CP303

DEVELOPMENT OF SAND COMPOSITE FOR HIGH IMPACT RESISTANCE

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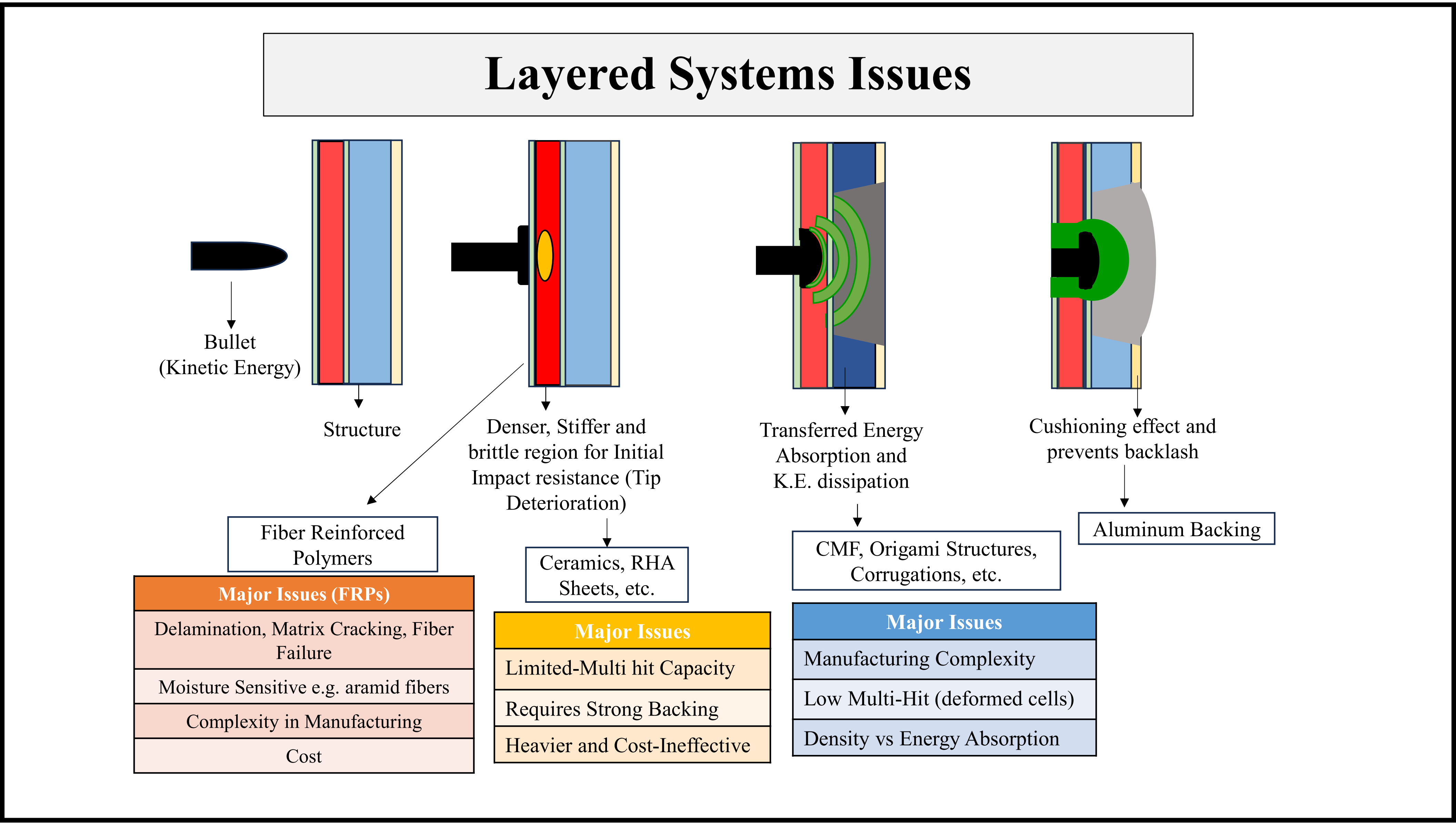
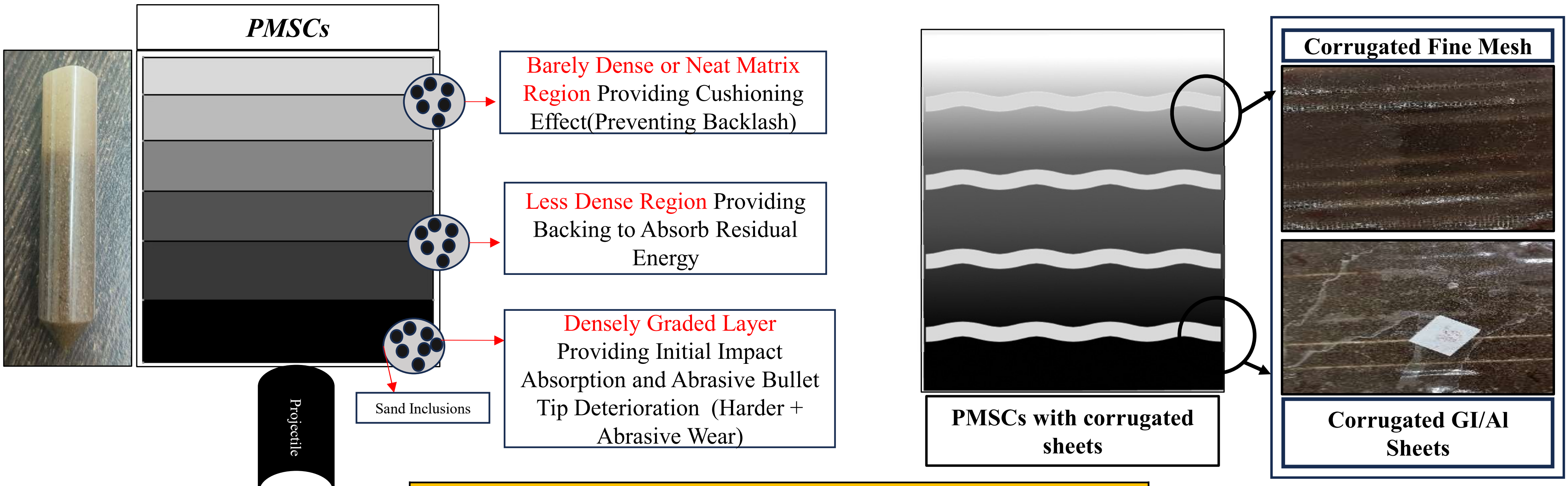
Supervised By: ***Dr. Srikant Sekhar Padhee***



Layered Systems Issues
Bullet
(Kinetic Energy)
Structure
Denser, Stiffer and brittle region for Initial Impact resistance (Tip Deterioration)
Transferred Energy Absorption and K.E. dissipation
Cushioning effect and prevents backlash
Fiber Reinforced Polymers
Ceramics, RHA Sheets, etc.
CMF, Origami Structures, Corrugations, etc.
Aluminum Backing
Major Issues (FRPs)
Delamination, Matrix Cracking, Fiber Failure
Moisture Sensitive e.g. aramid fibers
Complexity in Manufacturing
Cost
Major Issues
Limited-Multi hit Capacity
Requires Strong Backing
Heavier and Cost-Ineffective
Major Issues
Manufacturing Complexity
Low Multi-Hit (deformed cells)
Density vs Energy Absorption

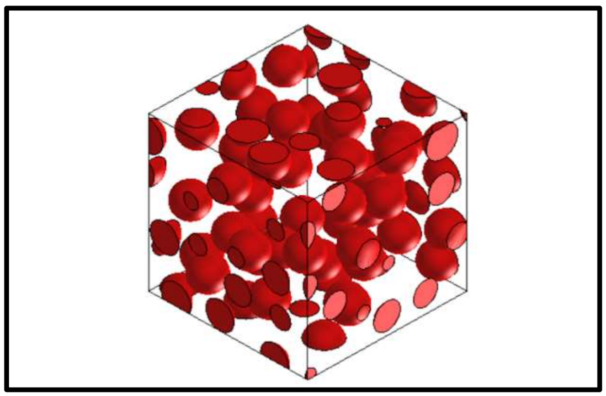
Conceptualization



Major Advantages
Sand particles increased the surface area resulting in better bonding
The abrasive nature of sand provides initial tip deterioration
Tailorable directional properties by varying particle size and fraction
Corrugated sheets act as stiff barriers or energy-absorbent mesh sheets at the end provide energy transfer to a larger area
Comparatively low cost, lightweight (Ceramics and metals), and manufacturing suitable structures.

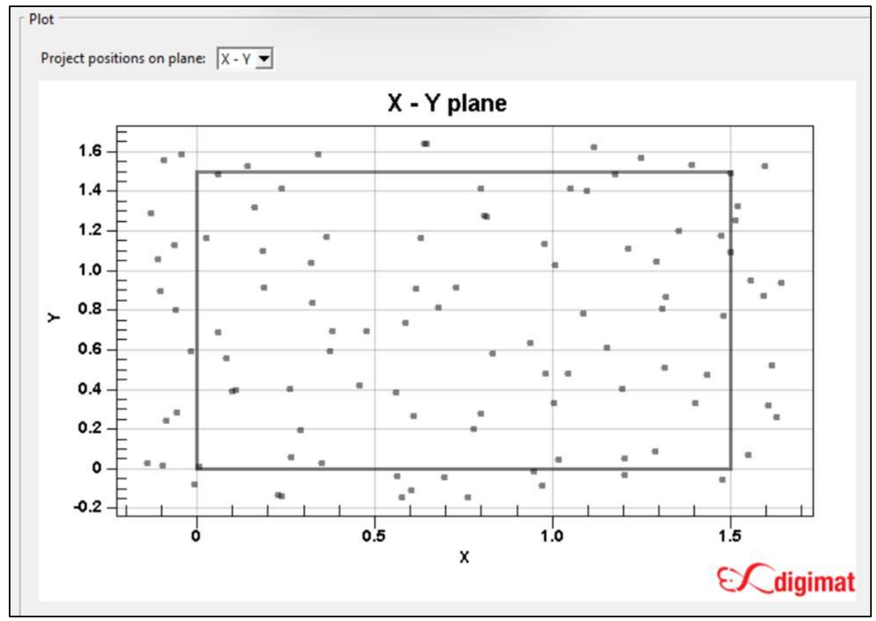
Evaluation of Sand Properties

We generated our representative volume element using **DIGIMAT** and altered the modulus of sand such that we reach the modulus value of the composite which we extracted from our experiment. In this way we will get the property of the sand when the displacement boundary condition is applied.

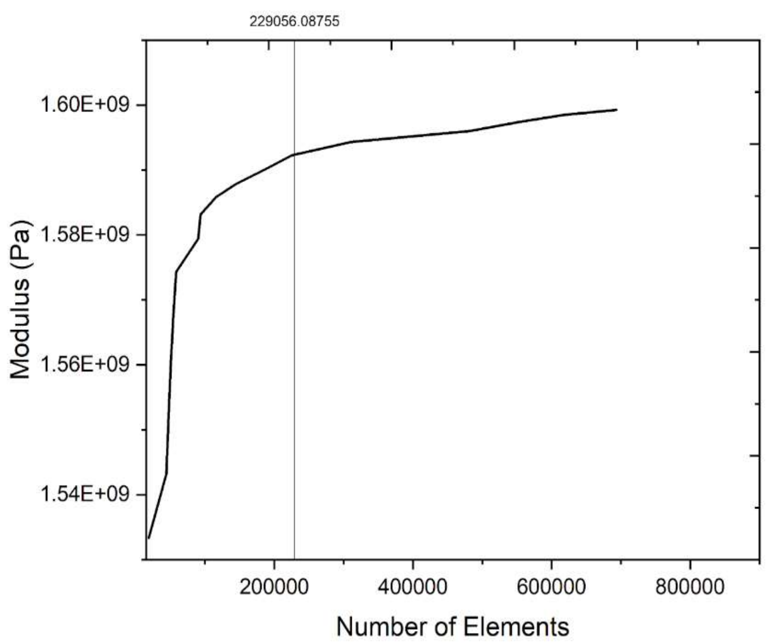


Summary data

	X	Y	Z
Mean	0.736	0.725	0.746
Standard deviation	0.556	0.544	0.532
Minimum	-0.138	-0.147	-0.124
Maximum	1.64	1.64	1.65



Element Size Determination

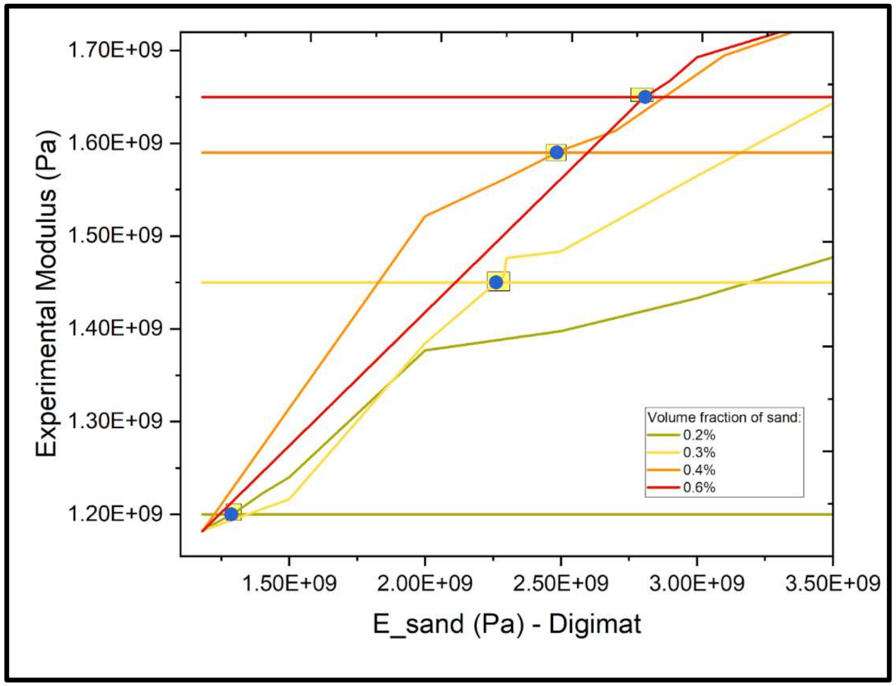


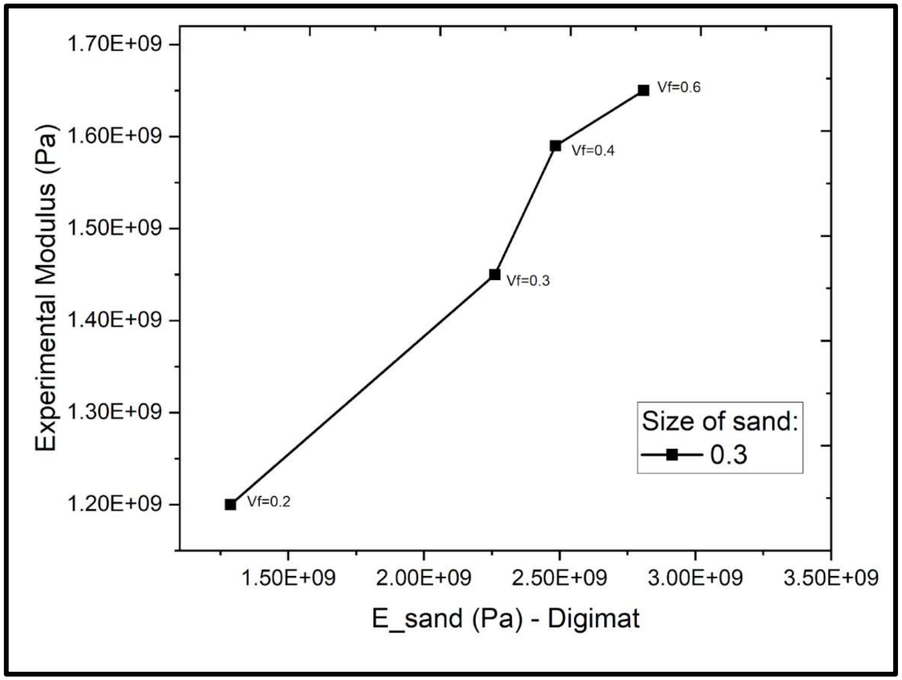
To ensure accurate and consistent results in the simulation of composite modulus, using a representative volume element (RVE) of a specific configuration (300 µm sand, 0.2 volume fraction). The **element size** was varied, and for each size, the **number of elements** and the corresponding **composite modulus (Pa)** were recorded.

It was observed that after approximately **229,056 elements**, the **modulus values stabilized**, indicating convergence. Since we cannot directly input the number of elements in the software, we **manually adjusted the element size** to achieve a mesh close to the converged number.

This step is **crucial for consistency**: without uniform element size, the software assigns different meshes for each case, leading to inconsistent modulus predictions.

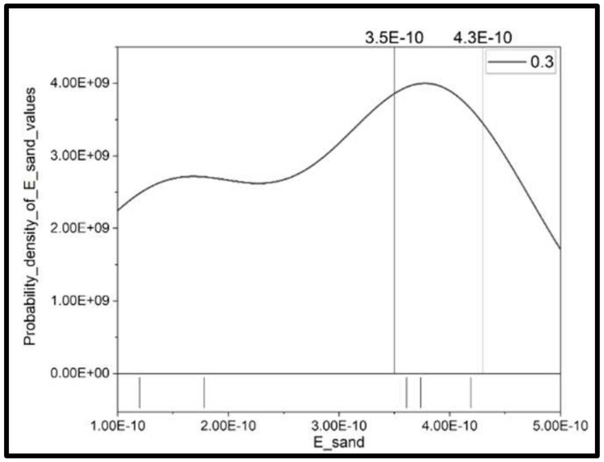
Intersection Graphs of Modulus of Sand



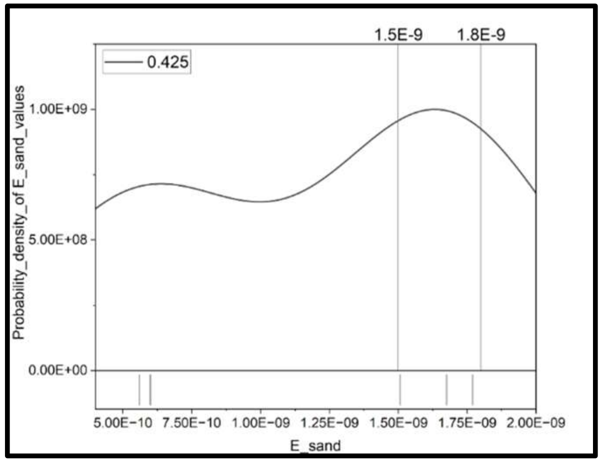


To estimate the unknown modulus of sand, we used Digimat simulations by varying sand modulus while keeping the epoxy modulus constant and observing the resulting composite modulus. This was done for different sand volume fractions (0.2, 0.3, 0.4, 0.6). Since we already had the experimental composite modulus, we plotted simulated composite modulus vs. sand modulus and added a horizontal line for the experimental value. The point where the two intersect gave us **an approximate modulus of sand for each volume fraction.**

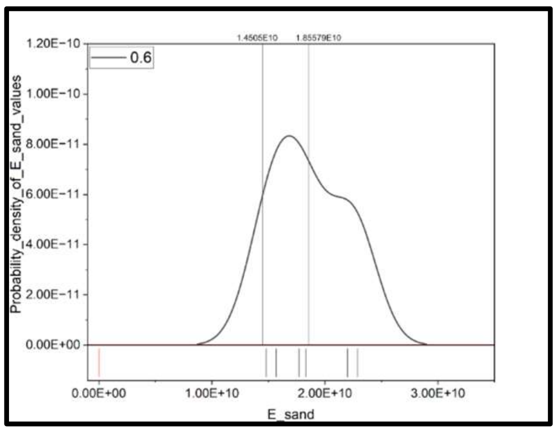
Distribution Graphs of Modulus of Sand



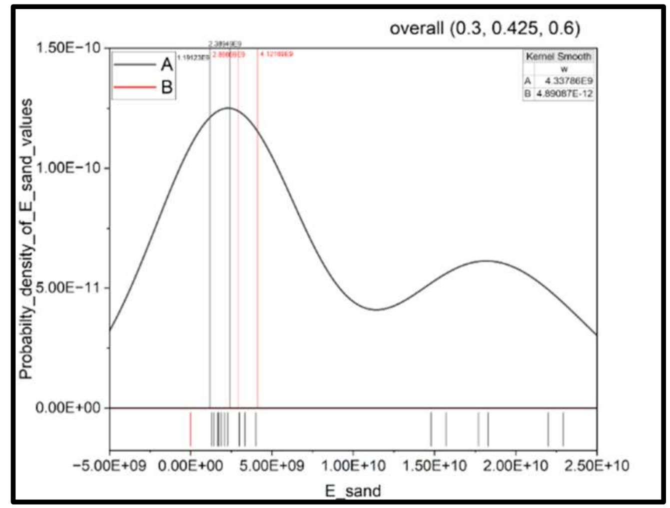
0.3 mm size



0.425 mm size



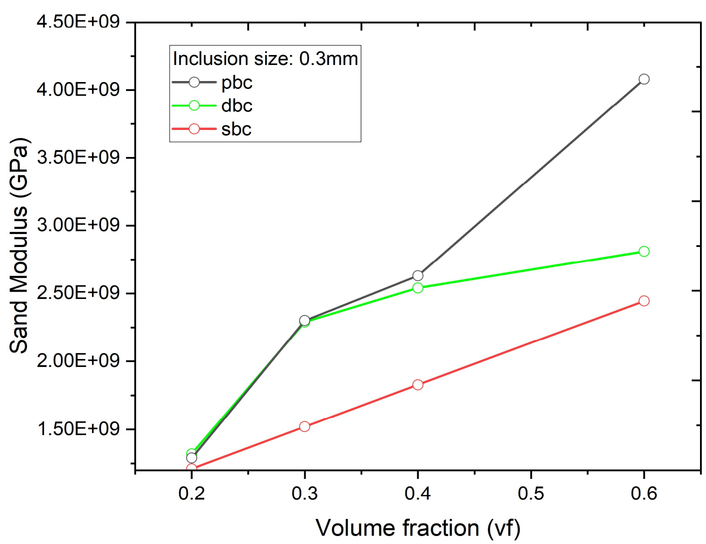
0.6 mm size



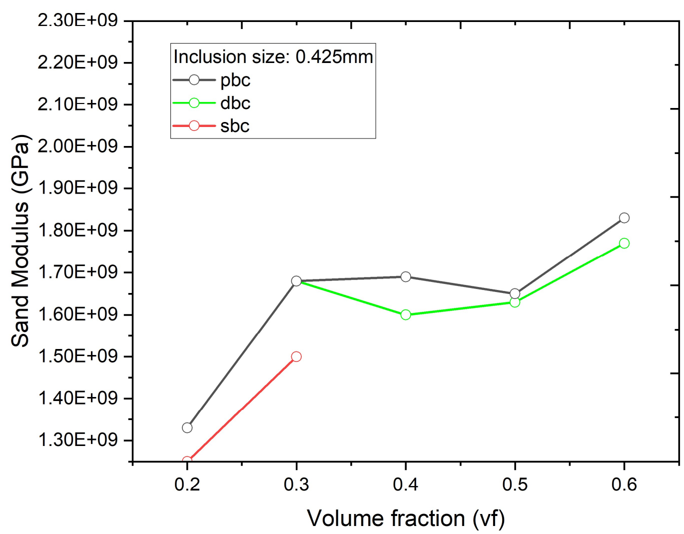
Overall Range in which our E_sand lies is determined from the combined graph

The range is 1.19E9 to 2.38E9

Boundary Conditions



0.3 mm size

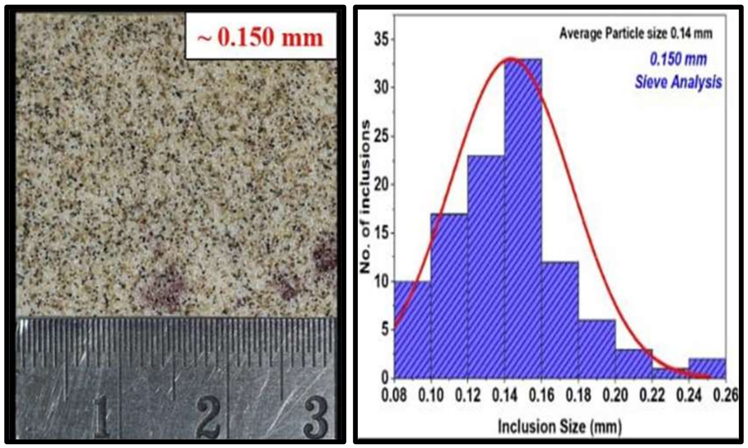


0.425 mm size

From our observation, PBC consistently gives the highest stiffness. DBC results lie between SBC and PBC, as expected. SBC yields the lowest modulus, due to less constraint and limited load transfer.

Sieve Analysis

Sample 1 (0.150 mm)

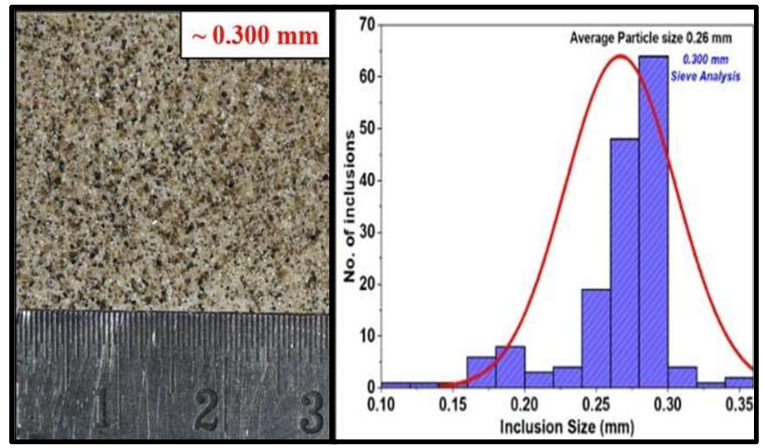


Type: Very Fine Sand

Avg. Particle Size: 0.147 mm

Distribution: Steep, narrow curve, Highly uniform

Sample 2 (0.300 mm)



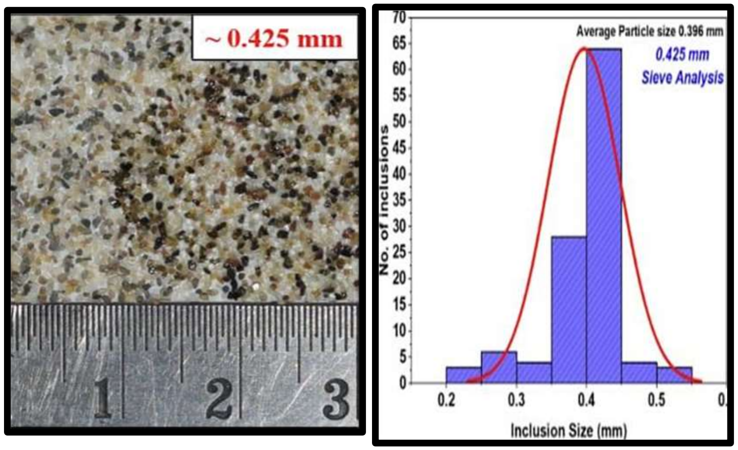
Type: Medium-Fine Sand

Avg. Particle Size: 0.26 mm

Distribution: Narrow, uniform gradation

Sieve Analysis

Sample 3 (0.425 mm)

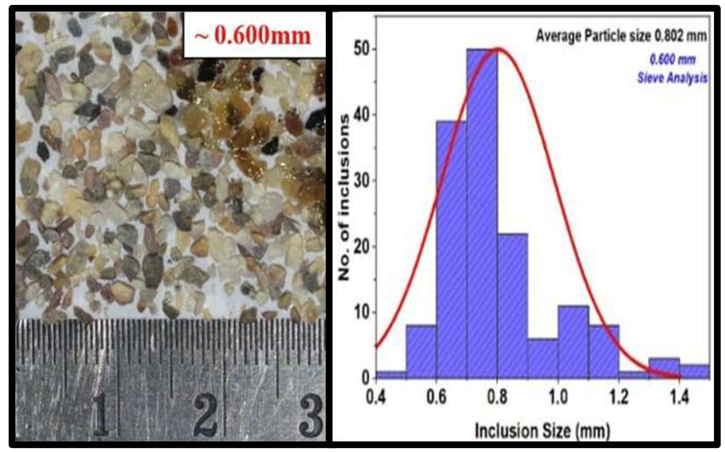


Type: Medium Sand

Avg. Particle Size: 0.396 mm

Distribution: Well-distributed, relatively uniform

Sample 4 (0.600 mm)



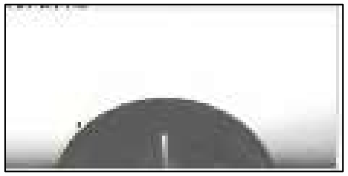
Type: Coarse Sand / Fine Gravel

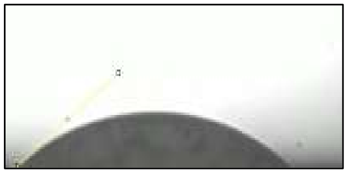
Avg. Particle Size: 0.702 mm

Distribution: Slightly broader, but still skewed towards uniformity

Contact Angle Test

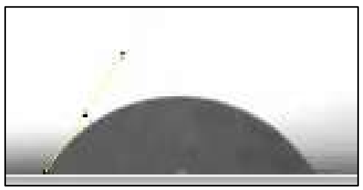
150


62.367°


33.69°


21.089°

300


51.892°


33.394°

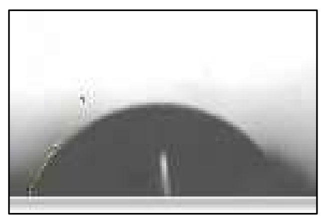

29.867°

425


41.836°


32.471°

600


53.011°


32.245°


16.891°

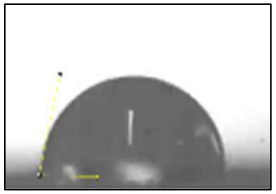
Epoxy Grade ER099 was dropped onto the sand particles of different sizes – 150, 300,425 and 600 µm.

The contact angles were noted at different times (equal intervals for each sand size).

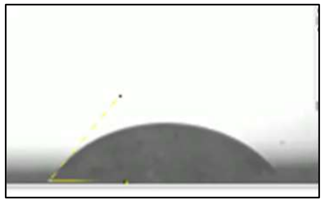
The interaction was observed to be "**Hydrophilic**"

Contact Angle Test

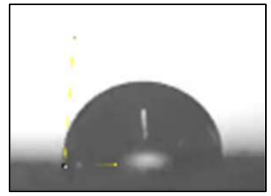
150

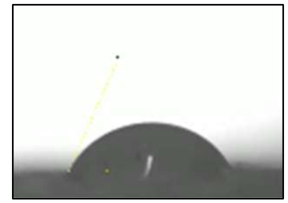

81.521°

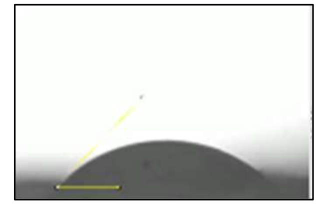

59.27°


44.145°

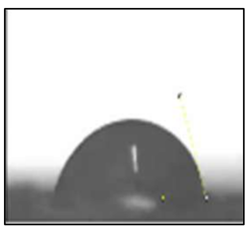
300

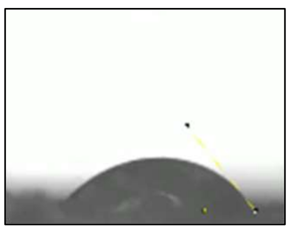

85.438°

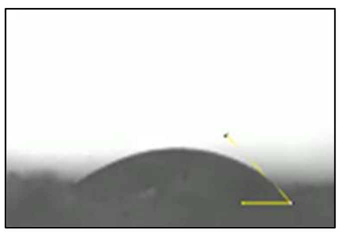

55.95°


50.512°

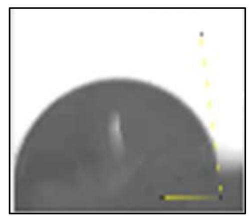
425

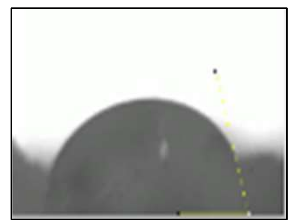

74.663°

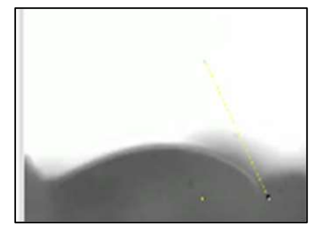

44.147°


32.918°

600


81.557°

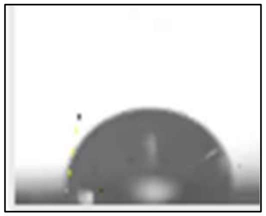

74.055°


60.072°

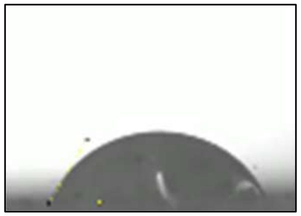
Hydrophilic Nature was observed for LY556 Epoxy as well

Contact Angle Test

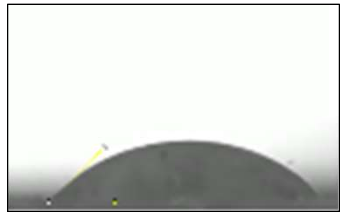
150



50.746°



26.9°



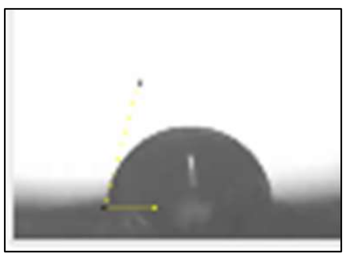
17.301°

300

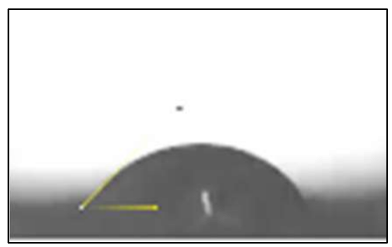
50.663°

35.121°

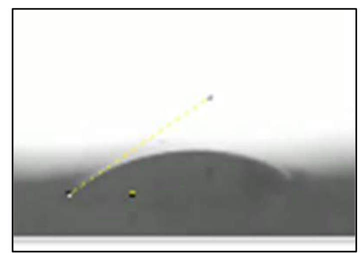
425



62.158°



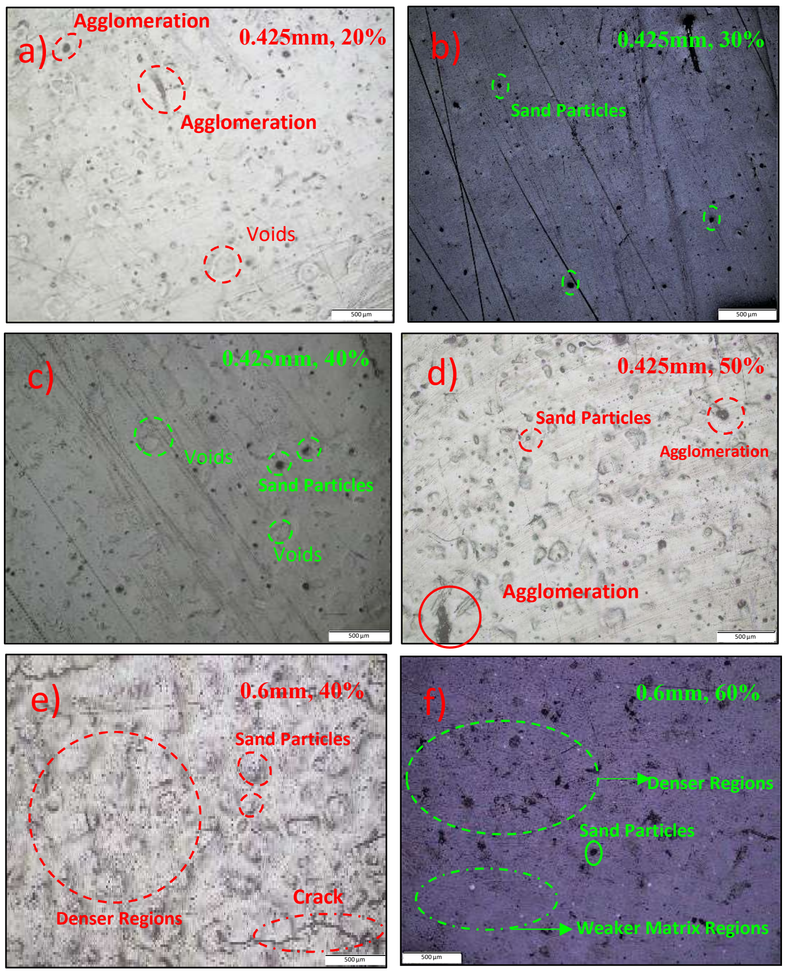
27.85°



17.816°

Hydrophilic Nature was observed for YDL Epoxy as well

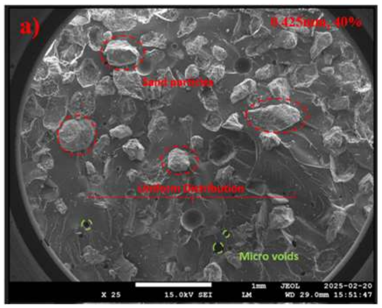
Microstructural Analysis



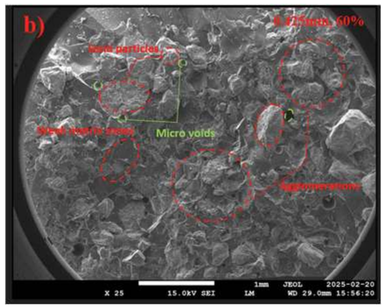
Observations

- The refined manufacturing process enabled a more uniform sand distribution up to a certain limit
- Fewer agglomerations in small grain sizes and lower weight fractions a),b).
- Larger Particles did not increase agglomerations although higher percentages increased agglomerations d).
- Voids were lower owing to minor inconsistency in filling or dispersion c).
- Denser sand regions and weak matrix regions are observed when increased percentage of sand.

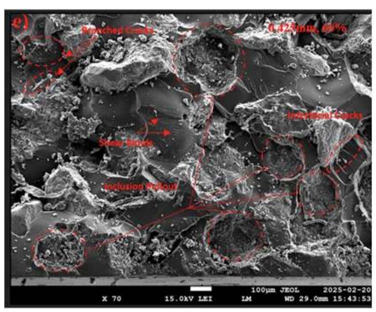
SEM Analysis



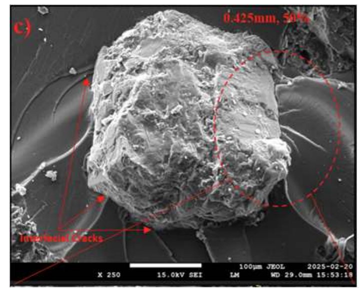
Severe agglomeration and branched cracks; poor bonding and brittle fracture.

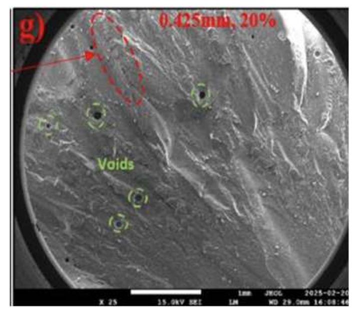


Severe agglomeration and branched cracks; poor bonding and brittle fracture.

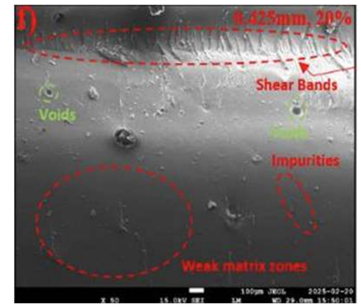


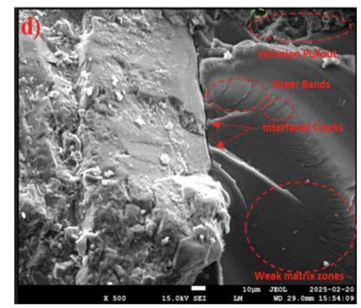
Fracture dominated by inclusion pull-out, branched cracks, and voids.





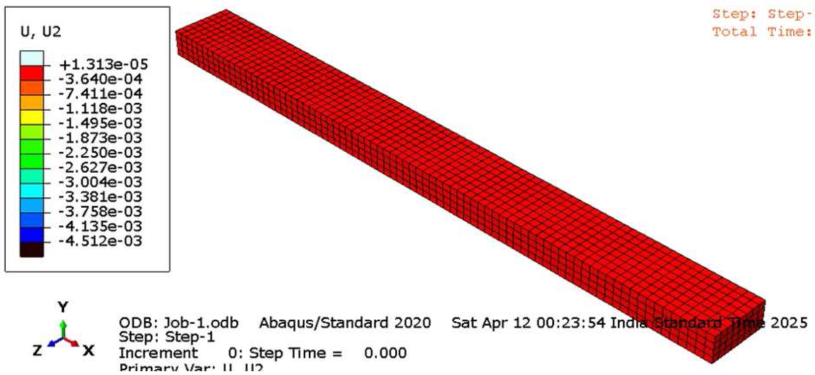
Moderate filler dispersion with visible voids and shear bands; early signs of matrix weakening.

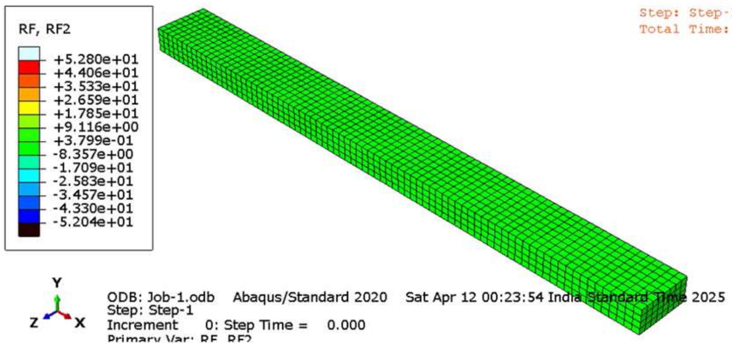


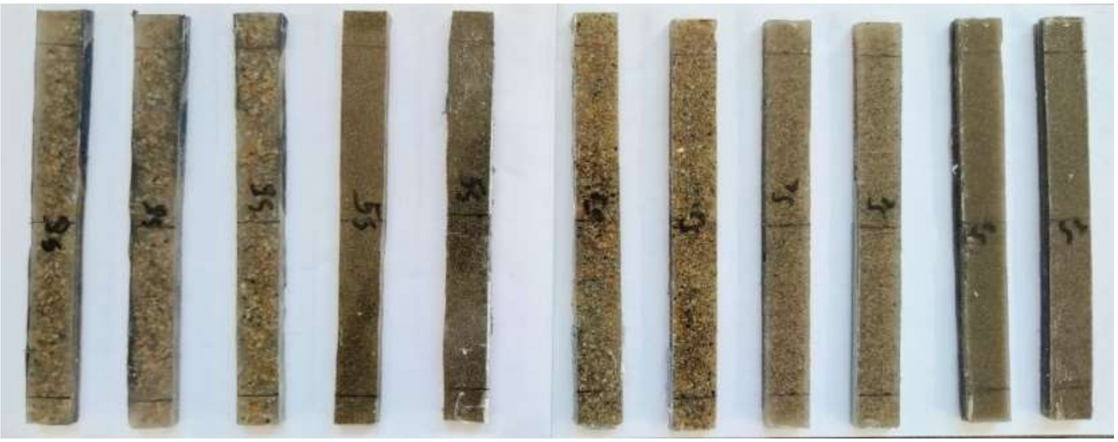


Matrix weakening evidenced by interfacial cracks, shear bands, and filler debonding indicating loss of cohesion under stress.

Flexural Test







Sample Number	Sample Composition
1	300 : (60,50,40,30)
2	425 : (60,50,40,30)
3	(600-50% , 425-40%, 425-30%, 300-30%)
4	(300-40%, 600-50%, 600-50%, 300-40%)
5	(300-30%, 425-40%, 600-50%, 600-50%)

Conclusion

Experimental and computational analyses confirmed that adding sand particles to epoxy improves hardness, impact resistance, and energy dissipation.

Use of Functionally Graded Materials (FGMs) significantly enhanced the flexural performance of epoxy–sand composites.

FGMs with strategic layering (hard-to-soft) and varied sand particle size/concentration enabled better stress distribution and energy absorption