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Comprehensive Evaluation of Physical, Mechanical, Thermo-Mechanical and Morphological behavior of Hybrid ABS Composites Reinforced with Glass Fiber and Granite Powder

Prashant K Mulge[1], Dr. Shashidhar[2], S Kalashetty[3]

[1]Reserach Scholar, Department of I&PE, PDA College of Engineering, Kalaburagi-Karnataka-India

[2]Assistant Professor, Department of Mechanical Engineering, Faculty of Engineering & Technology (Co-Ed.), Sharnbasva University Kalaburagi-Karnataka-India

[3]Professor, Department of I&PE, PDA College of Engineering, Kalaburagi-Karnataka-India.

***Abstract*—This study presents a comprehensive investigation into the physical, mechanical, thermo-mechanical, and morphological properties of hybrid acrylonitrile butadiene styrene (ABS) composites reinforced with glass fiber and granite powder. Four composite formulations were developed using injection molding, including virgin ABS, ABS with 10% glass fiber, ABS with 10% granite powder, and a hybrid composite containing both reinforcements. A series of tests, including density, melt flow index (MFI), shrinkage, warpage, tensile strength, compressive strength, impact strength, flexural strength and hardness tests), were conducted to evaluate their performance. The hybrid composite demonstrated significant improvements in compressive, reduced shrinkage and warpage, and enhanced thermal stability compared to virgin ABS. Scanning Electron Microscopy (SEM) analysis revealed better filler-matrix interaction and uniform dispersion in the hybrid composite. These results affirm the potential of hybrid reinforcement in optimizing the performance of ABS-based composites for structural and thermal applications.**

***Index Terms*—Hybrid ABS composites, Glass fiber, Granite powder, Mechanical properties, Thermo-mechanical behavior, Morphological analysis, Injection molding SEM analysis**

I. INTRODUCTION

In recent years, polymer matrix composites (PMCs) have garnered substantial attention in both academic research and industrial applications due to their excellent balance of lightweight, high strength, and processability. Among the various thermoplastics used as matrix materials, Acrylonitrile Butadiene Styrene (ABS) stands out for its superior toughness, good dimensional stability, and ease of processing, particularly through injection molding. However, the performance of neat ABS often falls short in applications requiring enhanced mechanical strength, thermal resistance, and wear characteristics.

To address these limitations, reinforcing ABS with various fillers and fibers has become a widely adopted strategy. Glass fiber, a traditional reinforcement, is known to significantly improve the tensile, flexural, and impact properties of polymer composites while also offering better thermal stability. On the other hand, mineral-based fillers such as granite powder an industrial waste by-product—are increasingly being considered for sustainable composite development. Granite powder, rich in silicates and alumina, not only enhances stiffness and hardness but also presents an eco-friendly solution by repurposing waste into value-added materials.

The combination of glass fiber and granite powder in ABS forms a hybrid composite that potentially offers a synergistic improvement in physical, mechanical, and thermo-mechanical behavior. Despite several studies investigating glass or mineral-filled ABS composites individually, limited research has been conducted on hybrid reinforcements involving both glass fiber and granite powder. Understanding the interaction of these reinforcements in the ABS matrix is critical to optimizing performance and unlocking new applications in automotive, construction, and consumer product sectors.

This study aims to perform a comprehensive evaluation of the physical, mechanical, thermo-mechanical, and morphological properties of hybrid ABS composites reinforced with glass fiber and granite powder. Emphasis is placed on analyzing how varying reinforcement types and contents influence shrinkage, warpage, compressive strength, and thermal stability. The study also explores the microstructural features through morphological characterization to provide insights into the dispersion and bonding of the reinforcements within the ABS matrix.

II LITERATURE REVIEW

Polymer Matrix Composites (PMCs) are advanced materials that combine reinforcing fibers with polymer matrices, offering significant advantages in various industries, including aerospace, automotive, and defense, due to their lightweight, corrosion resistance, and high mechanical performance [1]. The global PMC market is projected to grow at a CAGR of 4.1% from 2018 to 2023, driven by the demand for high-performance materials [2]. Common thermoplastics used in PMCs include acrylonitrile butadiene styrene (ABS), which is valued for its toughness and impact resistance, alongside other materials like polyethylene and polypropylene [3]. The versatility of PMCs is further enhanced by the development of processing techniques that optimize fiber content and architecture, allowing for tailored mechanical properties [4]. Overall, PMCs represent a critical evolution in material science, balancing performance and cost-effectiveness across diverse applications [5].

Acrylonitrile-butadiene-styrene (ABS) polymers exhibit a unique combination of mechanical, thermal, and processing properties, making them widely applicable in various industries. Mechanically, ABS is known for its excellent toughness, dimensional stability, and good processability, which are attributed to its elastomeric phase dispersed within a styrene-acrylonitrile matrix [6]. Thermally, ABS demonstrates a relatively low melting temperature, facilitating its use in 3D printing and other manufacturing processes like injection molding and extrusion [7]. However, virgin ABS has limitations in advanced applications, particularly regarding its thermal stability and flame retardancy, which can be enhanced through additives but remain a concern for high-performance environments [8]. Additionally, while ABS offers good chemical resistance, its performance can degrade under prolonged outdoor exposure without protective coatings [9] [10]. Thus, while versatile, virgin ABS may require modifications for demanding applications.

Reinforcement strategies significantly enhance the performance of Acrylonitrile Butadiene Styrene (ABS) composites, with various types of reinforcements employed, including fibers, particulates, and hybrids. Fiber reinforcements, such as glass, carbon, and natural fibers like kenaf and cellulose, improve mechanical properties like tensile strength and impact resistance. For instance, glass fiber reinforced ABS composites exhibit superior tensile strength (45.76 MPa) compared to pure ABS (41.6 MPa) [11]. Hybrid reinforcements, combining materials like kenaf and glass fibers, not only enhance strength and stiffness but also promote sustainability through recyclability [12]. Additionally, carbon nanotubes have been shown to significantly increase the elastic modulus and strength of ABS composites, achieving ultimate strengths of 34.18 MPa [13]. The integration of particulates, such as granite powder, can also modify properties, although their effects may vary, sometimes reducing tensile strength [14]. Overall, the strategic selection of reinforcements is crucial for tailoring ABS composites for specific applications, balancing performance and sustainability.

Glass fiber reinforcement in ABS composites significantly enhances mechanical properties such as tensile, impact, and flexural strength. Studies have shown that incorporating glass fibers into ABS matrices results in increased tensile strength, with values rising from 183.6 MPa to 380.6 MPa in certain blends, and flexural strength improvements from 165.3 MPa to 335.6 MPa, demonstrating the material's enhanced load-bearing capacity [15]. Additionally, glass fiber/ABS composites exhibit superior flexural strength (64.46 MPa) and impact strength (0.089 J/mm²) compared to pure ABS, indicating their potential for applications requiring high mechanical resilience [16]. The thermal stability of these composites is also improved, as evidenced by a higher residue yield in thermogravimetric analysis, with

GF/ABS composites showing a final residue of 42.36% [17]. The addition of glass fibers affects the morphology and interfacial bonding of the composites, with scanning electron microscopy revealing improved adhesion between fibers and the ABS matrix, particularly when treated with coupling agents like 3-aminopropyltrimethoxysilane [18]. This enhanced interfacial bonding is crucial for the effective transfer of stress between the matrix and the fibers, contributing to the overall mechanical performance. Furthermore, the incorporation of glass fibers reduces the coefficient of thermal expansion, enhancing dimensional stability under thermal stress [19]. These improvements make glass fiber-reinforced ABS composites suitable for demanding applications in automotive and aerospace industries, where both mechanical strength and thermal stability are critical [20].

Mineral fillers such as granite powder and fly ash play a significant role in enhancing the sustainability and performance of cementitious materials. The incorporation of granite powder not only reduces landfill waste but also contributes to lower carbon dioxide emissions associated with cement production, as both granite powder and fly ash can partially replace cement in concrete mixes [21] [22]. Studies indicate that these fillers improve mechanical properties, including compressive strength and abrasion resistance, by facilitating the formation of calcium-silicate-hydrate (C-S-H) gel, which enhances the durability of the concrete [23] [24]. Additionally, the use of granite powder in geopolymer concrete formulations has shown promising results in reducing embodied energy and improving early strength gain, making it a viable eco-friendly alternative in construction [25]. Overall, the integration of these mineral-based fillers not only promotes sustainability but also leads to cost reductions in material production.

Research on granite powder reinforcement in thermoplastic composites reveals significant enhancements in mechanical and thermal properties across various polymer matrices. For instance, granite powder was incorporated into polybenzoxazine composites, resulting in increased char yield and micro-hardness, with zero water absorption observed, indicating excellent dimensional stability [26]. Similarly, in epoxy composites, the addition of granite powder improved tensile and flexural strengths, particularly at 15% weight, while also demonstrating enhanced thermal and chemical resistance [27]. Studies on hydroxyl-terminated polyurethane toughened epoxy composites showed that granite powder reinforcement improved compression and impact resistance, further validating its effectiveness as a filler [28][29]. Additionally, in Acrylonitrile Butadiene Styrene (ABS) composites, while granite powder alone reduced tensile strength, its combination with glass fiber yielded improved compressive strength and hardness, showcasing the potential for tailored property enhancements in composite applications [30]. Overall, granite powder serves as a promising, cost-effective reinforcement in thermoplastic composites, enhancing various mechanical and thermal properties.

Despite extensive research on polymer matrix composites (PMCs), there remain notable gaps in the current literature concerning the development and characterization of hybrid ABS composites. While several studies have explored the mechanical and thermal behavior of ABS reinforced with individual fillers such as glass fiber or mineral particles, limited attention has been given to systems that integrate both reinforcements in a hybrid format. The mechanical properties of glass fiber-reinforced ABS composites are well-documented, yet the comprehensive performance—including thermal, thermo-mechanical, and morphological behavior—of hybrid ABS composites remains underexplored. Additionally, although granite powder has shown promise as a filler in cement and epoxy-based systems due to its thermal stability and compressive strength benefits, its role in thermoplastics like ABS, particularly in combination with fibers, lacks in-depth investigation. There is also a scarcity of studies correlating morphological features, such as fiber-matrix interaction and filler dispersion, with key performance properties. Moreover, most of the available research tends to focus on isolated property evaluations, overlooking the need for a holistic assessment that encompasses shrinkage, warpage, mechanical strength, and thermal stability in a unified manner.

To address these limitations, this study proposes the use of a hybrid reinforcement system comprising glass fiber and granite powder in an ABS matrix. Glass fibers are known for enhancing tensile, flexural, and impact strength due to their high load-bearing capacity and aspect ratio, while granite powder can improve dimensional stability, compressive strength, and thermal resistance, alongside reducing the overall cost and environmental footprint of the composite. When used together, these reinforcements offer synergistic benefits that potentially overcome the shortcomings associated with single-filler systems. The integration of these two distinct fillers allows for a balanced material profile that supports both structural integrity and thermal performance.

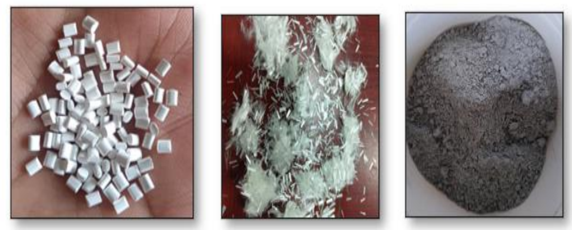
Hence, the present study emphasizes the need for a comprehensive evaluation of hybrid ABS composites, analyzing not just mechanical and thermal properties, but also physical changes and microstructural features through morphological analysis. This holistic approach will provide valuable insights into the optimization of ABS composites for applications that demand a combination of strength, stability, and durability, thereby contributing to the advancement of material science in both industrial and academic contexts.

III.MATERIALS AND METHODOLOGY

The development of high-performance polymer composites has garnered significant interest due to the growing demand for lightweight, durable, and sustainable materials across various engineering applications. Acrylonitrile Butadiene Styrene (ABS) is extensively utilized in industrial and commercial sectors owing to its excellent mechanical strength, impact resistance, and ease of processing. However, its moderate mechanical and thermal properties limit its applicability in high-performance and demanding environments. To address these limitations, the incorporation of reinforcements such as glass fibers and particulate fillers has been explored to enhance the composite's overall performance.

In the present study, glass fiber (GF) and granite powder (GP) are selected as reinforcements to develop a hybrid green composite based on the ABS polymer matrix. Glass fiber contributes significantly to improving mechanical strength and impact resistance, while granite powder a by-product of stone-cutting industries enhances wear resistance and thermal stability. The inclusion of granite powder not only strengthens the material but also promotes sustainability by repurposing industrial waste.

The composites are fabricated using plastic injection moulding, a widely adopted technique known for producing high-precision polymer components with excellent repeatability. As the final properties of the composites are strongly influenced by processing conditions, the Taguchi method is employed to optimize key injection moulding parameters. This robust statistical approach enables efficient experimental design with minimal trials, facilitating the achievement of superior mechanical, thermal, and morphological properties in the developed hybrid composites.



Virgin ABS Glass fiber Granite powder

Fig:3.1 Raw materials

3.1 Fabrication of Hybrid ABS pellets using Twin Extruder

Fig:3.2 Extruder machine

The compounding of ABS granules, glass fiber, and granite powder was performed using a twin-screw co-rotating extruder, as shown in Figure 3.2 (Flytech Engineering, Model FUE-1C). This high-performance compounding machine is specifically designed for precise and homogeneous blending of polymer-based materials. It operates at temperatures up to 400°C and offers an adjustable throughput capacity ranging from 5 to 15 kg/hr. The equipment requires a minimum feed quantity of 200 g, making it suitable for both small-batch experimental trials and pilot-scale production.

Table: 3.1Mixing proportion of materials

Batch Code	Batch Name	ABS % of weight	Glass fiber % of weight	Granite powder % of weight
A	Pure ABS	100%	0%	0%
B	ABS+GF	90%	10%	0%
C	ABS+GP	90%	0%	10%
D	ABS+GF+GP	80%	10%	10%

The compounded polymer matrix composite (PMC) extrudate was cooled and subsequently cut into uniform-sized pellets, as illustrated in Figure 3.3. These pellets serve as feedstock for subsequent injection molding or other downstream processing operations. To eliminate residual moisture—which could cause defects such as void formation, poor interfacial adhesion, or hydrolytic degradation—the PMC pellets underwent a controlled drying process. This involved heating at 60°C for 8 hours in a dedicated drying chamber. This crucial step ensures optimal processability during molding and contributes to the enhanced structural integrity and consistency of the final composite product.

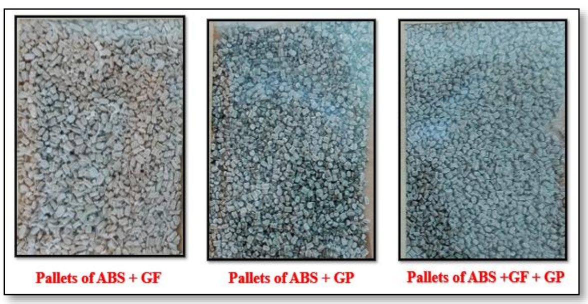


Fig:3.3 Compounder ABS pellets

3.2 Injection Moulding Process

Fig:3.4 Injection Moulding Machine

The prepared hybrid PMC pellets were molded into standardized test specimens using a Milacron Nova 80 Servo injection molding machine with an 80-ton clamping force, as shown in Figure 3.4 Injection molding was selected for its capability to produce highly precise, repeatable, and defect-free specimens, which are essential for conducting accurate mechanical and thermal characterization tests.

Fig:3.5 Tensile, Flexural & Compression moulds for specimen preparation

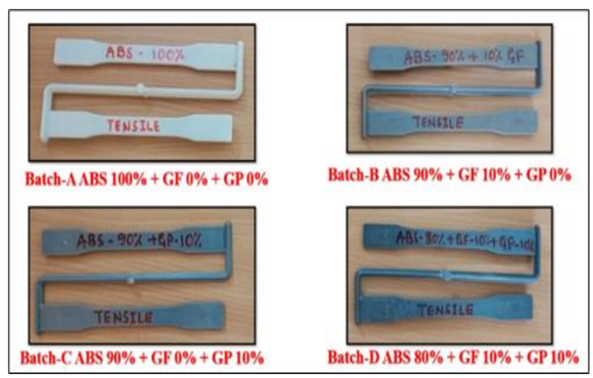


Fig: 3.6 Tensile Test Samples of Batches A, B, C, and D

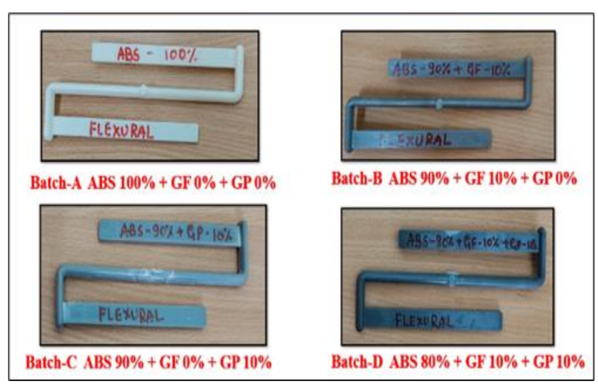


Fig: 3.7 Flexural Test Samples of Batches A, B, C, and D

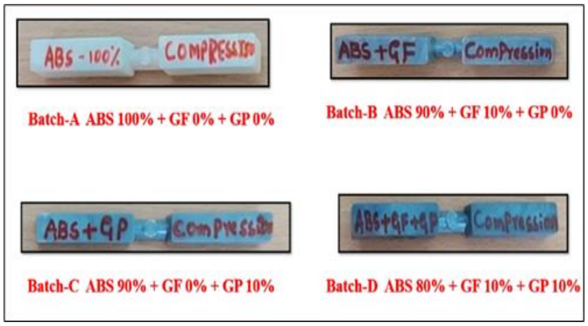


Fig:3.8 Compression Test Samples of Batches A, B, C, and D

IV. PHYSICAL CHARACTERIZATION

4.1 Density and Void Content

In polymer matrix composites (PMCs), density and void content are fundamental parameters that significantly influence the mechanical properties, durability, and overall performance of the material. Accurate determination of composite density provides insight into the effectiveness of the compounding and molding processes, while void content is an indicator of internal defects such as trapped air or incomplete matrix impregnation. These voids can act as stress concentrators, reducing strength, stiffness, and fatigue life. Therefore, minimizing void content is essential for ensuring structural integrity and consistent material behavior under various loading conditions. Both parameters also affect dimensional stability and long-term reliability, making them critical for quality assurance in engineering applications.

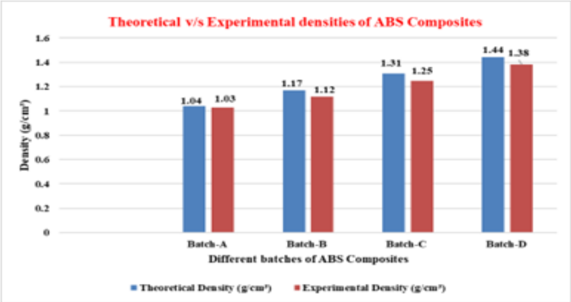


Fig: 4.1 Theoretical v/s Experimental densities of ABS Composites

The theoretical density of the composite is calculated from the weight fractions and densities of its constituents, while experimental density is measured via the Archimedes method. Due to voids and processing flaws, experimental values are typically lower. The inclusion of glass fiber and granite powder, both denser than ABS, increases composite density, with Batch-D showing the highest due to dual reinforcement. Void content, higher in filled composites (Batches B, C, and D), peaks in Batch-C (4.58%) likely due to poor granite powder dispersion. Since high void content undermines strength and durability, optimizing molding parameters is critical for quality enhancement.

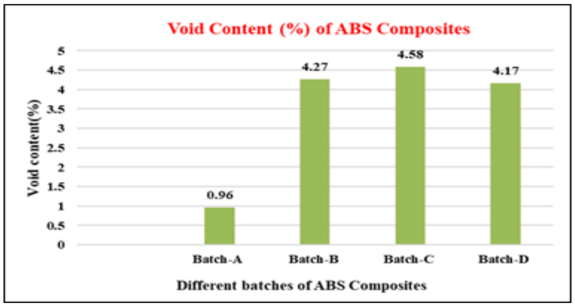


Fig: 4.2 Void content of ABS Composites

4.2 Warpage measurement of ABS Composites

Batch-A (Pure ABS): Highest warpage due to high thermal expansion and shrinkage. Batch-B (ABS + 10% GF): Lowest warpage since glass fibers reduce shrinkage and improve dimensional stability. Batch-C (ABS + 10% Granite Powder): Granite powder provides moderate stability, but fewer reinforcement effects than fibers. Batch-D (Hybrid Composite): Balanced warpage reduction due to synergistic effects of fibers and fillers.

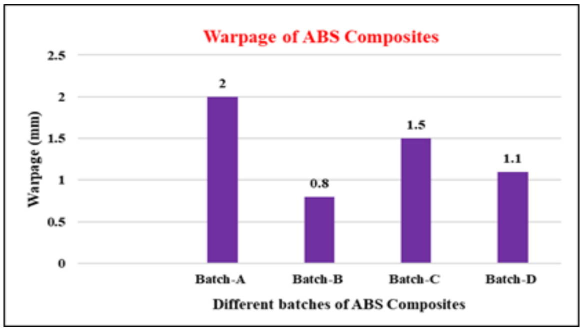


Fig: 4.3 Warpage measurements of ABS Composites

4.3 Shrinkage measurement of ABS Composites

Batch-A (Pure ABS) has the highest shrinkage due to its high thermal expansion. Batch-B (ABS + 10% GF) has the lowest shrinkage because glass fibers restrict polymer contraction. Batch-C (ABS + 10% Granite Powder) reduces shrinkage slightly but not as much as fibers. Batch-D (Hybrid Composite) exhibits moderate shrinkage, as both fillers reduce contraction.

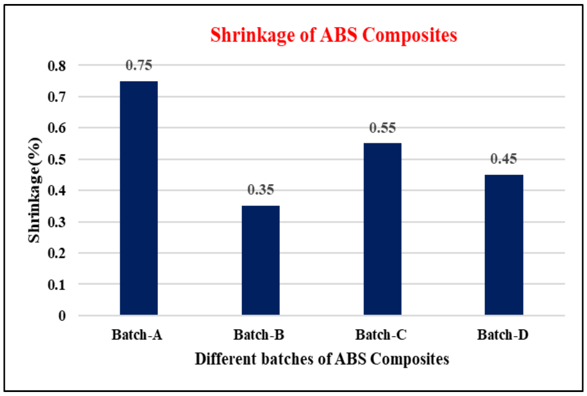


Fig: 4.4 Shrinkage measurements of ABS Composites

4.4 Melt Flow Index (MFI) Measurement of ABS Composites

Batch A (Virgin ABS): Has the highest MFI since pure ABS has no fillers to restrict flow. Batch B (ABS + 10% Glass Fiber): Adding glass fibers increases viscosity, reducing MFI due to restricted polymer chain movement.

Batch C (ABS + 10% Granite Powder): Granite powder behaves differently than fibers but still increases viscosity slightly. Batch D (ABS + 10% Glass Fiber + 10% Granite Powder): This batch has the lowest MFI because both fillers reduce polymer flow.

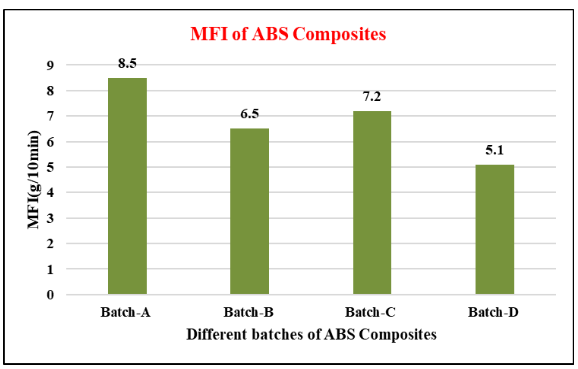


Fig: 4.5 MFI measurements of ABS Composites

V. MECHANICAL PROPERTIES OF ABS COMPOSITES

5.1 Tensile strength of ABS composites.

The addition of fillers impacts the tensile strength of ABS composites. Glass fiber (Batch B) increases tensile strength to 45.76 MPa from 41.6 MPa (Batch A), due to better load transfer and reinforcement. Granite powder (Batch C) lowers it to 36.9 MPa, likely from poor dispersion and weak matrix bonding. The hybrid (Batch D) shows intermediate strength (42.54 MPa), where glass fiber adds strength but granite powder introduces defects, slightly reducing the overall improvement.

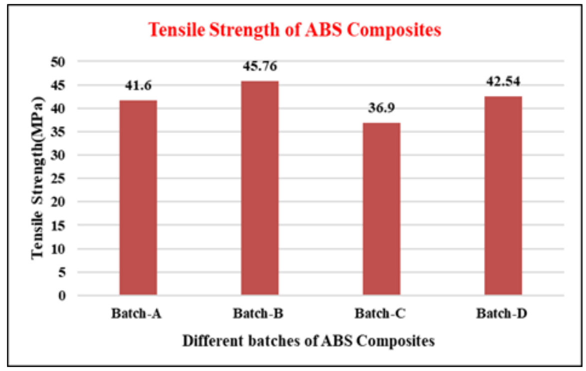


Fig: 5.1 Tensile strength of ABS Composites

5.2 Compressive strength of ABS composites

The compressive strength of ABS composites improves significantly with reinforcement. Virgin ABS (Batch A) have the lowest strength at 48.9 MPa due to its unreinforced nature. Adding 10% glass fiber (Batch B) raises the strength to 51.5 MPa, enhancing rigidity and load-bearing capacity. Granite powder (Batch C) further increases it to 52.48 MPa, likely due to added stiffness. The hybrid composite (Batch D) shows the highest strength at 53.6 MPa, demonstrating a synergistic effect of glass fiber and granite powder. Overall, the reinforcements boost compressive performance, making the composites suitable for high-load applications.

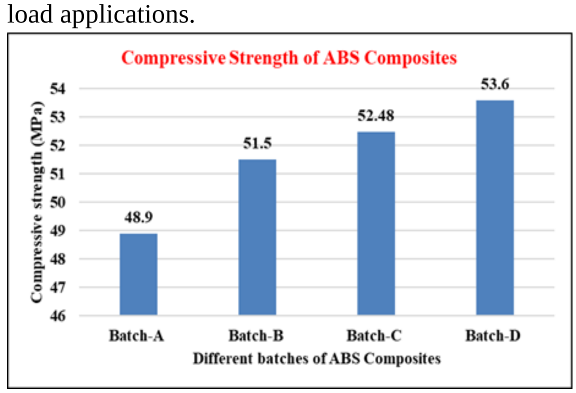


Fig: 5.2 Compressive strength of ABS Composites

5.3 Flexural strength of ABS composites

Virgin ABS (Batch A) show a baseline flexural strength of 65.9 MPa. Reinforcement with 10% glass fiber (Batch B) increases this to 68.7 MPa, demonstrating improved bending resistance. In contrast, Batch C with 10% granite powder drops to 61.2 MPa, indicating reduced flexibility and increased brittleness. The hybrid composite (Batch D) records the lowest value at 58.6 MPa, likely due to poor matrix-filler interaction from the dual fillers. While glass fiber improves flexural strength, excessive or incompatible fillers can compromise overall performance.

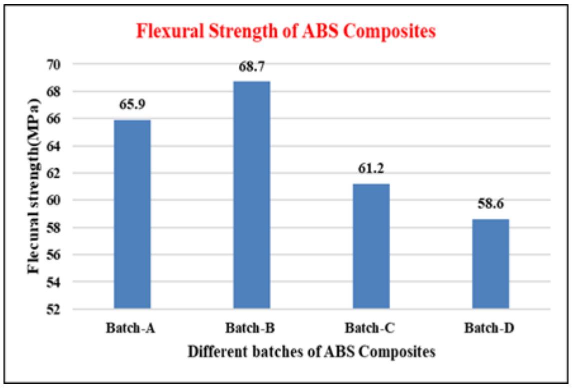


Fig: 5.3 Flexural strength of ABS Composites

5.4 Impact strength of ABS composites

Virgin ABS (Batch A) demonstrate the highest impact strength (12.37 KJ/m²), reflecting excellent toughness and energy absorption. With the addition of 10% glass fiber (Batch B), impact strength drops sharply to 5.31 KJ/m², indicating increased brittleness. Batch C, reinforced with 10% granite powder, shows an even lower value of 4.38 KJ/m², due to the rigid, brittle nature of the filler. The hybrid composite (Batch D) records the lowest impact strength (3.57 KJ/m²), suggesting that combining both reinforcements significantly compromises toughness. While fillers enhance stiffness, they considerably reduce impact resistance, making the material more brittle than virgin ABS.

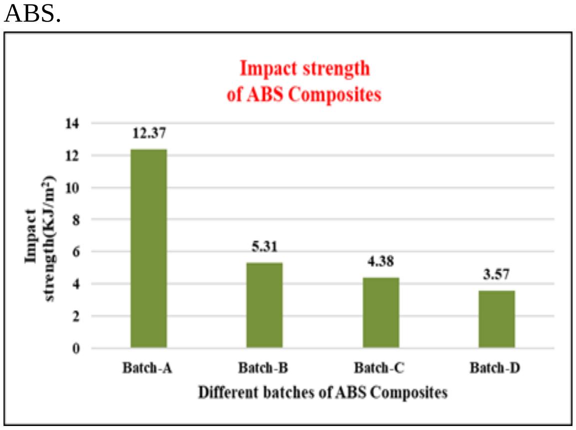


Fig: 5.4 Impact strength of ABS Composites

5.5 Hardness value of ABS composites

Batch D (ABS + 10% GF + 10% GP) exhibits the highest hardness value of 86, indicating a significant improvement in surface resistance due to the synergistic effect of dual reinforcements. Batch B (ABS + 10% Glass Fiber) follows closely with a hardness of 84, highlighting the effectiveness of glass fiber in enhancing rigidity. Batch C (ABS + 10% Granite Powder) records a moderate hardness of 81, showing that granite powder also contributes to surface strength, though to a lesser extent. Virgin ABS (Batch A) have the lowest hardness of 78, confirming its comparatively lower resistance to indentation.

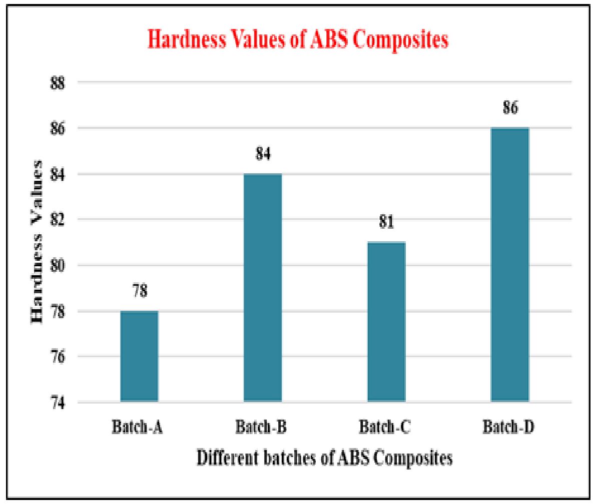


Fig: 5.5 Hardnes values of ABS Composites

VI. THERMO-MECHANICAL PROPERTIES OF ABS COMPOSITES

6.1 Dynamic Mechanical Analysis (DMA) for Batch A

DMA analysis of Virgin ABS (Batch A) shows a glass transition temperature (Tg) at 98.38°C, indicated by a drop in storage modulus, with a tan delta peak at 109.24°C confirming the transition. The high initial storage modulus reflects stiffness at low temperatures, which decreases beyond Tg. The loss modulus peaks at 410.79 MPa around 99.95°C, highlighting peak energy dissipation. Crossover points at 102.91°C and 117.59°C mark transitions to rubbery and viscous states. A tan delta peak of 1.8604 indicates strong damping, beneficial for impact absorption but may affect thermal stability.

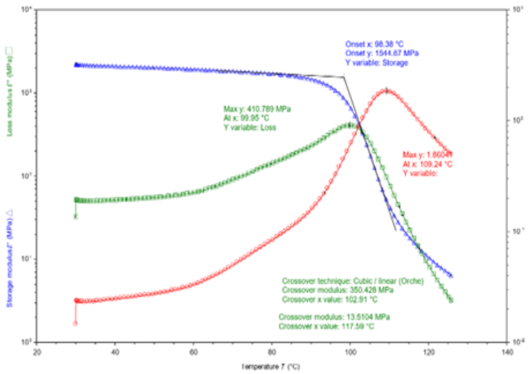


Fig:6.1 Dynamic Mechanical Analysis (DMA) for Batch A

6.2 Dynamic Mechanical Analysis (DMA) for Batch B

DMA results for Batch B (ABS + GF) show a glass transition onset at 99.15°C and a tan delta peak at 109.78°C, indicating increased molecular mobility. The initial storage modulus (E') is significantly higher (2082.68 MPa), confirming improved stiffness due to glass fiber reinforcement. Despite decreasing beyond Tg, it remains higher than Batch A. The peak loss modulus (564.54 MPa at 101.22°C) reflects enhanced energy dissipation and stress transfer. Crossover points at 103.90°C and 118.25°C indicate transitions to viscoelastic and rubbery states. A lower than delta peak (1.699) suggests reduced damping but improved structural rigidity.

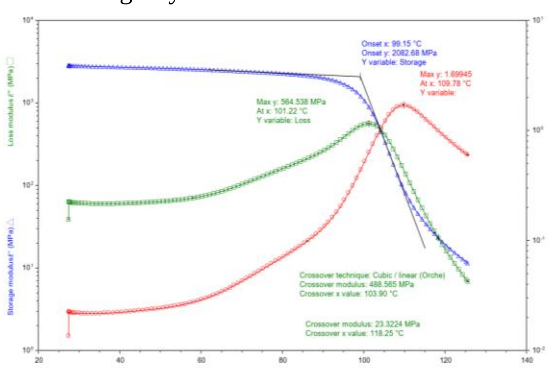


Fig:6.2 Dynamic Mechanical Analysis (DMA) for Batch B

6.3 Dynamic Mechanical Analysis (DMA) for Batch C

For Batch C, the glass transition begins at 98.62°C, with a tan delta peak at 109.61°C confirming peak molecular mobility. The initial storage modulus (1681.22 MPa) is higher than virgin ABS but lower than glass fiber-reinforced Batch B, showing moderate stiffness improvement due to granite powder. The peak loss modulus (441.26 MPa at 100.31°C) suggests enhanced energy dissipation over Batch A. Crossover points at 103.24°C and 117.98°C reflect transitions into viscoelastic and rubbery states. A higher than delta (1.837) than Batch B indicates better damping, making Batch C suitable for vibration-absorbing applications.

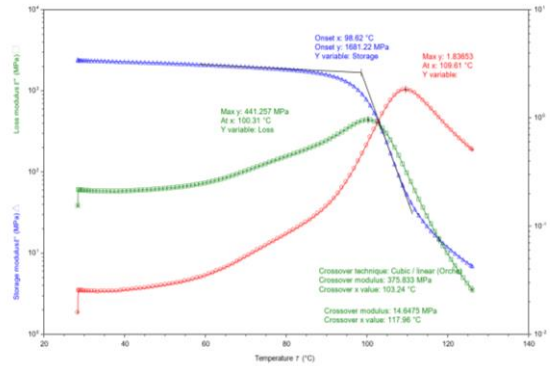


Fig:6.3 Dynamic Mechanical Analysis (DMA) for Batch C

6.4 Dynamic Mechanical Analysis (DMA) for Batch D

Batch D shows the onset of glass transition at 98.95°C, with a tan delta peak at 110.41°C, indicating high molecular mobility. Its initial storage modulus (2428.82 MPa) is the highest among all batches, reflecting superior stiffness due to dual reinforcement. The peak loss modulus (558.64 MPa at 101.11°C) indicates effective energy dissipation, just below Batch B. Crossover points at 104.08°C and 119.19°C mark transitions to viscoelastic and rubbery states. The tan delta peak (1.827), comparable to Batch C, shows balanced damping, making Batch D ideal for applications demanding both rigidity and moderate impact absorption.

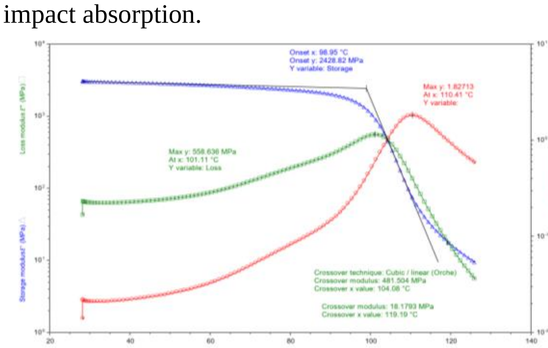


Fig:6.4 Dynamic Mechanical Analysis (DMA) for Batch D

6.5. Thermo Gravimetric Analysis (TGA) for Batch-A

The initial major decomposition of the material begins at 427.07°C, where 54% weight loss occurs, marking the primary degradation stage confirmed by the DTG peak. Residual weight at 800°C is 1.49%, indicating the presence of thermally stable inorganic fillers or char. The curve shows a single major decomposition step followed by minor events, suggesting thermal breakdown of various components. Overall, the material remains thermally stable up to ~400°C, making it suitable for high-temperature applications.

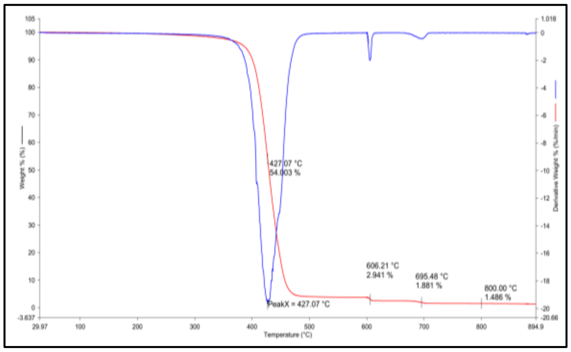


Fig: 6.5 Thermo Gravimetric Analysis (TGA) for Batch-A

6.6. Thermo Gravimetric Analysis (TGA) for Batch-B

The primary decomposition of Batch B occurs at 427.15°C with a 57.2% weight loss, marking significant polymer degradation. A second stage at 604.37°C shows an additional 9.44% loss, likely from reinforcing material breakdown. At 800°C, 7.81% residue remains, indicating the presence of thermally stable glass fiber. Compared to Batch A, Batch B exhibits slightly higher thermal stability and slower degradation in later stages, confirming the thermal reinforcing effect of glass fiber.

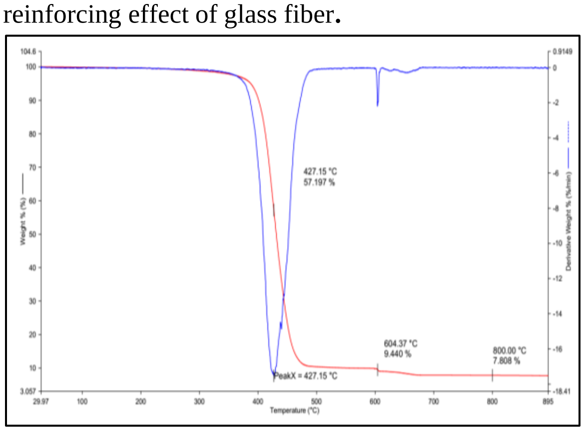


Fig: 6.6 Thermo Gravimetric Analysis (TGA) for Batch-B

6.7. Thermo Gravimetric Analysis (TGA) for Batch-C

Batch C shows a primary decomposition at 428.78°C with a 55.76% weight loss, slightly higher than Batches A and B, indicating improved thermal stability. A second stage at 604.43°C causes a 9.75% weight loss, likely from granite powder interaction. The final residue at 800°C is 8.18%, reflecting better char formation due to the ceramic nature of granite. Compared to the other batches, Batch C demonstrates enhanced high-temperature stability and slower late-stage decomposition, suggesting effective thermal shielding by granite powder.

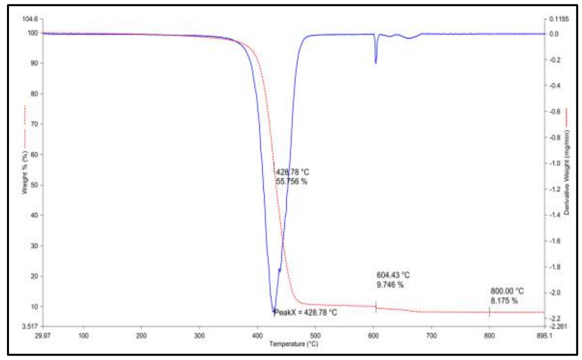


Fig: 6.7 Thermo Gravimetric Analysis (TGA) for Batch-C

Batch D undergoes major decomposition at 426.35°C with a 61.22% weight loss, slightly earlier than other batches but still indicating good thermal resistance. A notable second degradation stage at 603.85°C leads to an additional 20.88% weight loss, the highest among all, suggesting strong filler-matrix interaction. At 800°C, a significant 19.69% residue remains — the highest recorded — highlighting superior thermal shielding due to the combined effect of glass fiber and granite powder. Despite a slightly lower initial degradation temperature, Batch D exhibits the best overall thermal stability and resistance to high-temperature decomposition.

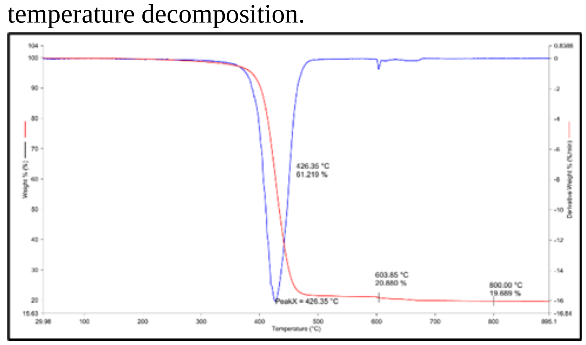


Fig: 6.8 Thermo Gravimetric Analysis (TGA) for Batch-D

VII. MORPHOLOGICAL CHARACTERIZATIONS OF ABS COMPOSITES

7.1 Morphological Characterizations of Virgin ABS-Batch-A

The microstructure of the virgin ABS sample reveals pores and cavities, likely caused by incomplete polymer consolidation during the injection molding process, which can adversely affect mechanical properties such as strength and toughness. The absence of reinforcement phases like glass fibers or granite powder results in a homogeneous surface, distinguishing it from fiber-reinforced or filler-added composites. Additionally, faint flow lines are visible in certain regions, indicating the direction of polymer flow during molding, which may contribute to mechanical anisotropy.

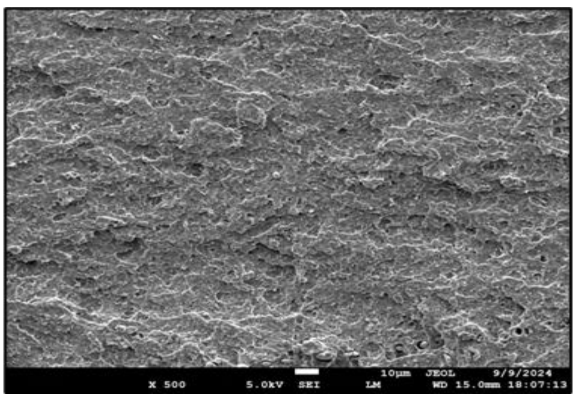


Fig: 7.1 Morphological Characterizations of Virgin ABS (Batch-A)

7.2 Morphological Characterizations of Virgin ABS-Batch-B

The microstructure of the fiber-reinforced ABS composite reveals the presence of glass fibers, which are relatively uniformly distributed and contribute to enhanced structural integrity and mechanical performance. However, some regions exhibit fiber pull-out and debonding, suggesting a weak fiber-matrix interface, likely due to poor adhesion or insufficient wetting by the ABS matrix, which may reduce load transfer efficiency. Voids and pores, similar to those in the virgin sample, are also present, potentially caused by air entrapment during molding and acting as stress concentrators. The fracture surface indicates a mixed failure mode, combining ductile polymer deformation with brittle fiber fracture, thereby offering a balance between strength and toughness.

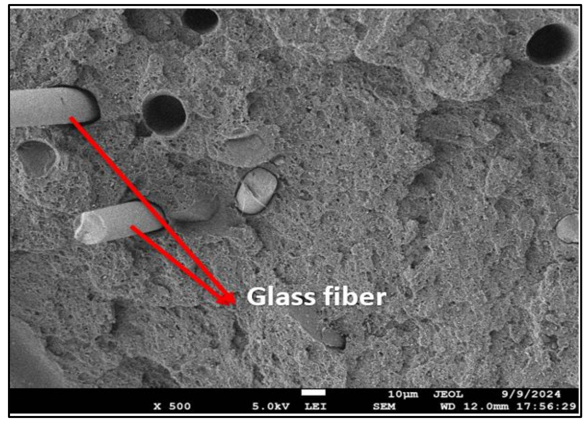


Fig: 7.2 Morphological Characterizations of ABS Composite (Batch-B)

7.3 Morphological Characterizations of Virgin ABS-Batch-C

The microstructure of the granite powder-reinforced ABS composite shows well-embedded granite particles, although some have debonded, leaving voids that indicate suboptimal interfacial bonding with the ABS matrix. These voids, along with particle pull-out sites, suggest a predominantly brittle fracture mechanism, contrasting with the ductile behavior observed in pure ABS. Additionally, the sharp edges of the granite particles may serve as stress concentrators, promoting crack initiation and propagation. While this could reduce the composite's toughness, it may also contribute to improved hardness and wear resistance.

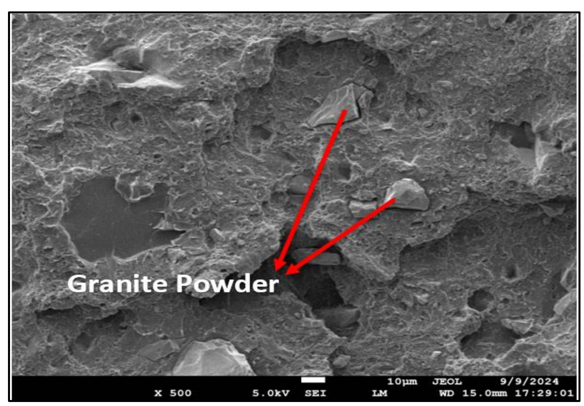


Fig: 7.3 Morphological Characterizations of ABS Composite (Batch-C)

7.4 Morphological Characterizations of Virgin ABS-Batch-D

The hybrid ABS composite reinforced with both glass fibers and granite powder demonstrates a synergistic effect, where glass fibers contribute to tensile strength and flexibility, while granite powder enhances hardness and wear resistance, albeit with a potential trade-off in ductility. Microstructural analysis reveals some fiber pull-outs and particle debonding, indicating areas where interfacial adhesion could be improved. Additionally, the presence of pores may serve as stress concentrators, potentially reducing impact resistance. However, the dual reinforcement appears to aid in crack deflection, suggesting improved fracture toughness compared to composites reinforced with granite powder alone.

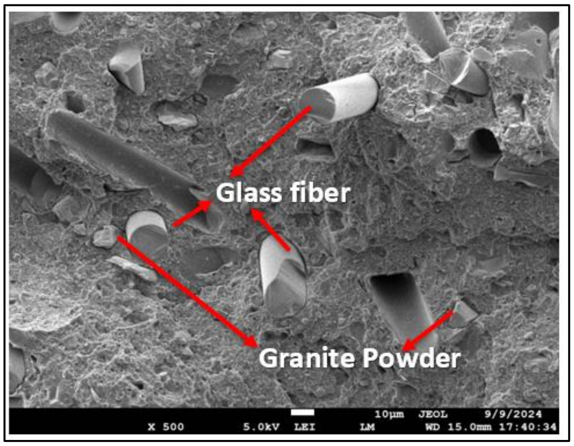


Fig: 7.4 Morphological Characterizations of ABS Composite (Batch-D)

VIII CONCLUSION

The experimental results clearly demonstrate that the hybridization of ABS polymer with glass fiber and granite powder significantly enhances the physical, mechanical, and thermo-mechanical properties of the developed composites. Among all the fabricated samples, Batch D (ABS with 10% glass fiber and 10% granite powder) exhibited the most superior performance in tensile strength, flexural strength, impact resistance, and heat deflection temperature. This improvement can be attributed to the synergistic effect of dual fillers, where glass fiber contributed to mechanical reinforcement while granite powder improved the dimensional stability and thermal resistance of the composite. The successful integration of these fillers using twin-screw extrusion followed by injection moulding not only ensured uniform dispersion but also enhanced the interfacial bonding within the matrix. Therefore, the developed hybrid ABS composite holds significant potential for use in high-performance engineering and industrial applications where strength, durability, and thermal stability are critical.

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