Experimental Investigation of Thin Wall Hybrid Composite Structure Based on Impact Loading

Ihab S. Hasan[1], Emad Q. Hussein[2]

[1]*College of Engineering, University of Kerbala, Karbala, Iraq, ihab.sh@s.uokerbala.edu.iq*
[2]*College of Engineering, University of Kerbala, Karbala, Iraq, emad.dujaily@uokerbala.edu.iq*

In mechanical engineering, the development of composite materials has revolutionized the field, especially in terms of improving strength-to-weight ratios. This research focuses on hybrid composites composed of epoxy resin, glass fibers, and fine aluminum powder, emphasizing their effectiveness in situations involving impact loads. The study uses ARALDITE CY 205 IN for the epoxy matrix, which has a glass transition temperature of 108°C, and strengthens it with E-glass fibers. The addition of aluminum powder in various weight fractions further augments these composites. The manufacturing process involved a standard hand-lay-up technique, and the samples were crafted in different orientations to examine how fiber orientation affects their performance. The research includes thorough testing procedures such as measuring density, assessing tensile strength according to ASTM D3039 standards, and conducting impact tests in line with ISO-180 standards. Initial findings indicated an increase in density with the incorporation of aluminum, although there were issues with the uniformity of the mixture and the presence of voids. The composites' mechanical properties under impact loads appeared promising, yet the impact of void volume fractions needs consideration. This study, integrating both numerical and experimental approaches, highlights the potential and challenges of using aluminum-enhanced glass-epoxy composites in high-impact situations.

Keywords: Aluminum Powder, Composite Structure, Glass-Epoxy, Thin Wall Hybrid.

1. Introduction

In the constantly advancing field of materials science, there is a relentless quest to discover materials that surpass existing standards in efficiency, longevity, and practicality (Singh & SK Jain, 2013). A key area of focus in this quest is the study of composite materials. Composites are notable for their ability to merge the positive attributes of different substances, thus balancing out the limitations of each component (Al Hilli, 2006). This combination often leads to the creation of materials that are stronger, lighter, or specifically designed for certain uses, compared to their single-material counterparts (Naik et al., 2005).

Within the broader category of composites, hybrid composites are of particular interest. These composites are characterized by the integration of multiple types of reinforcements into a single matrix, taking advantage of the strengths of various materials (bin Yaakob et al., 2020). This study explores a specific hybrid composite made of epoxy resin, glass fibers, and fine aluminum powder. Each component contributes its own unique benefits, making this amalgamation particularly effective for applications that require impact resistance (Mangalgiri, 1999).

Epoxy resins, exemplified by products like ARALDITE CY 205 IN, are frequently used as the matrix material in various composites because of their inherent adhesive characteristics, resistance to chemicals, and ease of processing (Sikarwar et al., 2012). The thermosetting nature of these resins guarantees that, upon curing, they maintain exceptional dimensional stability and can withstand a variety of environmental conditions (Friedrich & Almajid, 2013). A key aspect of these resins is their glass transition temperature, which is a vital indicator of the temperature range within which the material maintains its mechanical strength (Yeager et al., 2017).

Glass fibers are a popular choice for reinforcing a wide range of composites due to their significant tensile strength, cost-effectiveness, and compatibility with different matrix materials (Miracle, 2005). These fibers significantly boost the structural integrity of the composite. Additionally, by altering the orientation of these fibers within the composite, it's possible to customize the material's directional characteristics, which is particularly crucial in scenarios where the direction of applied loads is known (Pastuszak & Muc, 2013).

Integrating aluminum powder as a filler adds another layer of complexity to the composite. Aluminum is well-known for its outstanding strength-to-weight ratio. In its powdered form, it can be evenly distributed throughout the matrix, potentially improving the composite's rigidity and thermal conductivity. The microstructure, particle size, and distribution of the aluminum powder are critical factors that impact the overall characteristics of the composite (Balasubramanian, 2013).

Despite the apparent benefits of such a composite system, various challenges also exist. These include the fabrication process, ensuring even distribution of the components, managing void content, and achieving optimal bonding at the interfaces between different materials (Wei et al., 2015). The hand-lay-up technique, though traditional, provides a level of control essential for managing these complexities, particularly when working with multiple components (Salman et al., 2016).

Figure 1.

In summary, the objective of this research is to conduct a comprehensive examination of this novel hybrid composite system. The approach integrates both experimental techniques and computational analysis, aiming to provide a detailed understanding of the potential benefits, inherent challenges, and future possibilities of employing this composite, particularly in situations requiring impact resistance (Tham et al., 2008). By thoroughly investigating aspects such as the fabrication process, the distinct properties of the materials, and their performance under diverse test conditions, this study endeavors to make a significant contribution to the ongoing conversation about hybrid composites in the field of mechanical engineering (Denchev & Dencheva, 2012).

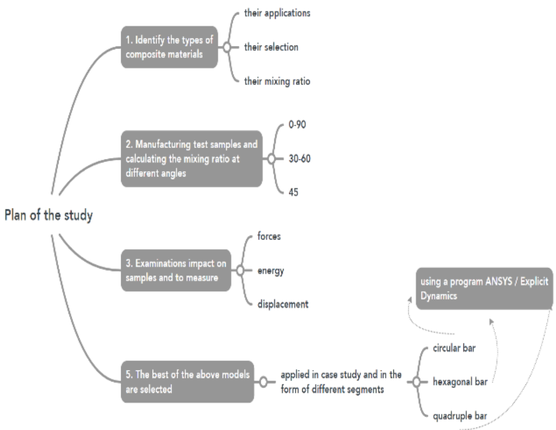


Figure 2.

2. MATRIX SYSTEM: EPOXY RESIN AND CURING AGENT

Understanding the properties of the materials used in the formulation of the composite is pivotal for anticipating the behavior and performance of the final product. This section delineates the characteristics of the epoxy resin, Fiberglass, and fine Aluminium dust utilized in the composite:

2.1. Epoxy

Epoxy polymers are renowned for their excellent thermal and mechanical attributes, making them a preferred choice in the creation of composites. Known for their compatibility with a wide array of fibers, they demonstrate commendable resistance to chemicals and wear. Due to their affordability and versatility, epoxy polymers find extensive applications in adhesives, coatings, and as the primary matrix in composite materials.

Araldite GY 257 is an epoxy resin employed as the foundational material in the composite under study. It is supplemented with a hardener, ANCAMINE 1618 , at a precise ratio to ensure optimal curing and mechanical properties.

Table1: Characteristics of Polymer Binder and Curing Agent

Material	Commercial and Scientific Designation	Parts by Weight	Density (gm/cm³)	Reactive Epoxy Group Measure
Polymer Base	GY 257	100	1.27	182-196
Hardener	ANCAMINE 1618	10	0.94	------

2.2. Fine Aluminium dust

Fine Aluminium dust, possessing distinctive qualities, often serves as a pivotal filler in composite systems. Its small average particle size, which remains below 40 microns, coupled with its impressive purity level of roughly 98.70 %, makes it an ideal candidate for enhancing various material properties.

When amalgamated with epoxy, the Aluminium dust is meticulously incorporated through specific mechanical mixing methodologies. This ensures that the powder is uniformly disseminated within the matrix, achieving a consistent distribution, which is crucial for optimized mechanical properties.

Table 2: Mechanical characteristics of Epoxy, Fiberglass, and Aluminium dust

Property	PolyEpoxide	Fiberglass	Aluminium dust
Tensile Strength (GPa)	0.11	3.4	0.047
Modulus of elasticity (GPa)	4.1	72.3	70
Poisson’s Ratio	0.35	0.2	0.33

2.3. Glass Fiber

Glass fibers are highly esteemed in the realm of synthetic fibers for their compelling balance between remarkable tensile strength and a relatively low specific weight. These fibers have carved out a distinct reputation for their enduring durability, thermal resilience, dimensional stability, and negligible elongation at break.

Table 3: Properties of Glass Fiber

Property	Value
Density (Kg/ml)	2.59
Tensile Strength (GPa)	3.4
Young's Modulus (GPa)	72.3

Ductility (%)	Not specified
Melting Temp. (°C)	Not specified

When amalgamated with epoxy, the Aluminium dust is meticulously incorporated through specific mechanical mixing methodologies. This ensures that the powder is uniformly disseminated within the matrix, achieving a consistent distribution, which is crucial for optimized mechanical properties.

Table 4: Mechanical characteristics of Epoxy, Fiberglass, and Aluminium dust

Property	PolyEpoxide	Fiberglass	Aluminium dust
Tensile Strength (GPa)	0.11	3.4	0.047
Modulus of elasticity (GPa)	4.1	72.3	70
Poisson’s Ratio	0.35	0.2	0.33

3. FABRICATION OF COMPOSITES

The fabrication of composites, especially those that integrate multiple components, requires a meticulous approach to ensure uniformity, desired properties, and structural integrity. This study delves into the fabrication of composites with varying concentrations of epoxy, glass fiber, and aluminum powder.

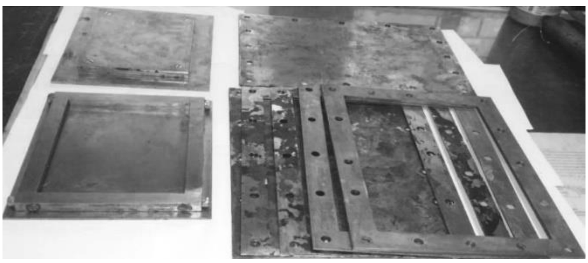


Table 5: Titles and formulations of the engineered composite materials.

Code of Sample	Labeling	Formulation Details
C	EG	Epoxy (40 %) + Glass Fiber (60 %)
D1	EG5Al	Glass Fiber (60 %) + Epoxy (35 %) + Aluminium (5 %)
D2	EG10Al	Glass Fiber (60 %) + Epoxy (30 %) + Aluminium (10 %)
D3	EG15Al	Glass Fiber (60 %) + Epoxy (25 %) + Aluminium (15 %)

*This categories repeated 3 times based on orientation of fiber (0-90 , 30-60 , 45)
- Subsequently, these saturated fibers are systematically layered inside the prepared mould.

3.1. Fabrication Process

1. Conventional Hand-Lay-Up Technique:

- The hand-lay-up method is one of the most common and simple methods for fabricating composite materials. In this technique, layers of reinforcing materials (in this case, glass fibers) are manually placed into a mold, and the resin mixture is then poured or brushed onto the fibers.

- For samples D1, D2, and D3, the requisite amount of aluminum powder is mixed into the resin before the application to ensure a uniform distribution of the filler material throughout the composite.

- Each layer of glass fiber is meticulously aligned based on the desired orientation (0-90, 30-60, or 45 degrees) for each replicate.

2. Light Compression:

- After the hand-lay-up, the composite is subjected to light compression. This ensures that there are no voids or air bubbles trapped within the composite, which could adversely affect its mechanical properties.

- The compression also helps in ensuring a good bond between the resin and the fibers, enhancing the interfacial strength and the overall integrity of the composite.

3. Curing:

- Once the desired thickness and composition are achieved, the composite is allowed to cure. Given the nature of the resin and hardener used, this is done at room temperature.

- The curing process solidifies the resin, anchoring the fibers and aluminum powder in place, and thereby providing the composite its final shape and mechanical properties.

3.2. Quality Checks

- Upon completion of the curing process, the composite is carefully examined for uniformity, strength, and absence of defects, ensuring that it adheres to predefined specifications.

- Through this carefully calibrated process, an aluminum-infused epoxy composite, characterized by enhanced mechanical properties, is successfully fabricated and made ready for subsequent analyses and applications.

3.3. Fabrication Steps of Composites

The fabrication of composites is a meticulous process, ensuring each component contributes effectively to the final material's desired properties. Here's a step-by-step breakdown based on the provided information:

1. Preparation and Precalculation:

- Based on the mold's dimensions, preliminary calculations are performed to ascertain the quantity of each component required.

- The objective is to maintain the designated weight percentages of the composite's constituents, ensuring consistency in the end product.

- Woven fabrics are pre-cut to dimensions of 150mm x 100mm in the required number.

2. Mixing of Resin and Hardener:

- Using a clean, dry glass container placed on a weighing machine, the initial weight is set to zero.
- The epoxy resin, Araldite CY-205 IN, is added slowly to the container until the desired weight reading is displayed.
- To this, hardener (HY 951) is introduced at a ratio of 10:1 by the resin's weight.
- The mixture is then mechanically stirred for approximately 10 minutes, ensuring thorough mixing. This process is halted right as exothermic reactions begin.

3. Incorporation of Aluminum Powder:

- For composites containing aluminum particulates, the aluminum powder is introduced to the epoxy resin before the addition of the hardener.
- This mixture undergoes continuous stirring, ensuring a homogenous dispersion of aluminum within the epoxy resin. After achieving this uniformity, the hardener is added and mixed thoroughly.

4. Mold Preparation:

- The mold's inner surfaces are lined with a thin, tear-resistant plastic film with a few microns' thickness.
- This film serves a dual purpose: acting as a releasing agent and preventing the potential infusion of any external releasing agent into the glass fiber, thereby ensuring purity.

5. Lamination:

2. The mixed epoxy (either the resin-hardener mix or the aluminum-epoxy mix) is uniformly applied onto the woven fibers. This ensures each fiber layer is fully saturated.
3. Once wetted, these fibers are systematically layered one over the other inside the prepared mold.

6. Compression:

- The entire assembly, including the wetted fibers in the mold, is subjected to compression using a weight (about 20 kg).
- This weight is maintained for 24 hours. The compression aids in expelling any trapped air bubbles and squeezing out any excess resin, ensuring a void-free composite.

7. Post-Curing:

- After the initial set, a post-curing stage is instituted.
- The composite is allowed to undergo further curing at room temperature for an extended period of 48 hours. This step ensures the composite fully hardens, setting it up to exhibit its optimal mechanical properties.

By meticulously following these steps, the composite ensures a harmonious integration of its constituents, be it resin, hardener, glass fibers, or aluminum powder, promising a composite with the desired attributes.

Table 6. Dimensions of Different Test Samples

Serial no	Name of the test	Sample dimension
1	Density	30 mm× 12 mm× 6 mm
2	Tensile strength (ASTM D3039-07)	150 mm× 12 mm× 6 mm
3	Impact test	10 mm× 80 mm× 3 mm

Explanation of Table 4:

The table enumerates the dimensions of the samples employed for various tests, emphasizing the meticulous preparation required to ensure accurate and reliable results.

1. Density:

- Sample Dimensions: 30 mm × 12 mm × 6 mm
- The density test requires a smaller sample size. The size is optimal to obtain accurate measurements without waste. Determining the density is crucial because it informs about the composite's weight per unit volume, essential for applications where weight considerations are paramount.

2. Tensile Strength (ASTM D3039-07):

- Sample Dimensions: 150 mm × 12 mm × 6 mm
- The specified dimensions adhere to the standards set by ASTM D3039-07, ensuring that the tensile testing results are both reliable and comparable to other tests conducted under this standard. The elongated shape allows for a consistent application of tensile load, ensuring the sample breaks due to tension, not bending or other secondary stresses. Tensile strength, a measure of a material's resistance to breaking under tension, is one of the most crucial mechanical properties for many applications.

3. Impact Test:

- Sample Dimensions: 10 mm × 80 mm × 3 mm
- This slender sample is designed for impact testing, which gauges the material's ability to absorb sudden forces or shocks without breaking. The thinness ensures that the impact's force is concentrated, thereby truly testing the composite's resistance to sudden, high-energy impacts.

In summary, the sizes and shapes of the samples in Table 4 are tailored for specific tests. Adhering to these dimensions, especially for standardized tests like ASTM D3039-07, ensures that the tests' outcomes are both reproducible and comparable to benchmarks or results from other studies.

4. TEST PROCEDURES FOR COMPOSITE MATERIALS

Composite materials exhibit unique properties, a result of the amalgamation of different constituents. To ensure these composites perform as intended, they undergo various tests. This article elucidates the procedures for three such tests: Density, Tensile Strength, and Impact.

4.1. Density Test

Theoretical Density Calculation:

Before conducting the test, a theoretical density (ρct) is estimated using the weight fractions of the composite's constituents. The equation for this is given by:

$$\rho_{ct} = \frac{1}{\left(\frac{W_f}{\rho_f}\right) + \left(\frac{W_m}{\rho_m}\right) + \left(\frac{W_P}{\rho_P}\right)}$$

Where:

- ($_f$, W_m, W_P) are the weight fractions of the fiber, matrix, and particulate, respectively.

- ($_f$, ρ_m, ρ_P) represent the respective densities.

Experimental Procedure:

The experimental determination of the composite's density is achieved using the water immersion technique. Samples, having dimensions 30 mm × 12 mm × 6 mm, are immersed in water. The principle of displacement helps in determining the sample's volume, and subsequently, its density. To ensure accuracy, four samples of the same composite are tested, and an average value is derived.

Volume Fraction of Voids Calculation:

Voids within a composite can degrade its mechanical properties. Their volume fraction (Vv) is calculated using:

$$V_{V=\frac{\rho_{ca}-\rho_{ce}}{\rho_{ca}}}$$

Where:

- ($_{ca}$) is the composite's apparent (or measured) density.

- ($_{ce}$) is the composite's expected (or theoretical) density.

4.2. Tensile Strength Test

Sample Preparation

For the tensile strength test, samples are cut to the specified dimensions using a CNC machine, adhering to the ASTM D3039 standard. This standardization ensures that the test results are consistent and comparable with other studies or benchmarks.

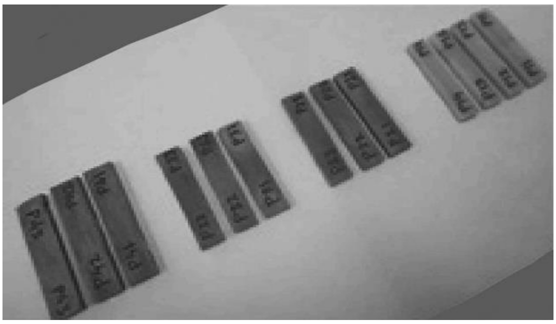
Test Setup and Procedure:

The samples are subjected to tension using a tensile test instrument. This instrument measures parameters like tensile strength, modulus of elasticity, stiffness, and deformations as the material is pulled apart. For the composites in this study, tests are executed at room temperature, approximately 27°C. Moreover, a quasi-static strain rate of 10E-4/s is maintained throughout the test. These conditions help in achieving results that are representative of typical use-case scenarios for the composites.

4.3. Impact Test

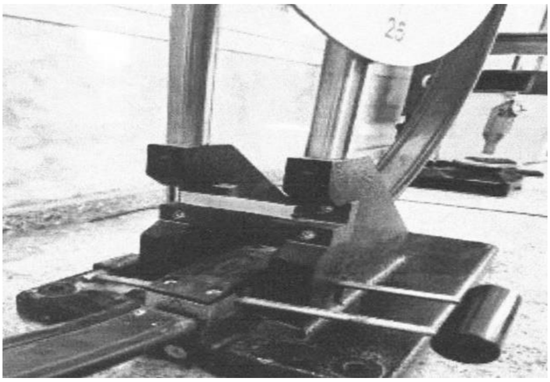
Sample Preparation:

Impact tests provide insights into a material's toughness and ability to absorb energy without fracturing. For this purpose, samples are prepared according to the ISO-180 standard with dimensions of 10mm × 80mm × 3mm.



Test Setup and Procedure:

The samples are tested using an impact tester device, specifically designed for composite materials. This device delivers a sudden force or shock to the sample, and the resultant behavior is analyzed. The University of Babylon's College of Engineering Materials, Department of Polymers, is equipped with these testers, ensuring that the tests are conducted under standardized conditions. To achieve accurate results, the samples' responses are gauged multiple times to determine their average behavior.



Conclusion:

Testing is an indispensable aspect of material science and engineering. For composites, with their intricate amalgamation of different constituents, testing becomes even more paramount. By meticulously adhering to established standards like ASTM D3039 and ISO-180, these tests provide invaluable data on the composite's performance metrics. These insights guide engineers and researchers in optimizing composite formulations, ensuring they cater to the specific demands of their intended applications.

5. RESULTS & DISCUSSION

The density of a composite material is a crucial metric that can influence its mechanical properties and potential applications. The density can be affected by the volume fraction of its constituents and the presence of voids, which can be deliberate or unintentional imperfections. Moreover, the presence of voids can lead to reduced strength, decreased stiffness, and diminished durability.

Table 5. Measured and Theoretical Densities with Void Fractions of Glass Epoxy and Aluminum Powder-filled Glass Epoxy Composites.

Table 7: Density and void fraction

Constituents			Calculated Mass per Unit Volume (gm/cc)	Observed Mass per Unit Volume (gm/cc)	Proportion of Empty Spaces (%)
C	EG	Glass Fiber (60 %) + Epoxy (40 %)	1.77	1.79	1.11
D1	EG5Al	Glass Fiber (60 %) + Epoxy (35] %) + Aluminium (5 %)	1.84	1.87	1.6
D2	EG10Al	Epoxy (30 wt %) + Glass Fiber (60 %) + Epoxy (30 %) + Aluminium (10 %)	1.91	1.95	2.05

D3	EG15Al	Glass Fiber (60 %) + Epoxy (25 %) + Aluminium (15 %)	1.97	2.03	2.95

5.1. Analysis of Tensile Tests

The results from our tensile tests on various samples are summarized in the table below, providing a comprehensive view of the tensile strength, influenced by different weight percentages (WT %) of Aluminum (Al) across three orientations.

Table 8: Results of Analysis of Tensile Tests

WT % OF AL	Tensile Strength (MPa) at 45°	at 30-60°	at 0-90°
0	290	313	347.6
5	257	282	306.64
10	203	237	278
15	176	190	210

From the table, several observations can be drawn:

1. The tensile strength for samples with 0 WT % of Al appears to be the highest across all orientations. Specifically, the strength at 0-90° orientation peaks at 347.6 MPa, indicating the maximum tensile capability of the sample without any aluminum.

2. With the introduction of Aluminum into the composite (5 WT %), there's a noticeable decline in tensile strength across all orientations. However, the reduction is not uniform. The most significant drop is witnessed at the 0-90° orientation, where the strength falls to 306.64 MPa.

3. With the bump-up of Aluminum to a heftier 10 Weight Percent and then to 15 Weight Percent, there's a noticeable drop in the muscle to pull strength at every single angle checked out. This kind of hints that while Aluminum could be tossing in some perks to the mix, it's also putting a bit of a squeeze on how much the composite can tug without taking a break.

Critically, while the results offer valuable insights, they also raise questions. The consistent decline in tensile strength with the increment of Aluminum content might indicate possible weak bonding between the aluminum particles and the matrix, or the influence of Aluminum's inherent properties. A deeper investigation into the microstructural level might offer more clarity.

Graphical representation of these results would further enhance the clarity and allow for easier comparison. Plotting the tensile strengths against the aluminum weight percentages for each orientation would visually depict the trends and variations, simplifying the understanding and interpretation of the data.

In conclusion, the tensile test results offer a comprehensive understanding of how Aluminum content influences the tensile strength of our samples across various orientations. While the direct relationship between Aluminum content and tensile strength decline is clear, the underlying causes and mechanics warrant further study.

5.2. Impact Strength Analysis

The study aimed at understanding the impact strength of various samples with different weight percentages of aluminum (AL). The analysis was conducted at three distinct angles: 45°, 30-60°, and 0-90°. The results are depicted in the table below:

Table 9: Impact Strength Results

WT % of Al	Impact Strength (kN/M) at 45°	at 30-60°	at 0-90°
0	33	36	40
5	39	45	60
10	46	52	73
15	59	67	81

5.3. Observations and Analysis

- A consistent trend can be observed where increasing the weight percentage of aluminum improves the impact strength across all tested angles.
- The maximum impact strength is seen at an angle of 0-90° across all samples, suggesting that this orientation provides the maximum resistance to impact.
- A notable jump in impact strength is observed when the aluminum percentage is increased from 10 % to 15 %, especially evident in the results from the 0-90° orientation. This suggests a significant contribution of aluminum content to the composite's overall strength.

5.4. Critical Evaluation

While the trend of increasing strength with higher aluminum content is evident, it might be beneficial to understand the underlying mechanism. It's essential to ensure that the observed increase in strength isn't at the cost of other crucial material properties. Also, considering the economic feasibility of adding more aluminum, a trade-off analysis between strength and cost could provide more clarity.

In conclusion, the results present a promising avenue for enhancing the impact strength of materials through aluminum content manipulation. However, a comprehensive analysis considering other factors is crucial for making informed decisions in practical applications.

6. RECOMMENDATIONS AND FUTURE RESEARCH DIRECTIONS

The detailed analysis of the hybrid composite system, encompassing epoxy resin, glass fibers, and aluminum powder, has not only provided valuable insights but also highlighted areas for improvement and further exploration. Combining recommendations with future research pathways, the following comprehensive list emerges:

1. Advanced Fabrication: Future studies should prioritize advanced fabrication techniques. While the hand-lay-up method has its merits, modern methods like 3D printing might offer better uniformity and design complexity. Automation or semi-automated techniques could optimize constituent dispersion and reduce void fractions.

2. Material Characterization: Diving deeper into microstructural analysis using tools like scanning electron microscopy can offer a granular understanding of the composite. This is pivotal in ensuring optimal interfacial bonding and understanding material interactions.

3. Nano-Reinforcements: The introduction of nanomaterials like carbon nanotubes or graphene can significantly alter the composite's properties. Future research should investigate the potential enhancements and challenges of this integration.

4. Thermal and Electrical Analysis: Considering the incorporation of aluminum, there's potential for the composite to display enhanced thermal and electrical properties. Comprehensive assessments in these areas can diversify application areas.

5. Long-term Durability: Understanding the composite's long-term performance under varied environmental conditions will be crucial. Areas like UV radiation resistance, thermal cycling resilience, and cyclic loading behavior should be prioritized.

6. Sustainability: The recyclability and overall environmental impact of the composite should be a significant focus. Future studies must delve into sustainable fabrication, usage, and disposal methods.

7. Hybrid Fiber Exploration: Beyond glass fibers, the integration of other fibers like carbon or aramid can be explored. Such hybrid combinations can potentially lead to a composite with a wider range of mechanical and physical properties.

8. Self-Healing and Smart Composites: The next frontier in composite research could be materials that can autonomously repair minor damages or materials embedded with sensors, leading to "smart" composites capable of self-assessment or environmental monitoring.

9. Impact Behavior Analysis: It is essential to understand the composite's impact resistance across varied temperature ranges, ensuring its viability in diverse real-world applications.

10. Comparative and Economic Analysis: A head-to-head performance comparison with other commercial composites, coupled with an economic feasibility study, can position the composite aptly in the market landscape.

11. Industry-specific Customization: Tailoring the composite for specific industries, understanding their unique challenges, and molding the material properties accordingly should be a pivotal focus.

In sum, while the current research has paved a robust foundation in understanding the hybrid composite system, the above recommendations and future research avenues ensure that the composite's potential is maximized. This holistic approach, combining both corrective actions and forward-looking research, can lead to groundbreaking innovations in the realm of composite materials.

References

1. Al Hilli, A. H. M. (2006). Analytical and Experimental Study of High Velocity Impact on Composite Plates. College of Engineering of Nahrain University.
2. Balasubramanian, M. (2013). Composite materials and processing. CRC press.
3. bin Yaakob, M. Y., Saion, M. P. Bin, & bin Husin, M. A. (2020). Potential of hybrid natural/synthetic fibers for ballistic resistance: A review. Technology Reports of Kansai University, 6(7), 3447–3459.
4. Denchev, Z., & Dencheva, N. (2012). Manufacturing and properties of aramid reinforced composites. Synthetic Polymer-Polymer Composites, 251–280.
5. Friedrich, K., & Almajid, A. A. (2013). Manufacturing aspects of advanced polymer composites for automotive applications. Applied Composite Materials, 20, 107–128.
6. Mangalgiri, P. D. (1999). Composite materials for aerospace applications. Bulletin of Materials Science, 22, 657–664.
7. Miracle, D. B. (2005). Metal matrix composites–from science to technological significance. Composites Science and Technology, 65(15–16), 2526–2540.
8. Naik, N. K., Shrirao, P., & Reddy, B. C. K. (2005). Ballistic impact behaviour of woven fabric composites: Parametric studies. Materials Science and Engineering: A, 412(1–2), 104–116.
9. Pastuszak, P. D., & Muc, A. (2013). Application of composite materials in modern constructions. Key Engineering Materials, 542, 119–129.
10. Salman, S. D., Leman, Z., Sultan, M. T. H., Ishak, M. R., & Cardona, F. (2016). The effects of orientation on the mechanical and morphological properties of woven kenaf-reinforced poly vinyl butyral film. BioResources, 11(1), 1176–1188.
11. Sikarwar, R. S., Velmurugan, R., & Madhu, V. (2012). Experimental and analytical study of high velocity impact on Kevlar/Epoxy composite plates. Central European Journal of Engineering, 2, 638–649.
12. Singh, S., & SK Jain, P. (2013). An experimental and numerical investigation of mechanical properties of glass fiber reinforced epoxy composites. Advanced Materials Letters, 4(7), 567–572.
13. Tham, C. Y., Tan, V. B. C., & Lee, H.-P. (2008). Ballistic impact of a KEVLAR® helmet: Experiment and simulations. International Journal of Impact Engineering, 35(5), 304–318.
14. Wei, J., Vo, T., & Inam, F. (2015). Epoxy/graphene nanocomposites–processing and properties: a review. Rsc Advances, 5(90), 73510–73524.
15. Yeager, M., Whittaker, A., Todd, M., Kim, H., Key, C., & Gregory, W. (2017). Impact detection and characterization in composite laminates with embedded fiber Bragg gratings. Procedia Engineering, 188, 156–162.