the multiple readings to obtain a representative value for the composite material's hardness. Compare the Barcol hardness value obtained from the composite material with the hardness values of known materials or standards. This can provide a relative indication of the composite's hardness. The Barcol hardness scale ranges from 0 to 100, with higher values indicating greater hardness.

2.4 Flexural measurement

The ASTM D7264 standard will conduct the flexural test in this study. Cut or shape the composite material into appropriate dimensions according to the specifications in ASTM D7264. The standard provides specific requirements for specimen geometry, such as width, thickness, and length. Ensure that the specimen edges are smooth and free from any defects or irregularities that could affect the test results. Before testing, condition the specimens in an environmentally controlled chamber at the specified temperature and humidity conditions for a sufficient time. This step is crucial to ensure consistent and accurate test results. Place the conditioned specimen onto the supports of the flexural testing machine. The distance between the supports should correspond to the specified span length according to the standard. Make sure the specimen is properly aligned and centred on the supports. Set the appropriate test parameters on the flexural testing machine, such as the crosshead speed, load range, and data acquisition frequency, according to the specifications provided in ASTM D7264. Apply a preload to the specimen to ensure proper contact and eliminate any gaps or voids at the support points. The preload should be applied gradually to avoid damaging the specimen. Start the flexural test, which typically involves applying a load at a constant rate to the midpoint of the specimen until failure occurs or until reaching the specified deflection. The flexural test measures the load-deflection response of the specimen as it bends under the applied load. The testing machine will record the load and deflection data throughout the test. Calculate the flexural properties of the composite material based on the recorded load-deflection data, following the equations and procedures outlined in ASTM D7264. The standard guides calculating parameters such as flexural strength, flexural modulus, and other relevant properties. Prepare a test report documenting the test setup, specimen details, test parameters, and results obtained from the flexural testing. Include any relevant observations or deviations from the standard procedures. All specimens will be resized to meet the specified dimensions of 80 mm in length and 13 mm in width in preparation for the flexural test. The experiment will be carried out utilising the Instron Universal Machine.

2.5 Compression measurement

During a compression test, a composite specimen is subjected to a compressive force along its longitudinal axis using a testing machine capable of applying controlled and uniform loading. The specimen is typically cylindrical or prismatic in shape, and the compressive force is gradually increased until failure or a predetermined displacement is reached. By analysing the stress-strain relationship obtained from the compression test, valuable mechanical properties of the composite material can be determined. These include compressive strength, which represents the maximum load sustained by the specimen before failure, and compressive modulus, which measures the material's stiffness in compression. ASTM D3410 specifies this compression test procedure for composite materials having dimensions of 110 mm in length, 10 mm in width, and 2 mm in thickness.

2.6 Scanning Electronic Microscope (SEM)

Obtain a representative sample of the material and ensure that the sample is clean and free from contaminants. If necessary, cut or shape the sample to an appropriate size for SEM analysis. The size will depend on the capabilities and requirements of your SEM instrument. Depending on the nature of the sample, additional preparation steps may be needed, such as polishing, coating, or cryofixation. Attach the prepared sample securely to a sample holder or stub using a conductive adhesive, double-sided carbon tape, or any other suitable method. Ensure that the sample is positioned correctly, providing clear access for the electron beam and maximising the desired region for analysis. Place the sample holder with the mounted sample into the SEM chamber. Close and seal the chamber to create a vacuum environment. The SEM operates under high vacuum conditions to prevent electron scattering and maintain imaging quality. Configure the SEM settings, such as accelerating voltage,

beam current, and working distance, according to the requirements of analysis objectives. Adjust the sample stage position and tilt to optimise the viewing angle and focus. Position the sample under the electron beam and adjust the focus, astigmatism, and aperture settings to obtain a clear, high-resolution image. Begin scanning the electron beam across the sample surface, typically in a raster pattern, to generate the SEM image. Experiment with different imaging parameters, such as beam current, dwell time, and signal detection settings, to optimise the image quality and gather the desired information. Capture images or acquire image sequences at various magnifications and areas of interest on the sample.

3. FINDINGS

The results obtained in this study represent the mean values obtained from the analysis of five individual samples for each specific composite laminate type. The observed variability in the sample relates to the weight percentage of micro granite added to the resin before the pouring stage in the hand lay-up fabrication process. The present study investigated the characteristics of different composite laminates, encompassing parameters such as density, hardness, flexural strength, and compression strength. The laminates examined in the research comprised polyester (PE), basalt fibre-reinforced composite (BFRC), and glass fibre-reinforced composite (GFRC).

3.1 *Effect of micro granite on Barcol Hardness*

According to the values obtained in Figure 3, Each system demonstrates a positive correlation between the weight percentage of MG filled into the polyester polymer and the corresponding increase in value. The composite material 3MGPE, containing 3wt% of MG, exhibited the highest performance among polyester (PE) composites, with a notable increase of 52% compared to the Neat-PE sample. The highest value of BFRC is 54.60, increasing 30.6% from unmodified BFRC. Meanwhile, the highest value of GFRC is 52.40, with increasing of 54.12% from unmodified GFRC. This observation demonstrates that an increase in the weight percentage of MG incorporated into the polyester resin resulted in a corresponding increase in hardness values. Hence, it was observed that the hardness of pure polyester resin is comparatively lower compared to the resin filled with MG. The composite's hardness will positively correlate with the filler's weight percentage. The hardness of polyester (PE), basalt fibre-reinforced composite (BFRC), and glass fibre-reinforced composite (GFRC) materials exhibit an increasing trend up to a filler concentration of 3wt%, followed by a subsequent decrease at a filler concentration of 5wt%. According to recent studies conducted by Keerthi Gowda et al. (2021) and Nayak et al. (2021), it has been observed that the hardness of basalt composites surpasses that of glass composites. (Keerthi Gowda et al., 2021; Nayak et al., 2021)

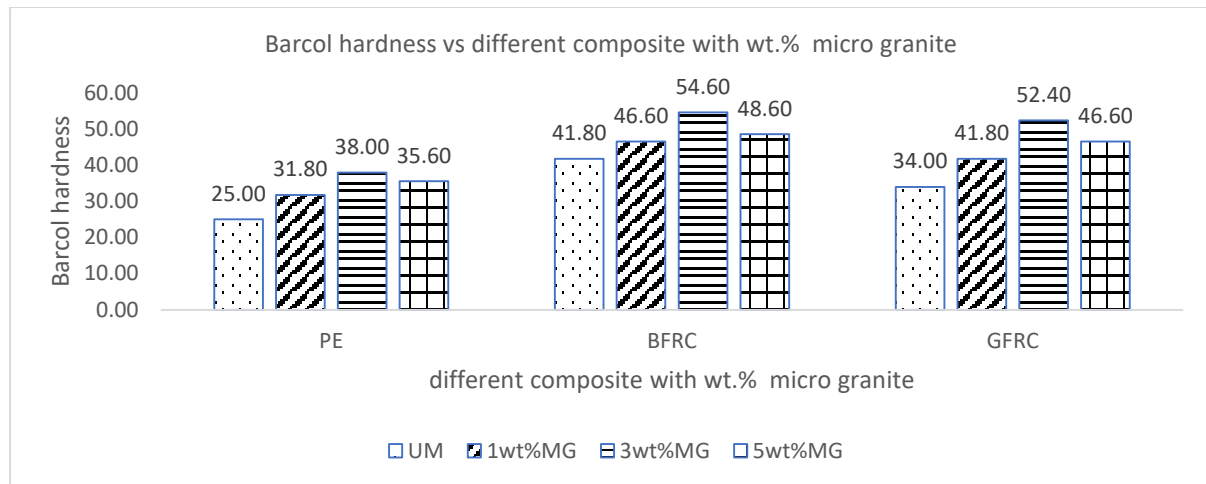


Figure 3. Barcol Hardness vs different composite wt.% micro granite

3.2 Effect of micro granite on flexural strength

The flexural value for unmodified PE is 79.87MPa, and 97.93MPa at 3wt% contains micro granite with an increasing value of 22.61%. The value continuously decreased to 74.59MPa. The flexural value for GFRC from 223.64MPa to 268.69MPa (the highest value), with an increasing value of 20.14%. After that, the value continuously decreased to values of 206.61MPa. The flexural value for BFRC went from 244.20MPa to the highest value at 3wt.%, 282.08MPa, with an increasing value of 15.51%. After that, the value continuously decreased with values of 221.30MPa. Incorporating micro granite particles yielded a discernible enhancement in the flexural strength of the composite material. The impact of different fillers on the mechanical characteristics of polymer composites, specifically the inclusion of granite dust in polyester resin composites with glass and basalt fibres, was examined by (Gheith et al., 2019; Raihanah Hashim et al., 2021; Senthilkumar et al., 2022). According to the findings, including granite dust as a filler enhanced the composites' mechanical properties, specifically regarding flexural strength. The optimal weight percentage for this improvement was observed to range between 1 wt.% and 5wt%.

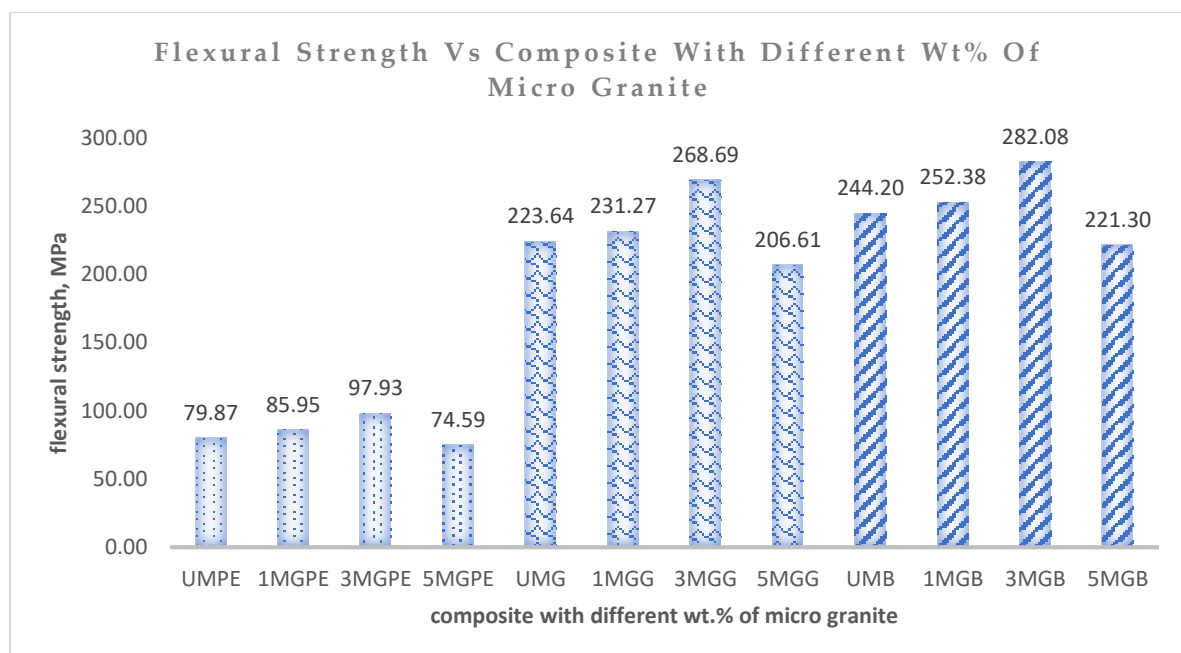


Figure 4. Flexural strength vs composite with different wt% of micro granite

3.3 Effect of micro granite on compression strength

After analysing the test result, a graph was plotted as Figure 5. The compressive strength value for polyester composite increased from 86.67MPa to 92.81MPa with an increasing percentage of 7.08% at 1wt% containing micro granite. Then it increased again to 95.90Mpa with an increasing value of 3.33% at 3wt.%. The value decreases to 93.84MPa with increasing micro granite. The adding maximum is 3wt%, with an increasing percentage of 10.62%. Based on the results obtained, the effect of micro granite on polyester composite properties of compressive strength enhancement ranged from 3% to 10%. The compressive strength value also increased for maximum value in GFRC from 99.78MPa to 151.69MPa with an increasing percentage of 52%. The value decreases to 134.06MPa at 5wt%. The effect of micro granite on GFRC properties of compressive strength ranged from 40% to 50%. The compressive strength value also increased in BFRC 125.76MPa to 137.67MPa and 149.04Mpa with an increasing percentage of 9.5% and 8.25%. The value decreases to 115.96MPa at 5wt%. The effect of micro granite on BFRC properties of compressive strength ranged from 8% to 9%. This is because micro granite has a wide surface area to fill in the polyester until a certain amount of wt.%, in this experiment, until 3wt% (Arumugaprabu & Johnson, 2019; Muslim et al., 2022).

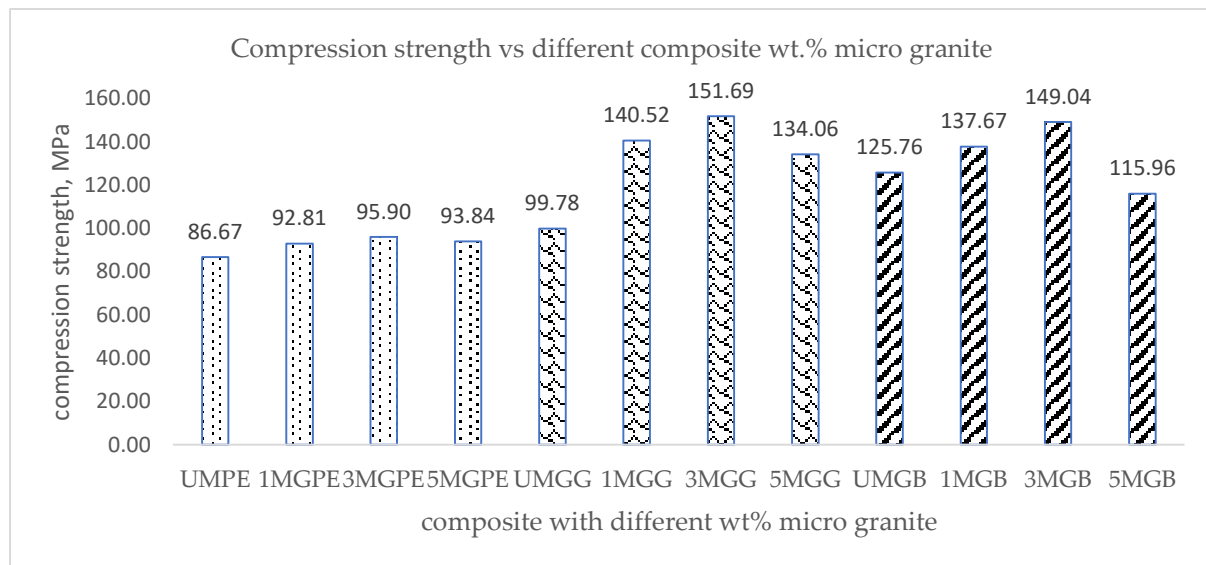


Figure 5. Compression strength vs different composite wt.% micro granite

3.4 Scanning Electronic Microscope

In this study, SEM was used to examine the fracture surface of FRP composite materials after mechanical testing, as shown in Figure 6. SEM result based on wt% of micro granite. In the case of both BFRC and GFRC, the addition of 5wt% of micro granite can lead to the formation of agglomerates within the material. In a broader context, the existence of agglomerates within BFRC and GFRC, both of which incorporate 5wt% of micro granite, possesses the capacity to impact the dispersion, distribution, and bonding characteristics of the composite material. The comprehension and successful resolution of these concerns is crucial for achieving the desired mechanical properties and performance of fibre-reinforced composites. The term "agglomerates" pertains to the consolidation or fusion of particles, which are bound together by particle size, shape, and interactions between particles. The presence of agglomerates can have diverse implications for the properties and behaviour of the composite material. Firstly, the existence of agglomerates can have an impact on the dispersion and distribution of micro granite particles within the matrix.

Insufficient dispersion can lead to a non-homogeneous arrangement of the reinforcing particles, resulting in localised variations in properties such as strength and stiffness. Moreover, the

existence of agglomerates possesses the capability to hinder the efficient bonding mechanism between the matrix substance and the reinforcing fibres. The interfacial region between the fibres and the matrix experiences a reduction in strength, leading to a decline in load transfer capability and the potential occurrence of fibre pull-out during material failure. The phenomenon known as "fibre pull-out" refers to where the reinforcing fibres are removed from the matrix without significant debonding or fracture. Fibre pull-out indicates a potential weakening or deterioration in the interfacial adhesion between the matrix and resin materials. This phenomenon may arise due to inadequate adhesion between the fibres and the matrix material or the presence of agglomerates that create regions with weak bonding. The fibre pull-out is a clear indication of reduced load transmission between the fibres and the matrix, which negatively impacts the composite material's overall mechanical properties and operational effectiveness. In their study, Karimi et al. (2020) put forth the notion that a variety of strategies can be employed to tackle the challenges linked to agglomeration and fibre pull-out effectively. Various strategies can be utilised to enhance the performance of micro granite particles during the mixing process. The strategies mentioned earlier encompass the optimisation of particle dispersion, the establishment of adequate adhesion between fibres and the matrix via appropriate surface treatments or coatings, and adjusting composition and processing parameters to augment the strength of interfacial bonding.

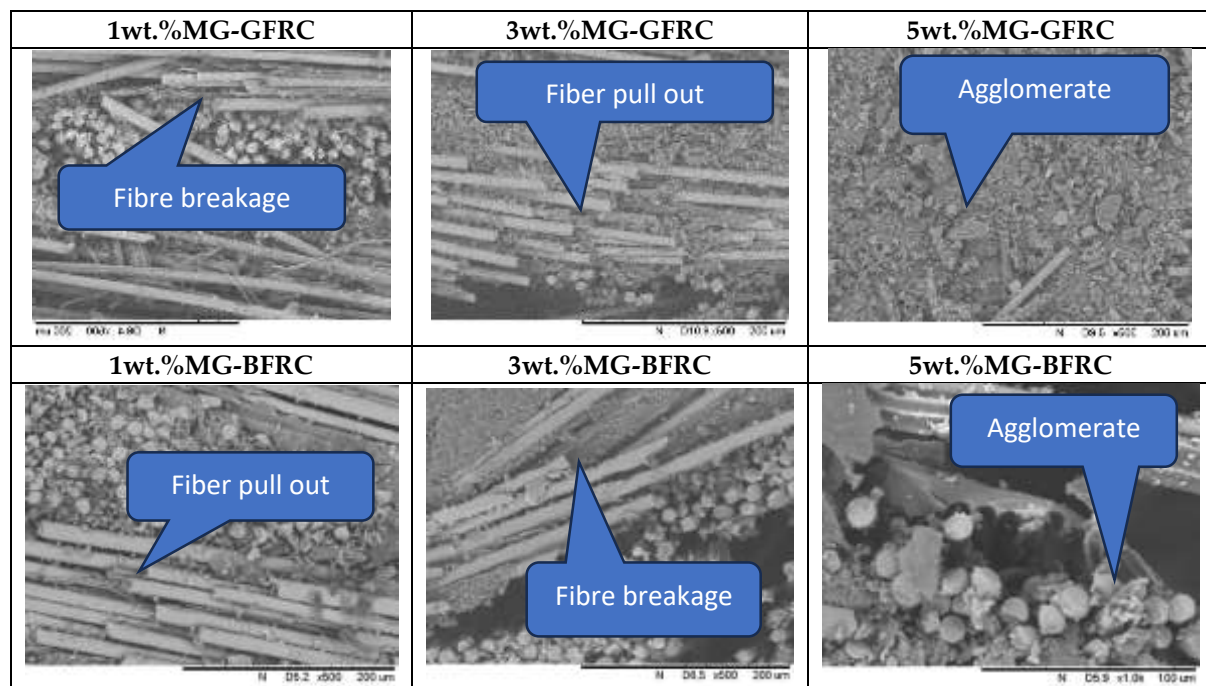


Figure 6. SEM result based on wt% of micro granite

4. CONCLUSION

Based on the findings, it has been observed that incorporating micro granite as a filler in polyester resin leads to improvements in the hardness, density, and tensile strength characteristics of PEC, BFRC, and GFRC. It is expected that the addition of filler content will lead to a proportional rise in the density of Polymer-Modified Engineered Cementitious Composites (PEC), Basalt Fiber Reinforced Concrete (BFRC), and Glass Fiber Reinforced Concrete (GFRC). The weight percentage of 3wt% has been determined as the optimal value for attaining the desired hardness and tensile strength levels. It has been observed that the presence of micro granite in quantities exceeding 5% by weight decreases both hardness and tensile strength, leading to a reduction in their respective values. The scanning electron microscopy (SEM) analysis reveals that the incorporation of micro granite at a concentration of 5wt% results in agglomeration. Including micro granite in the material, the composition is expected to increase flexural and compressive strength, with the optimal concentration being three weights per cent. The application of micro granite in this context holds promise for

effectively reducing waste production in the granite industries, thereby promoting the use of sustainable resources.

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