Progress Report

(For End-Semester Evaluation)

B-Tech Project (CP302)

Development of Sand Composite for High Impact Resistance

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With heartfelt thanks and warm regards,

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1. INTRODUCTION

As the threat of ballistic impacts continues to rise, the need for solutions that are both effective and economically viable becomes increasingly critical. In response to this challenge, sand-based composites have gained attention for their potential as cost-effective materials offering robust ballistic protection. This ongoing research continues from our previous work (Development Engineering Project) with sand-reinforced epoxy composites, now expanding its focus to investigate their application in enhancing ballistic impact resistance.

The current study explores the integration of sand into polymer matrix composites in a graded manner, designed to provide a stepwise defense against varied ballistic threats. The composite features a dense, brittle, and hard base impact zone, capable of eroding projectiles, followed by a less dense region that enhances tensile strength and reflects tensile waves, reducing overall impact energy. By incorporating sand particles, the composite's surface area increases, leading to better adhesion between the inclusions and the epoxy matrix. This improved adhesion facilitates more efficient load transfer, resulting in greater hardness and enhanced energy dissipation.

As part of this continuation, we are using different epoxy formulations and molds compared to the previous phase to further optimize the properties of sand-based composites. Comprehensive testing—including tensile, Izod impact, and flexural assessments—has been conducted to evaluate the mechanical and physical properties of the composites. Initial experimental results show that adjusting the volume fraction of sand significantly impacts both the mechanical performance and ballistic resistance of the material. These findings highlight the potential of sand as an environmentally sustainable and cost-effective reinforcement for advanced ballistic protection applications.

2. OBJECTIVE

The primary objective of our project is to enhance the impact resistance of polymer matrix composites through the inclusion of sand in a graded manner. By utilizing sand as a reinforcement, the goal is to create a cost-effective and environmentally sustainable composite material capable of offering robust protection against varied ballistic threats. This research aims to optimize the mechanical properties of the composite—such as hardness, tensile strength, and energy dissipation—by experimenting with different sand types, volume fractions, and epoxy formulations. Ultimately, the project seeks to develop an efficient, economical, and sustainable solution for advanced ballistic protection applications.

3. EXISTING STUDIES

Effective ballistic resistant structures often exhibit an amalgamation of several layers with either different material configurations or distinguished structural configurations which ultimately provides high hardness, toughness, brittle, lightweight, and high energy absorbent characteristics in the structures. Monolithic structures, which often consist of a single material like iron, steel, or aluminum alloys, are commonly used for ballistic resistant structures. However, these structures tend to have high areal densities, resulting in excessive weight, making them inefficient in terms of weight management. Additionally, they usually exhibit low multi-hit capabilities, which reduces their effectiveness when subjected to repeated impacts. Moreover, the overall cost of such monolithic structures is often high, further limiting their suitability for ballistic impact applications [1-3]. Studies have been carried out in order to reduce the weight of the monolithic structure by incorporation of multi layered structures such as sandwich structures comprising regions with significant characteristics which combinedly works as the bullet pierces through the thickness of the structure. In order to restrict penetration, ballistic sandwich designs are usually constructed with a hard frontal layer, usually made of ceramics or Rolled Homogeneous Armor (RHA), to absorb initial impact energy. This causes bullet deformation and spreads contact stresses [4].Further to distribute the impact forces and reduce the back face signature enabling impact damage mitigation, the last layer is usually made up of a thin ductile layer [5]. Also, natural fibers such as flax and jute and synthetic fibers combine to create hybrid composites, which offer economical and environmentally beneficial solutions. The natural fibers help absorb energy, while the synthetic fibers increase load resistance [6]. Further improvements in ballistic performance can be achieved by (a) selection of tuned resin, (b) tailoring the fiber orientation and (c) tuning the fiber-matrix bonding through surface treatment. Despite its effectiveness, polymer matrix fiber composites' structural integrity is compromised by matrix cracking, delamination, and fiber pullout. Fiber composites and sandwich constructions frequently have significant manufacturing costs, and fibers like aramid are moisture-sensitive and degrade in harsh environments [7-8].

To improve structural integrity, functionally graded materials (FGMs) enable smooth property transitions between layers, allowing for direction-specific mechanical responses under high-velocity impacts. By maximizing material qualities where they are most required, this gradient design allows the structure to endure a variety of impact circumstances [9].

When combined, these techniques produce lightweight, multipurpose, ballistic-resistant structures that are appropriate for high-impact uses. Inclusion composites, using fillers like sand, ceramics, or metallic particles within a polymer matrix, are promising for ballistic protection [10]. These inclusions boost hardness and energy dissipation, enhancing resistance to high velocity impacts. Sand-filled composites, in particular, increase stiffness and hardness at a low cost, though optimizing particle type, size, and distribution remains as one of the daunting tasks. The densification of sand within the matrix limits voids, aiding impact resistance. Key factors like sand preparation, segregation, and curing processes significantly influence these composites' effectiveness [11,12]. Saleemsab Doddamani et al.'s [13] have used a rubber-sand composite and studied the effect of vulcanization on the composite's properties by varying the sulfur (phr), natural rubber latex (phr), sand (% vol. fraction), etc. The obtained results showed an increase in energy absorption with a decrease in sulfur content due to lower cross-linking density. Also, the increase in 10% of sand showed an increase of 69% of energy absorption compared to 0% volume. The amalgamation of ceramic composites for effective ballistic impacts for normal and oblique projectiles at different angles with the incorporation of numerical simulation was performed by Z. Fawaz et al.'s [14]. The computation results showed that for both normal and oblique projectiles projected towards ceramic as a face and polymer composite as a backed face, the kinetic energy reduced at a faster pace than the rate at which the internal energy increased.

C.Y. Ni et al.'s [15] examined the ballistic performance of an innovative hybrid-cored sandwich structure consisting of a metallic corrugated sandwich plate integrated with high- performance reactive powder concrete (RPC). Three distinct target plate configurations were developed: a monolithic RPC plate, a corrugated sandwich plate directly filled with RPC, and a corrugated sandwich plate incorporating RPC prism insertions with voids filled by epoxy resin. The ballistic resistance of each configuration was assessed through vertical projectile penetration tests at the plate centers, followed by numerical simulations using finite element methods. The findings indicated that the corrugated sandwich plate with RPC prism insertions and void-filling epoxy resin demonstrated superior ballistic performance. The epoxy resin enhanced the structural integrity of the sandwich, while the corrugated plates effectively confined the RPC. Sandwich construction has proven to be an excellent low-density multifunctional design for a wide range of applications in ballistic protection, energy absorption, and thermal insulation. The front panel has usually been made of high- strength and high-rigidity materials such as ceramics and steel plates for eroding, passivating, and crushing the projectile, and quickly reducing the kinetic energy of the projectile; the middle core has been made of a honeycomb structure with strong energy absorption ability, lightweight, and high impact resistance; and the back panel has usually been made of materials with good energy absorption performance such as metal or composite materials for absorbing the remaining kinetic energy of the projectile.

Jianzhong Lai et al.'s [16] have developed functionally graded cementitious composites (FGCC) with layered structures to enhance ballistic and explosive resistance. Each layer has served a distinct role, with the sacrificial crack-resistant layer protecting the core by dissipating energy. Fiber and high-strength aggregate reinforcements have reduced crater sizes and penetration depths, respectively. FGCC targets have exhibited strong resistance to high-velocity penetration, with minimal increases in penetration depth relative to velocity. Improved models for penetration and explosion, incorporating key parameters, have achieved deviations within 1%, 3%, and 10%. Soheil Ghadr et al.

In their study, they meticulously engineered compositions of sea sand and epoxy to achieve a gradient structure across the samples. The research involved rigorous testing, including tensile, compression, impact, and vibration resistance assessments. The results have highlighted notable improvements: a 12.47% increase in hardness, a 27.93% enhancement in flexural strength, a 3.05% rise in compressive strength, and a remarkable 2.35-fold increase in impact strength. These findings have underscored the efficacy of incorporating sea sand in developing functionally graded composites with superior mechanical performance. Jun Shi, Dingshi Chen, and Zhenyun Yu [17] have proposed and successfully implemented a novel approach involving epoxy-resin and sand-bonded systems that cure at room temperature without the need for water or cement. Their research revealed that this epoxy resin-bonded sand system exhibited exceptional early and ultimate strength, achieving a compressive strength of approximately 100 MPa and a flexural strength of 23 MPa within just three days at room temperature. This performance was observed with a 10 wt.% epoxy resin content, demonstrating the effectiveness of this innovative formulations. Ahmed and F.R. Jones [18] have investigated the influence of residual compressive stresses in composites with irregular sand particle agglomerations. Their study utilized Crystic 272 polyester resin combined with three grades of sand—coarse, medium, and fine. They employed a two-stage casting process to ensure the suspension of sand particles. Initially, activated resin was poured into a mold, and half of the premixed sand was sprinkled onto the surface before gelation. Following this, the second layer was cast using the same method. The samples were subsequently post-cured in an oven under specified temperatures and pressures. Tensile testing was performed with a Mayes SM200 machine. The findings revealed that a high- volume fraction of sand led to discontinuities in the stress-strain curves, which were attributed to the microstructural features of the composite, specifically the agglomeration of sand particles and the associated residual compressive stresses around these agglomerates. This research has highlighted the critical role of particle distribution and stress in determining the mechanical behavior of sand-resin composites.

Md. Rakibul Qadir et al.'s [19] performed a study on sand-reinforced polyester composites (SPCs) with 10-60% sand content, prepared via compression molding. Increased sand content generally reduced water absorption (except at 10%), compressive, and flexural strengths due to poor sand-polyester adhesion. Vickers hardness increased, while rebound hardness peaked at 10% sand. Thermal conductivity decreased from 0.00066 to 0.00022 cal/cm·s·°C, reflecting the insulating properties of sand. FTIR, SEM, and XRD analyses confirmed SPC formation, highlighting the significant impact of sand content on properties and the need for further application research. A. Hamidi, E. Azini, and B. Masoudi [20] have analyzed the impact of gradation on the shear strength and dilatancy of the mixture. They conducted 27 large-scale direct shear tests of three different soil gradations, namely sandy gravel with a specified gradation as the base soil and two other soils with different gradations. They evaluated the test results based on the contributions of friction and dilatancy to shear strength, considering factors such as relative density and applied surcharge pressure. Their findings revealed that the gradation of the soils has significantly influenced their shear strength and dilatancy. Among the gradations tested, they observed that scalped gradation was a better approximation for predicting peak shear strength in coarse-grained soils compared to parallel gradation.

4. PHASE – 1

4.1 Sample Preparation

To achieve the desired improvement in impact resistance, careful material selection and a structured fabrication process were crucial. This section outlines the key materials and methods used, focusing on the incorporation of sand in a graded fashion to optimize the mechanical and ballistic properties of the composites.

4.1.1 Materials Used

Last semester, ER099 Epoxy with EH150 hardener was used. This combination had provided strong performance, but for this semester, **LY556 Bisphenol-A grade epoxy**, combined with the **hardener HY951 Triethylenetetramine**, was chosen. LY556 was selected for its enhanced toughness, flexibility, and improved adhesion properties, which were essential for optimizing the integration of sand inclusions and enhancing the overall durability of the composites. The LY556 epoxy mixture has exhibited excellent mechanical, dynamic, and thermal properties, with high resistance to chemical reactions and acids up to 80°C. It also featured low viscosity and a long pot life, with reactivity adjustable through varying accelerator concentrations. Construction sand, utilized as the primary inclusion, has been rich in silica. The irregular shape of the sand particles improved their adhesion within the epoxy matrix, reducing voids and enhancing structural strength. Silica's chemical inertness ensured it integrated well with the epoxy, maintaining a chemically stable matrix. Moreover, the sand's abrasive nature and higher tapped densities, in contrast to bulk densities, have contributed to effective energy dissipation from projectiles. Finer sand particles, in particular, have been more efficient in slowing down and breaking up high-energy impacts.

4.1.2 Procedure

4.1.2.1 Sand Pre - Processing

The construction sand had been processed to achieve optimal performance in the composite material. The procedure had involved the following steps:

1. **Initial Drying**: The sand, initially wet, containing organic impurities, had been spread in a thin layer under sunlight for natural drying, which had reduced moisture content.
2. **Cleaning**: After drying, the sand had been cleaned of organic debris, followed by an isopropyl alcohol wash to remove remaining contaminants.
3. **High-Temperature Drying**: The sand had been further dried in a blast furnace at approximately 140°C for 6 hours to eliminate any residual moisture.
4. **Milling**: The sand had then been milled using the PULVERISETTE 7 ball milling machine, which provided precise grain size distribution with particles reduced to less than 0.1 µm. This process ensured uniform particle size and improved packing density.
5. **Sieving**: After milling, the sand had been sieved to obtain fractions of 0.15 mm, 0.3 mm, 0.425 mm, and 0.6 mm. These fractions had optimized packing density and composite performance.
6. **Storage**: The processed sand fractions had been stored in airtight pouches to preserve their properties and protect them from external effects.

4.1.2.2 Mold Preparation

Initially, silicone rubber and acrylic sheets had been used for mold preparation. However, difficulties with uniform cutting and finishing had led to switching to 3D-printed molds for improved precision and efficiency. Molds were prepared using additive manufacturing with a 3D printer. For property testing samples, Thermoplastic Polyurethane (TPU) had been used, with a 0.2 mm nozzle, a bed temperature of 70°C, and a transverse speed of 65 mm/s. TPU's elastomeric properties had facilitated easy sample removal and minimized shrinkage. This switch to 3D-printed molds had enhanced accuracy, durability, and cost-effectiveness in mold preparation and testing.

4.1.2.3 Sample Preparation

1.Mixing Epoxy and Hardener: Epoxy LY556 (Bisphenol-A grade) and hardener HY951 (Triethylenetetramine) had been weighed using the weighing machine, with the hardener added at 10% of the epoxy weight.

2.Adding Sand: The sand had been weighed according to its volume fraction in the mixture. For example, 20 grams of sand for every 100 grams of the epoxy-hardener mixture.

3.Stirring: The epoxy and hardener mixture had been hand-stirred for 2-3 minutes, then stirred with an overhead stirrer at 800 rpm for 5-6 minutes. Sand had been added and mixed at the same speed for 7-8 minutes, totaling a mixing time of approximately 20-22 minutes.

4.Mold Preparation: Molds had been placed on an OHP sheet, with a releasing agent (Polyvinyl Alcohol) applied to facilitate specimen removal.

5.Pouring and Curing: The mixture had been poured into the molds and allowed to air-dry for at least 24 hours. After drying, specimens had been removed from the molds and post-cured in a hot-air oven at 100°C for 12 hours.

6. Finishing: Samples had been initially finished with 120-grit sandpaper, then polished using the grinding and polishing machine. The flat side of the samples had been attached to a base plate with double-sided tape to prevent movement during finishing. Final polishing had been done with 220-grit paper on the same machine.

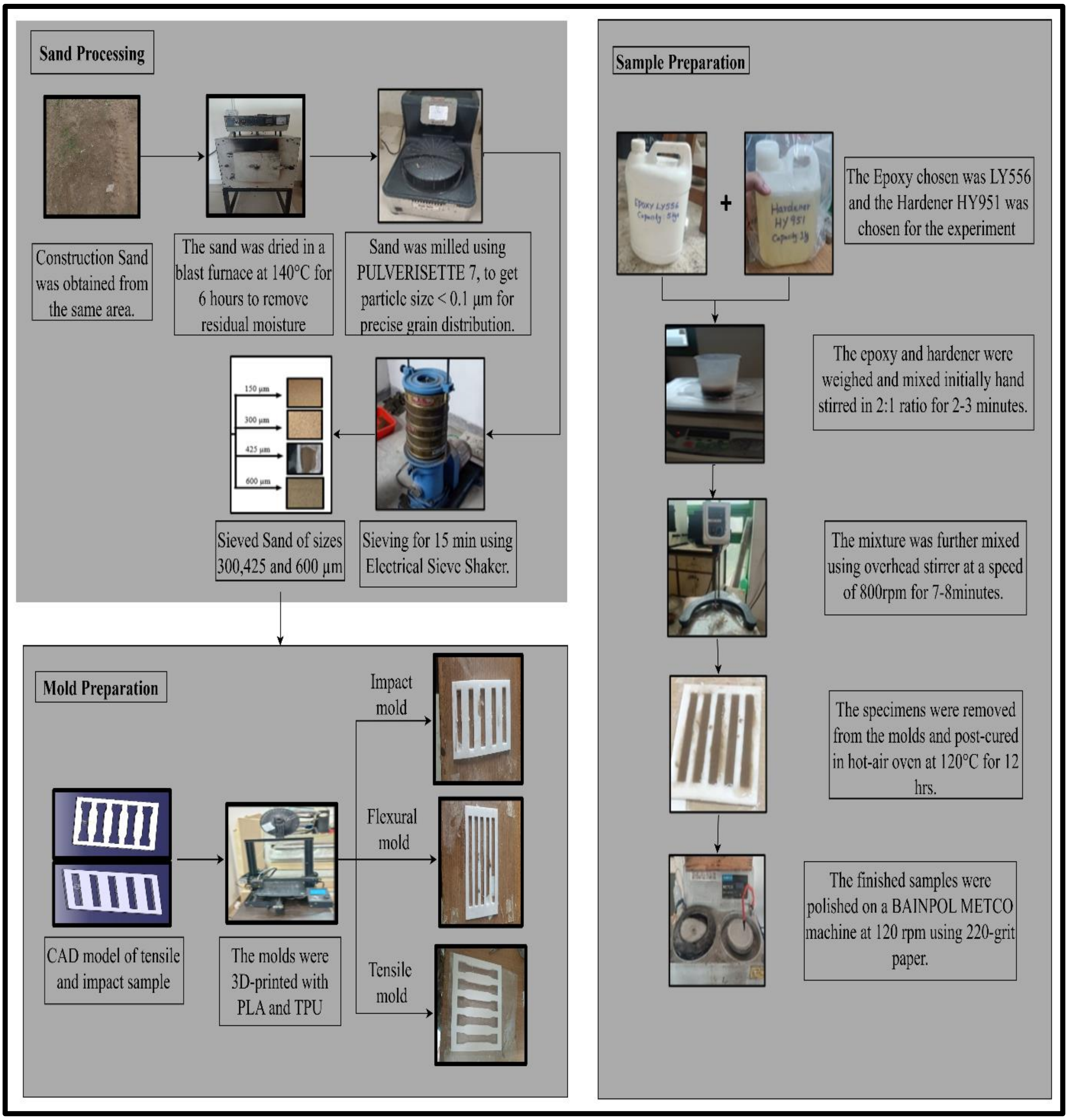


Figure 1: Overall Preparation Procedure of the samples

4.2 TESTS AND TEST RESULTS

4.2.1 Impact Test

We performed Charpy-Izod Impact Tests on some of our samples. The results are detailed below, with the average value derived from the three best-performing samples used for our analysis. The ASTM Standard of the samples is ASTM D790.

S.No	Sample Type	Sample1	Sample2	Sample3	Sample4	Sample5	Average
1	10% Silica + Epoxy	39.2	57.2	42.6	-	-	46.33333333
2	20% Sand - 425 micron	25.8	32.4	8	16.8	-	20.75
3	30% Sand - 425 micron	32.4	33	31	-	-	32.13333333
4	40% Sand - 425 micron	29	49.8	25.8	-	-	34.86666667
5	50% Sand - 425 micron	32.4	29	42.6	52	19.6	35.12
6	60% Sand - 425 micron	42	42.6	55	70	-	52.4
7	70% Sand - 425 micron	93.4	157	29	29	-	77.1
8	20% Silica - 300 micron	68.8	22.8	42.6	53.4	-	46.9
9	30% Sand - 600 micron	35	46.2	52.2	75	-	52.1
10	40% Sand - 600 micron	68.8	49.8	35.8	90	-	61.1
11	50% Sand - 600 micron	45	53.4	60	161.8	-	80.05

4.2.2 Tensile Test

The ASTM Standard of the samples is ASTMD638. A load cell of 10kN was used and the testing was performed corresponding to the speed 5 mm min-1. The specimens measured 19mm in width, 50mm in gage length and the distance between the grips was 115mm

Sand Gradation	Sand Percentage	Young's Modulus			
		1	2	3	Average
0.425	20%	1204.3	1239.9	1186.8	1210.67
	30%	1320.4	1315.9	1308.2	1314.83
	40%	1349.8	1326.5	1327.6	1334.63
	50%	1392.9	1365.9	1388.3	1382.367
	60%	1452.5	1428.3	1576.6	1485.8
	70%	1066	1103.7	1170	1113.233
Pure		1173.1	1193.6	1198.2	1188.3
0.3	20%	1214.3	1197	1199.6	1203.633
	30%	1466.8	1414.2	1459.9	1446.967
	40%	1622.5	1545.6	1614.9	1594.33
	60%	1705.4	1704.1	1545.6	1651.7
	70%	1838	1813.6	1774.4	1808.67

0.6	20%	2123.2	2010.12	2125.27	2086.19
	30%	2766.9	2346.19	2275.12	2462.73
	40%	2801.1	2552.25	2424.45	2592.6
	50%	2935.7	2782.27	2537.57	2751.84
	60%	3041.7	3042.5	3115.2	3066.46
	70%	3257	3157.77	3259.5	3224.75

4.2.3 <u>Flexural Test</u>

The ASTM Standard of the samples is ASTM D790

Sand percentage	**Young's Modulus (Mpa)**				
	Sample-1	Sample-2	Sample-3	Sample-4	Average
30%	49.1	51.9	49.9	44.9	48.95
40%	59.1	60	60.5	63.5	60.775
60%	21.8	37.6	62.9	49.6	42.975

Yield Stress (Mpa)				
Sample-1	Sample-2	Sample-3	Sample-4	Average
11.5	9.78	12	10.8	11.02
12.1	13.3	12.9	9.12	11.855
1.65	16.7	17.3	13.9	12.3875

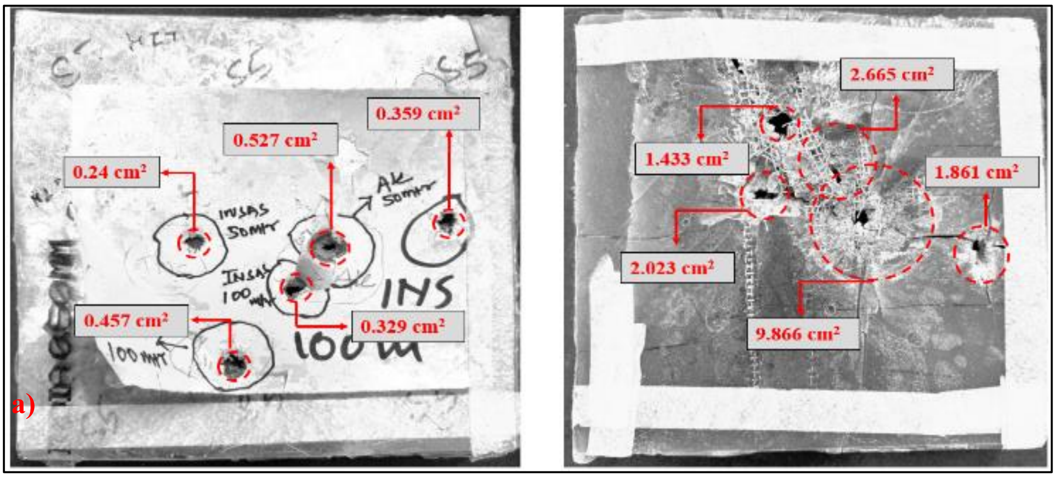
Ultimate Stress (Mpa)				
Sample-1	Sample-2	Sample-3	Sample-4	Average
11.48	9.78	12	10.8	11.015
12.09	13.28	12.9	9.12	11.8475
13.5	16.68	17.29	13.89	15.34

5. PHASE – 2

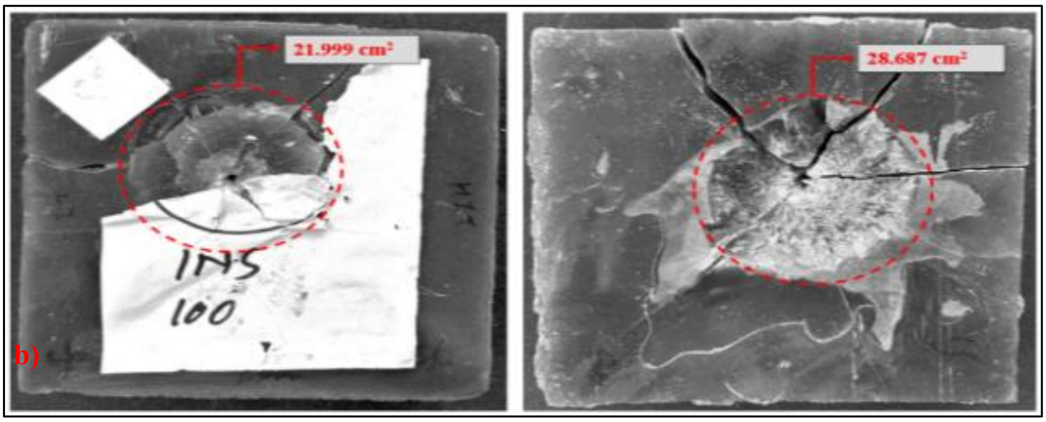
In this phase, we built upon our mid-semester findings by conducting hardness test of our samples and also worked on ballistic samples by incorporating.

5.1 Ballistic Sample Testing

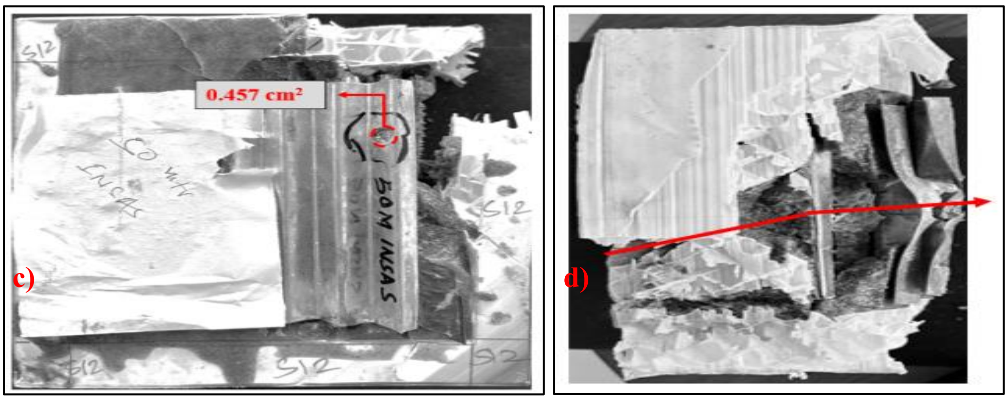
Some ballistic samples have been prepared just before our midsemester and the testing of which happened later. The results and the configuration of the samples are as follows:



Front - LY25_06 **Back – LY25_06**



Front - ER40_06 **Back – ER40_06**



LY80_04_1 **LY80_04_2**

Figure 2: Tested Ballistic samples

Testing Apparatus and Configuration:

- The testing setup included various firing distances and guns used for ballistic testing.
- Sample configurations and setup details are provided in the table.

Role of Corrugated Sheets and Mesh:

- Corrugated sheets and mesh were employed to provide a stiff structure.
- The mesh distributed stresses across a larger area.

Samples Configurations for Ballistic Impact

Sample Name	**ER40_06**	**LY25_06**	**LY80_04_1**	**LY80_04_2**
Sample Composition	**Epoxy** – ER099; **Hardener-** EH150; **Sand -**0.6mm **Dimensions:** 130 X 130 X 40mm **Layer order (from front to back):** GI Sheet, 20 mm 50% Sand Epoxy, GI Sheet, 20 mm 30% Sand Epoxy, GI Sheet	**Epoxy** – LY556; **Hardener-** HY951; **Sand -**0.6mm **Dimensions:** 130 X 130 X 25 mm **Layer order (from front to back):** 15mm 50% sand epoxy, 10mm 30% sand epoxy	**Epoxy** – LY556; **Hardener-** HY951; **Sand -**0.425mm **Dimensions: -** 130 X 130 X 80 mm **Layer order (from front to back):** 60% Sand Epoxy, GI Corrugated, 60% Sand Epoxy, GI Corrugated, 60% Sand Epoxy, GI Corrugated, 60% Sand Epoxy, GI Corrugated, 50% Sand Epoxy, Mesh Corrugated, 50% Sand Epoxy, GI Sheet	**Epoxy** – LY556; **Hardener-** HY951; **Sand -**0.425mm **Dimensions: -** 130 X 130 X 80 mm **Layer order (from front to back):** 60% Sand Epoxy, GI Corrugated, 60% Sand Epoxy, Mesh Corrugated, 50% Sand Epoxy, GI Corrugated, 50% Sand Epoxy, Mesh Corrugated, 50% Sand Epoxy, GI Corrugated, Sand Epoxy

1. **Ballistic Testing Results (Figures 12 a, b):**

Samples underwent ballistic testing using an INSAS rifle at a firing distance of 100 meters.

<u>Comparative analysis showed:</u>

- Sample LY25_06: Larger bullet impact area due to higher stiffness of the LY556 epoxy, indicating greater bullet deformation.
- Sample ER40_06: Stronger polymer-inclusion bonding enhanced material integrity, resulting in fewer visible cracks.
- Observation: Cracks in LY25_06 suggest it absorbed more impact energy compared to ER40_06.

2. **Ballistic Testing at 50 Meters (Figure 12 c):**
   - Sample configuration from was tested ballistically with an INSAS rifle.
   - Increased layer counts introduced complexity, leading to delamination caused by stress concentration at interfaces.

3. **SIG Rifle Testing (Figure 12 d):**
   Sample LY80_04_1 was tested at 50 meters using a SIG rifle.
   Observations:
   - Bullet trajectory deviation occurred due to varying properties across layers, which absorbed and redirected impact energy.
   - Delamination was observed in both samples due to stress concentration at interfaces, weakening bonds despite overall material performance.

5.2 Shore D - Hardness Test

The hardness of both neat epoxy samples with different sizes and weight fractions of sand inclusions was measured using Shore D durometer in accordance with ASTM standard D2240-15. The specimens are of dimensions 35mm in length ,25 in width and 6mm in thickness.

Particle Size (µm)	0	20	30	40	50	60	70
300 microns	73.2	77	80.8	82	-	83	82.9
	72	75	81.5	81.9	-	81.6	83
	73.1	74	79.8	80.7	-	82.1	82.7
425 microns	73.2	77.9	79.7	80.7	83.7	86.2	89
	72	77	80.1	80.2	82.2	85.1	88.4
	73.1	74	80.4	80.5	82.7	86.4	89.2
600 microns	73.2	75	76.7	78.4	78.1	86.7	90.5
	72	76.4	77.2	78.7	79.5	89.5	91.9
	73.1	75.8	78.4	78.1	78.9	89.1	95.5

5.3 Microstructural Analysis

Optical images were captured using an Olympus-base microscope and classified based on sand inclusion size and volume fraction.

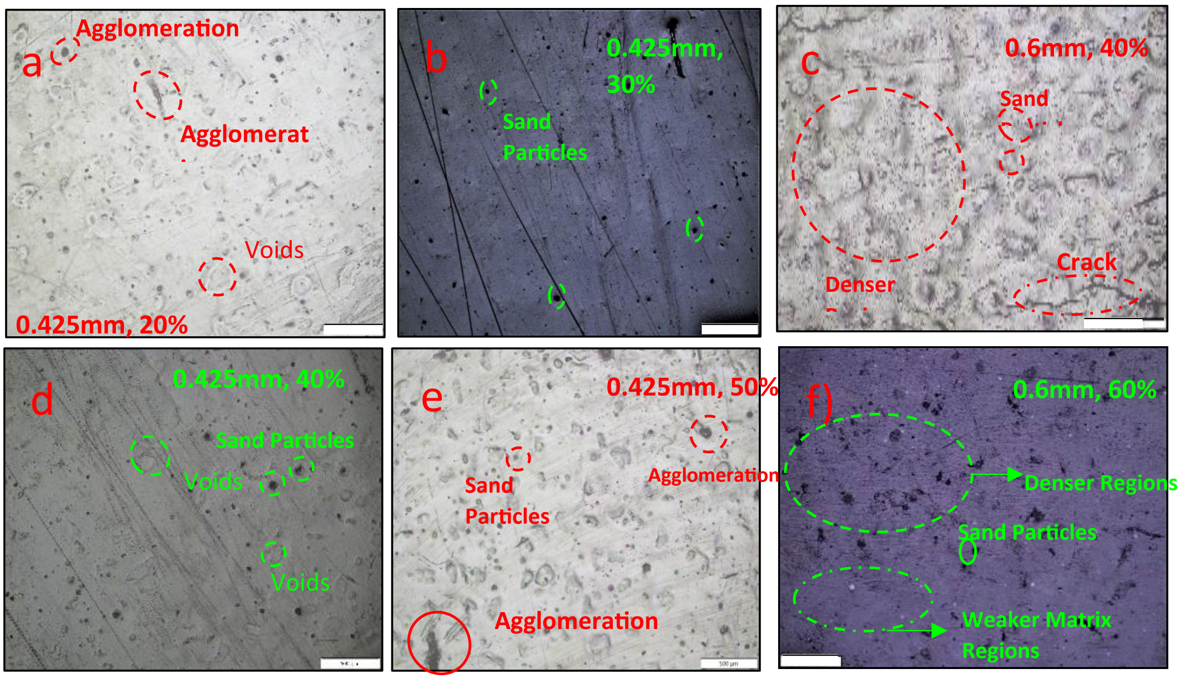


Figure 3: Microstructural samples

The refined manufacturing process resulted in a more consistent distribution of sand, up to a certain limit. In samples with smaller grain sizes and lower volume fractions, fewer agglomerations were observed, as shown in Figure 8a. While larger particles didn’t significantly increase agglomeration, higher volume fractions led to denser regions due to particle clustering, as seen in Figure 8e. Voids were present in most samples, as shown in Figure 8d, though they were minimal and likely due to slight inconsistencies in filling or dispersion during production. Under load, cracks developed in the less dense, neat epoxy areas, which were weaker than the sand-reinforced sections, as shown in Figures 8c and 8f.

5.4 Preparation of New Ballistic Samples

5.4.1 Materials and Mold Preparation

Grinding wheels and crumb rubber materials were chosen to be incorporated into ballistic samples for their unique properties. Grinding wheels are made from abrasive materials that help enhancing the hardness and impact resistance, which can be beneficial for ballistic applications. Crumb rubber, produced from recycled tires, is a lightweight and energy-absorbing material. It has the ability to dissipate energy upon impact, reducing the force transferred to the ballistic material. This makes it ideal for enhancing the material's ability to absorb shocks, improve overall durability, and contribute to sustainability by utilizing recycled resources. Additionally corrugated GI Sheets and Meshes were also used in between the layers like the previous ballistic samples. The molds were prepared using 3D printing in a similar manner as the previous molds.

5.4.2 Sample Preparation

The preparation process for the epoxy mixture and sand pre-processing was similar to the process followed in Phase-1. Crum rubber was measured by weight and added in the mixture. The mixing process was similar to the sand and epoxy mixing process. The sample configurations and the procedure of preparation is shown below.

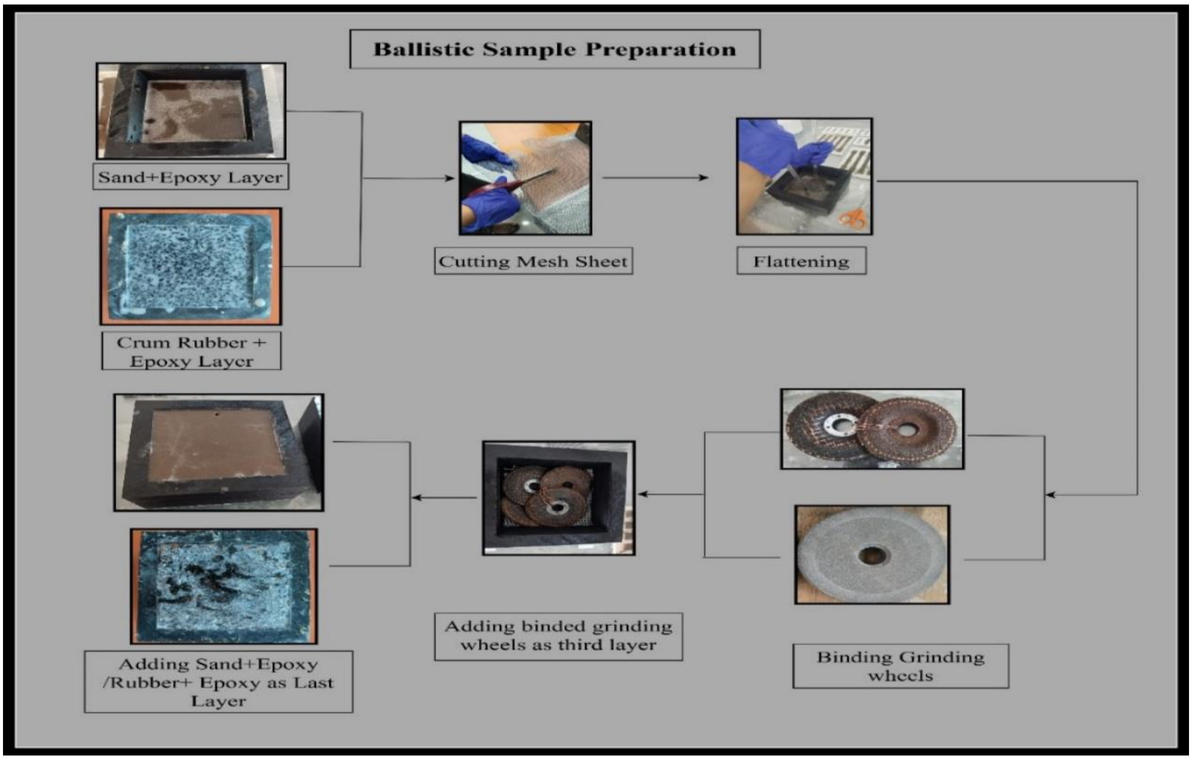


Figure 4: Manufacturing Process of ballistic samples

These ballistic samples are yet to be tested.

5.4.3 Graphs

These Graphs represent the data of the samples of (ER099) epoxy which we did in our DEP.

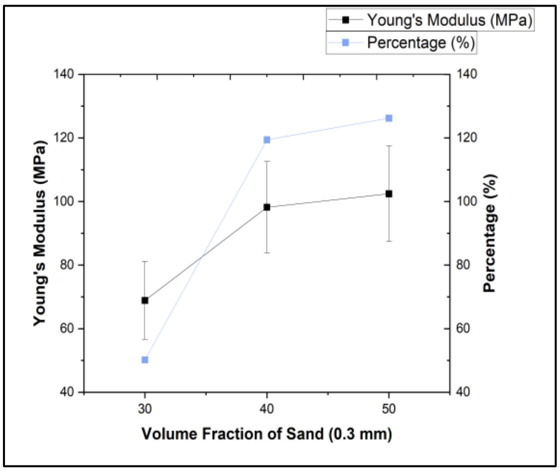


Fig 3. Young’s Modulus vs Volume Fraction

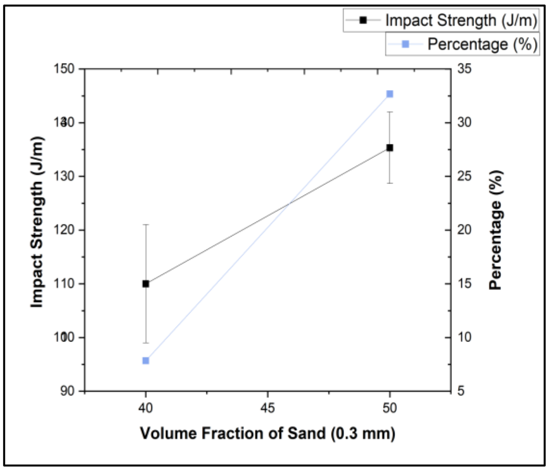


Fig 4. Impact Strength vs Volume Fraction

The comparison can be made with the improved epoxy – LY556, that we incorporated this semester. The results are as follows:

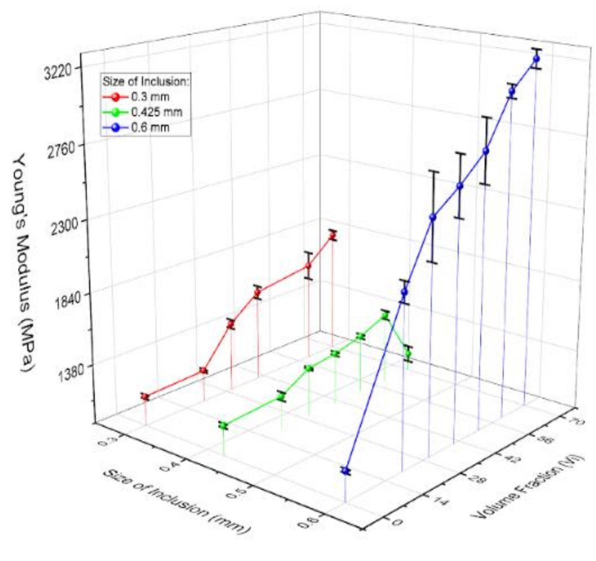


Fig 5. Variation of Young’s Modulus with Volume Fraction and Inclusion size

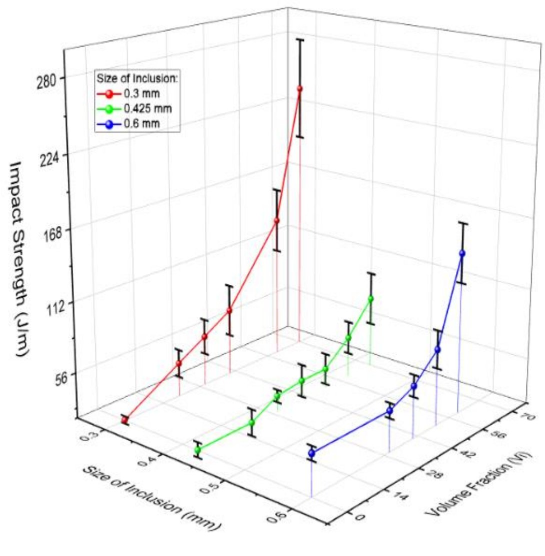


Fig 6. Variation of Impact Strength with Volume Fraction and Inclusion size

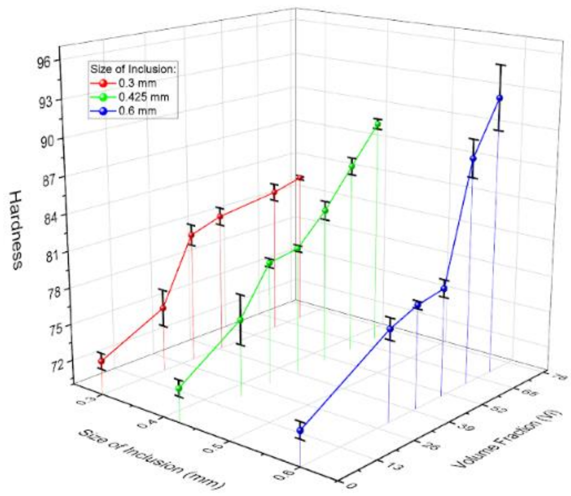


Fig 7. Variation of Hardness with Volume Fraction and Inclusion size

Experimental testing, including uni-axial tensile tests, Izod impact tests, and Shore-D hardness tests, was conducted, with standard specimen sizes and dimensions specified in the testing section.

Tensile testing of ER 099 (Epoxy) with EH 150 (Hardener) and 0.3 mm sand particles, varying sand volume fractions from 30% to 50%, was conducted as part of the Department Engineering Project (DEP) during the previous semester. The results revealed that a 30% sand volume increased the modulus by 50.20% to 366 MPa compared to neat epoxy. At 40% and 50% sand volumes, the modulus reached 534.67 MPa and 539 MPa, marking 119% and 121.20% increases, respectively. Impact strength for the same configuration rose to 110 J/m and 135 J/m at 40% and 50% sand volumes, showing improvements of 7% and 32% over the neat mixture. However, higher sand volume fractions presented challenges due to manufacturing irregularities. These results emphasized the need for mitigating agglomeration to reduce localized stress in weaker matrix regions.

Building on the insights from the previous semester, a more viscous and harder epoxy grade, was explored in this iteration, demonstrating advantages over the earlier grade. Tensile tests with 0.3 mm and 0.425 mm sand particles at increasing volume fractions showed enhanced properties. For 0.3 mm sand, Young's Modulus increased by 51% (1810 MPa) at 70% volume, while for 0.425 mm sand, it rose to 1445 MPa, a 25% increase at 60% volume. However, higher sand volumes up to 70% for the 0.425 mm sand size led to a decrease in modulus due to agglomerations which can be avoided by further refining the manufacturing process. Impact strength reached 210 J/m for 0.3 mm sand at 70% volume and increased gradually for 0.425 mm and 0.6 mm sand, achieving 100 J/m and 150 J/m at 60% and 70% volumes, respectively. Shore-D hardness tests revealed values of 83.5, 89, and 92.5 for 0.3 mm, 0.425 mm, and 0.6 mm sand at 70% volume, representing a 13.7% improvement over the pure matrix.

6. CONCLUSION

Incorporating sand particles into epoxy resin significantly enhanced the material's mechanical properties, particularly in terms of stiffness and impact resistance. The optimization of sand inclusion size and volume fraction was crucial in reducing agglomeration, ensuring a more uniform distribution of sand particles throughout the epoxy matrix. This, in turn, improved the overall structural performance of the composite, with sand-reinforced regions demonstrating superior mechanical strength and crack resistance compared to the neat epoxy regions.

As the sand volume fraction increased, there was a notable improvement in the Young's modulus, which rose by up to 125%, and a significant increase in impact strength by up to 32%. However, higher sand volume fractions above 70% led to agglomerations that localized stresses, slightly diminishing the composite's performance.

Ballistic performance tests showed that LY-556 samples exhibited superior impact absorption compared to ER-099 epoxy samples. The higher stiffness of LY-556 allowed it to dissipate impact energy more efficiently, resulting in larger impact areas and better resistance to damage. In contrast, ER-099 samples, though structurally sound, demonstrated fewer visible cracks due to stronger polymer-inclusion bonding but had slightly lower energy absorption capabilities. This highlights that LY-556 epoxy, when reinforced with sand, showed improved impact resistance and energy dissipation when compared to our development engineering project, where ER-099 epoxy was used. The use of LY-556 in this study proved to be more effective in terms of ballistic performance and impact strength, making it a more suitable candidate for applications requiring high durability under dynamic loading conditions.

The fabrication process was verified through simulations conducted by Mr. Manas (MTech Scholar), which utilized experimentally homogenized material properties. The simulations provided further insight into the material's stress distribution, energy absorption, and potential failure mechanisms, aligning well with the experimental results and validating the effectiveness of the composite design and processing techniques.

However, as layering was increased, stress concentrations at the interfaces between layers led to delamination, highlighting the importance of improving bonding techniques between layers. This delamination observed under high-impact conditions indicates that further optimization of the interfacial bonding and layering process is necessary to enhance the material's structural integrity.

Sand-reinforced epoxy composites offer a promising approach to developing advanced materials with improved mechanical and ballistic performance. The use of LY-556 epoxy, especially in combination with sand reinforcement, demonstrated significant improvements compared to ER-099 which we used in Development Engineering Project in terms of impact absorption and stiffness.

7. FUTURE IMPROVEMENTS

For future improvements, we will focus on optimizing the composition of the ballistic samples by exploring different levels and configurations of rubber inclusion or any new materials, alongside sand and epoxy. The goal is to enhance the ballistic performance by improving the toughness and impact resistance while maintaining the structural integrity of the material under high-impact conditions. Additionally, we plan to conduct more simulation studies to model the behavior of the samples with new configurations under ballistic impact. These studies will provide a better understanding of how the material performs and will guide the optimization process. To further evaluate the material's long-term durability, we will perform advanced testing, including weathering tests, to assess its environmental resistance. These tests will help determine how environmental conditions and fluctuations impact the material's properties. Through these investigations, we aim to improve the resilience, performance, and reliability of the ballistic composites, making them more suitable for use in protective gear and defense-related applications.

8. CONFERENCE SELECTION

We are grateful that our Abstract has been 'selected' for presentation at the ICMAMS 2024 International Conference (December 11^{th} -13^{th}, 2024) and for the iCNMDAO conference 2024 (conducted by IISC). We worked on the Full paper submission during the last few weeks. Additionally, we have submitted our abstract to TechConnect-RESCON 2024 and are currently awaiting the results.

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