Progress Report

(For Midsemester Evaluation)

B-Tech Project (CP302)

Development of Sand Composite for High Impact Resistance

Submitted By:

Bommiditha Jyothsnavi (2021MEB1277)

Nishika Nakka (2021MEB1301)

Surkanti Sai Sahasra (2021MEB1328)

Supervised By:

Dr. Srikant Sekhar Padhee

Contents

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. EXISISTING STUDIES

In the field of impact-resistant composites, various technologies have utilized epoxy with different inclusions to enhance mechanical properties. Sand-filled composites, in particular, have significantly contributed to improving ballistic impact resistance. These composites have incorporated sand as a filler to enhance hardness and stiffness, benefiting from its availability and low cost. However, their impact resistance has often been limited due to the lack of a systematic approach for selecting the type, size, and distribution of sand particles, as well as the methods used for mixing and curing the composites. The dilation of the overall composite, due to sand inclusion, has aided in impact resistance and penetration by minimizing void spaces between sand grains, preventing particle rearrangement into a denser structure. Additionally, the relative density of the sand has influenced penetration and erosion to some degree, as noted by Siau Chen Chian et al. Further, the projectile shape and mass along with sand relative density have affected the ballistic limit of the sand. Saleemsab Doddamani et al.'s [2] 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 [3]. 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 [4] 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 [5] 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. [6] conducted 24 undrained torsional shear tests on unreinforced and 1.5% fiber-reinforced angular silica sands (F161 and F131). Varying the inclination angle of maximum principal stress (α) from 15° to 60° and intermediate principal stress ratio (b) from 0.5 to 1.0, under 200 kPa confining pressure, the study found that unreinforced sand exhibited increased brittleness and weakness with higher α and b. Reinforced sand showed enhanced dilative and strain-hardening behavior, particularly at higher α values. Larger grains (F161) were more dilative and anisotropic, while finer sand (F131) benefited more from fiber reinforcement.

The integration of sea sand as a filler into functionally graded epoxy composites has demonstrated significant enhancements in mechanical properties, as reported by T.S. Kumar, S. Joladarashi, S.M. Kulkarni, and S. Doddamani [7]. 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 [8] 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 formulation.

S. Ahmed and F.R. Jones [9] 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 [10] 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 [11] 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. 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 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.

4.2 Procedure

4.2.1 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.

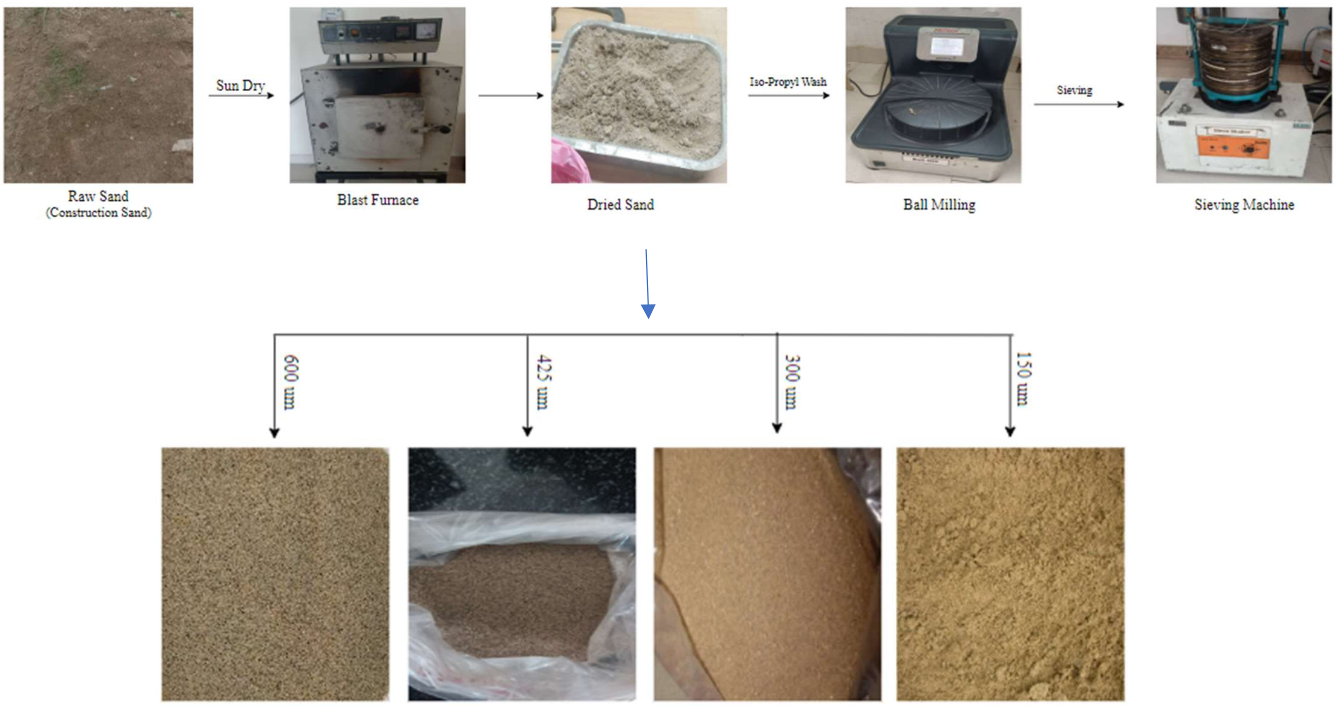


Fig. Flow Chart - Sand Processing Stepwise Segregation

4.2.2 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.

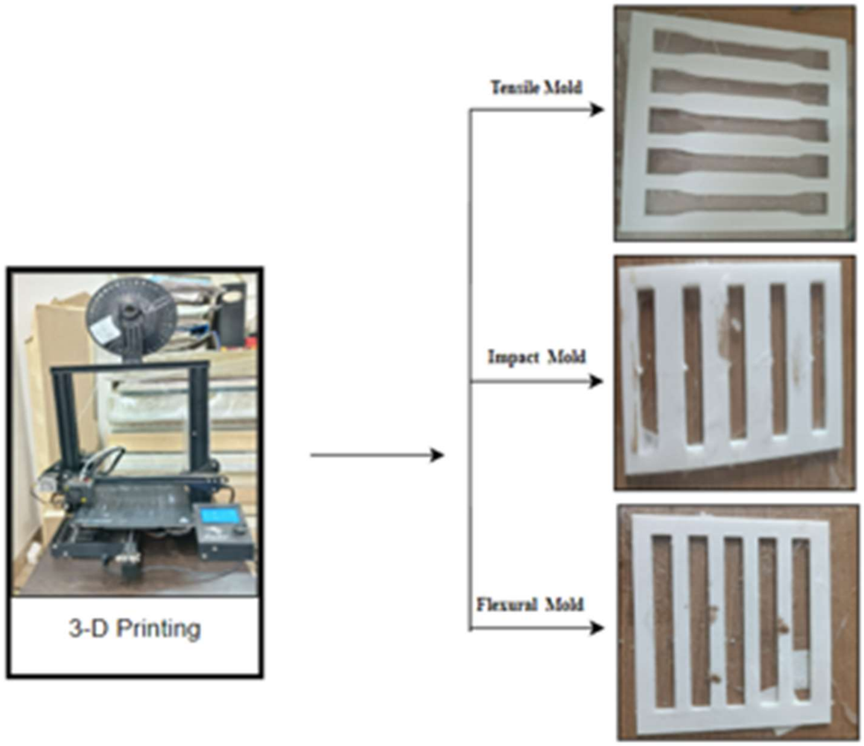


Fig. Flow Chart – Mold Preparation

4.2.3 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.

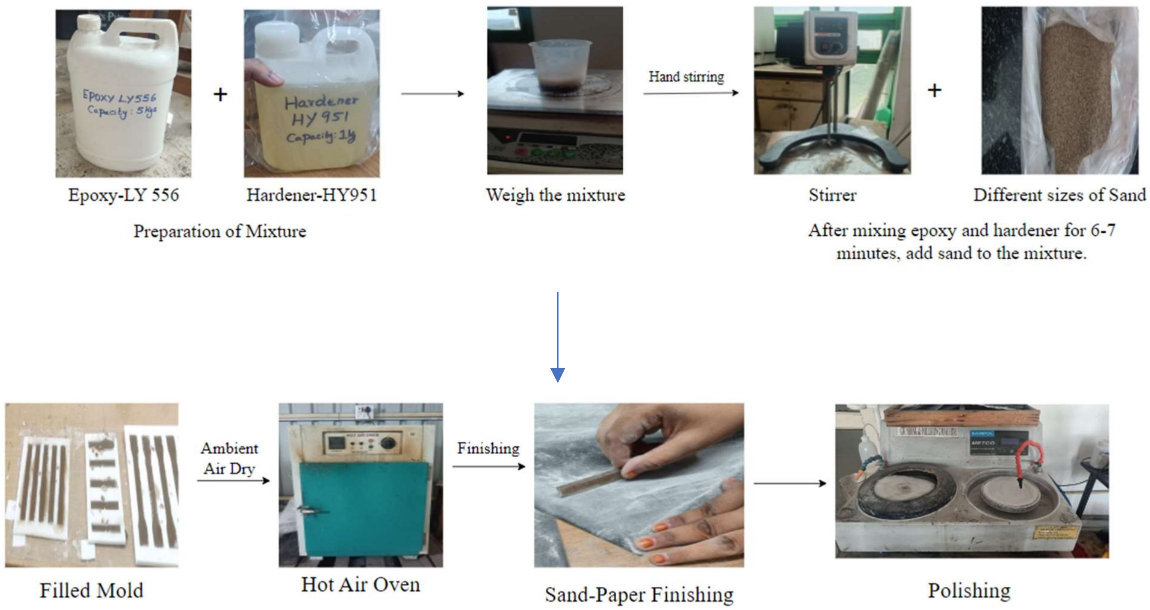


Fig. Preparation of Specimen stepwise process

5. TESTS AND TEST RESULTS

5.1 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	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
1	10% Silica + Epoxy	39.2	57.2	42.6	-	-	46.33
2	20% Sand - 425 micron	25.8	32.4	8	16.8	-	20.75
3	30% Sand - 425 micron	32.4	33	31	-	-	32.13
4	40% Sand - 425 micron	29	49.8	25.8	-	-	34.86

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

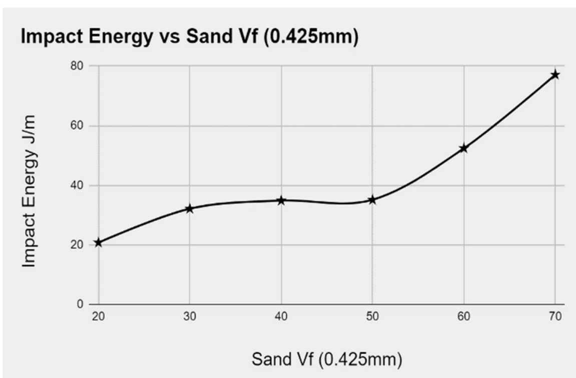


Fig. 425 µm sand – Impact vs Volume Fraction

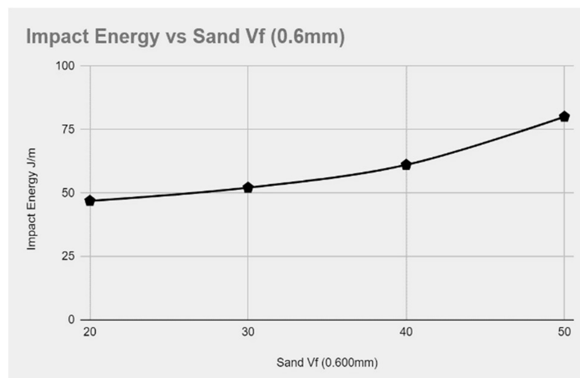


Fig. 600 µm sand – Impact vs Volume Fraction

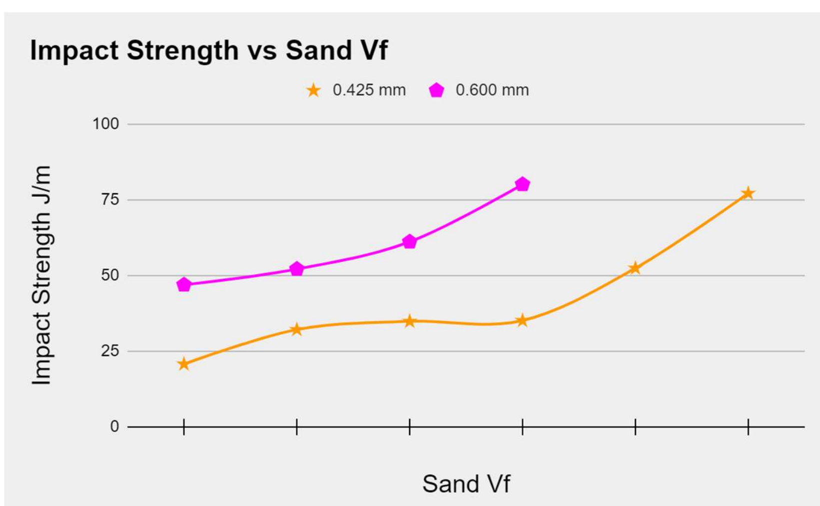


Fig. Combined Graph of 425 µm and 600 µm sand – Impact vs Volume Fraction

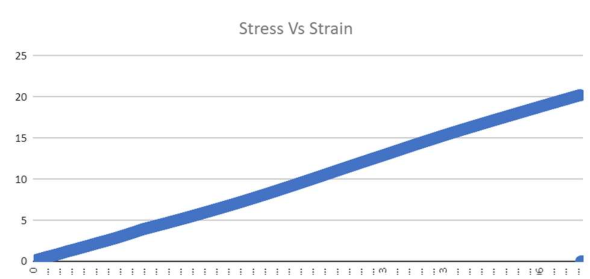
The graphs demonstrate the relationship between impact strength and sand volume fraction (Vf) for two different sand particle sizes: 425 µm and 600 µm. As the sand volume fraction increases, both particle sizes exhibit a rise in impact strength, with the larger 600 µm particles showing a more pronounced effect. Initially, the impact strength increases gradually for both sizes, but beyond 40% Vf, the 600 µm sand shows a steeper rise in impact strength compared to the 425 µm sand. This indicates that while both sand sizes improve impact resistance as their volume increases, the 600 µm sand provides better overall impact strength, particularly at higher volume fractions. Thus, for applications requiring enhanced impact resistance, larger sand particles at higher volume fractions are more advantageous.

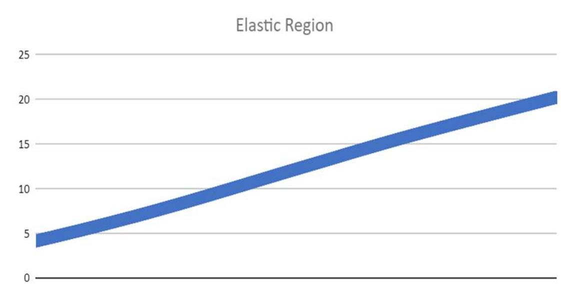
5.2 Tensile Test

The ASTM Standard of the samples is ASTMD638

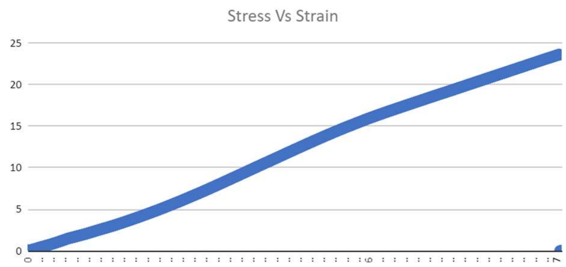
Sand Gradation (mm)	Sand Percentage	Young's Modulus (MPa)			
		1	2	3	Average
0.425	20%	1204.3	1239.9	1186.8	1210.67
	30%	1320.4	1315.9	1308.2	1314.83
	40%	1349.8	1326.5	1327.6	1334.63
	50%	1392.9	1365.9	1388.3	1382.367
	60%	1452.5	1428.3	1576.6	1485.8
	70%	1066	1103.7	1170	1113.233
Pure Epoxy		1173.1	1193.6	1198.2	1188.3

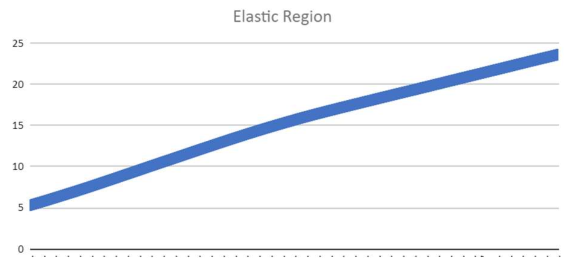
20% Sand Percentage



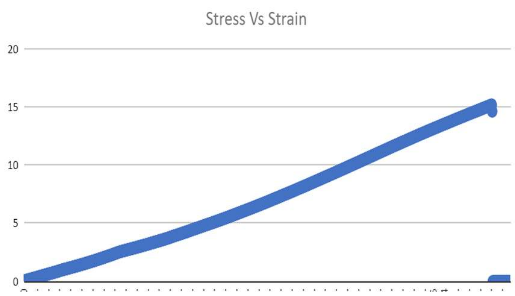


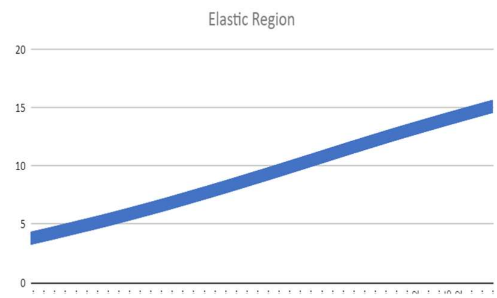
30% Sand Percentage



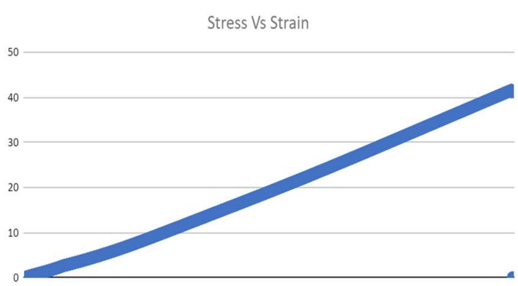


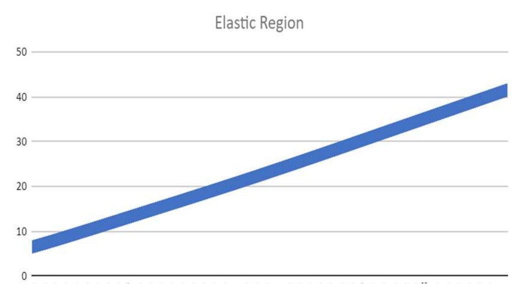
40% Sand Percentage



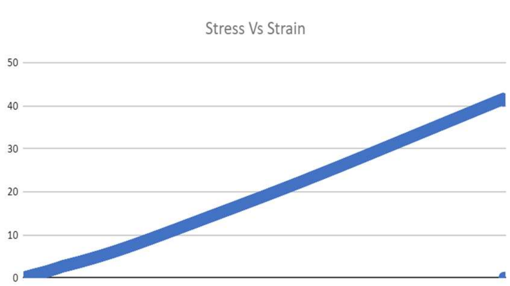


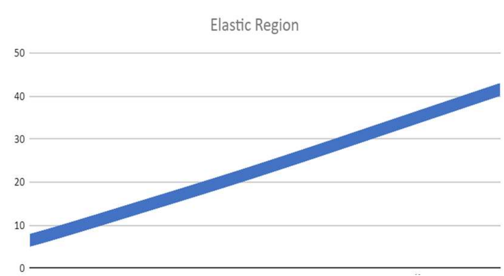
50% Sand Percentage



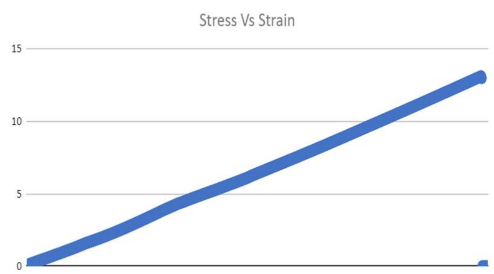


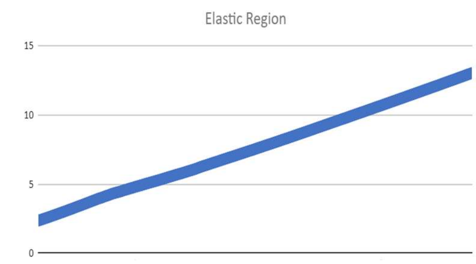
60% Sand Percentage



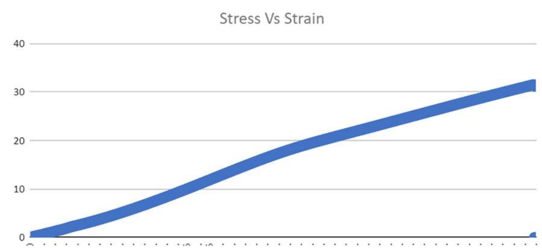


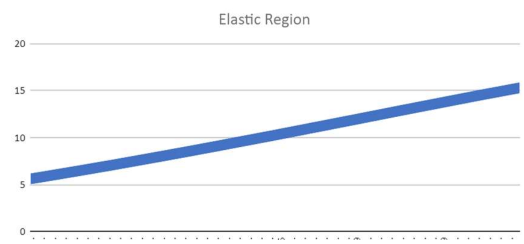
70% Sand Percentage





Pure





5.3 Flexural Test

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

6. CONCLUSION AND FUTURE PLAN

The sand-reinforced epoxy composites have shown great potential in enhancing impact resistance, making them well-suited for applications that require high mechanical durability. By systematically adjusting the volume fraction and particle size of the sand inclusions, we found that larger particles, especially those around 600 µm, provided better impact strength, higher modulus, and improved tensile strength at higher volume fractions compared to smaller particles. This demonstrates the capability of sand-based composites as a strong and cost-effective solution for ballistic protection.

Moving forward, our focus is on conducting additional tests on samples with varying compositions, particularly targeting weathering resistance and hardness. We aim to improve the bonding characteristics between sand and epoxy to further enhance the structural integrity of the composite. Additionally, we plan to perform gradation tests to establish a clearer relationship between different aggregates of sand and epoxy mixtures.

Our long-term objective is to develop an optimization equation that will contribute to the design of future composite materials with superior impact resistance.

7. REFERNECES

[1] Chian, S.C., Tan, B.C.V. and Sarma, A., 2017. Reprint of: Projectile penetration into sand: Relative density of sand and projectile nose shape and mass. *International journal of impact engineering*, *105*, pp.80-88.

[2] Doddamani, S., Kulkarni, S.M., Joladarashi, S., Gurjar, A.K. and Kumar, T.M., 2024. Development of rubber-sand composite for enhanced impact resistance: Implications of vulcanization. *Engineering Science and Technology, an International Journal*, *51*, p.101631.

[3] Fawaz, Z., Zheng, W. and Behdinan, K., 2004. Numerical simulation of normal and oblique ballistic impact on ceramic composite armours. *CompositeStructures*, *63*(3-4), pp.387-395.

[4] Ni, C.Y., Hou, R., Xia, H.Y., Zhang, Q.C., Wang, W.B., Cheng, Z.H. and Lu, T.J., 2015. Perforation resistance of corrugated metallic sandwich plates filled with reactive powder concrete: Experiment and simulation. Composite Structures, 127, pp.426-435.

[5] Lai, J., Zhou, J., Yin, X. and Zheng, X., 2021. Dynamic behavior of functional graded cementitious composite under the coupling of high speed penetration and explosion. *Composite Structures*, *274*, p.114326.

[6] Ghadr, S., 2020. Effect of grain size on undrained anisotropic behaviour of sand–fiber composite. Transportation Geotechnics, 22, p.100323.

[7]Kumar, T.S., Joladarashi, S., Kulkarni, S.M. and Doddamani, S., 2024. Influence of sea sand reinforcement on the static and dynamic properties of functionally graded epoxy composites. *Iranian Polymer Journal*, pp.1-18.

[8]Shi, J., Chen, D. and Yu, Z., 2024. Novel epoxy resin-bonded sand system: Mechanical strength, deterioration resistance, and failure mechanism. Engineering Failure Analysis, 158, p.108020.

[9] Ahmed, S. and Jones, F.R., 1990. Effect of particulate agglomeration and the residual stress state on the modulus of filled resin. Part II: Moduli of untreated sand and glass bead filled composites. *Composites*, *21*(1), pp.81-84.

[10] Sultana, Rajia & Akter, Ruma & Alam, Zahangir & Qadir, Md & Begum, Most & Gafur, Md. (2013). International Journal of Engineering & Technology IJET-IJENS Vol:13 No:02 111 135202-4747-IJET-IJENS © April 2013 IJENS Preparation and Characterization of Sand Reinforced Polyester Composites. International Journal of Engineering & Technology Sciences. 13. 111.

[11]Hamidi, A., Azini, E. and Masoudi, B., 2012. Impact of gradation on the shear strength-dilation behavior of well graded sand-gravel mixtures. *Scientia Iranica*, *19*(3), pp.393-402.