FLY ASH PARTICULATE REINFORCEMENT FOR PROPERTY ENHANCEMENT OF PU FOAM CORE SANDWICH COMPOSITES

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by

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Chapter 7. Conclusions and Future Scope

7.1. Conclusions

The study of FA reinforced composites has been conducted in three parts. First part is dedicated to using FA as viable option for the reinforcement of PU foam. The effectiveness of the reinforcement is validated by the shear test. Then, this reinforced PUF is utilised as core with GFRP/CFRP face sheet of sandwich composites. The performance of the FA-PUF with GFRP/CFRP face sheet has been examined under three-point bend test. In second part the compressive properties of the FA-PUF core have been investigated. Then, the indentation resistance of the sandwich composites has been investigated for the neat and reinforced PUF core. In this investigation the effect of FA reinforcement and indenter's nose tip profile has been investigated extensively. The third part comprises the study of GFRP and CFRP face sheet sandwich composites using neat and FA-PUF core. The effect of face sheet, FA reinforcement and indenter's nose profile geometry on the indentation resistance has been inspected elaborately. The conclusions made from the present study are:

- Surface treatment of FA included PUF core was carried out using silane solution (GPTS) and their strength properties were found to be better than the virgin specimens as seen from the shear elastic plots and SEM images.
- This improvement in shear properties can be ascribed to an enhanced synergetic interfacial bonding and reinforcement of foam structure consisting of cell struts and cell walls.
- The surface-treated fly ash reinforced polyurethane foam cores were found to be much stiffer and stronger than the neat polyurethane core and their shear modulus was improved from 14% to 39% depending on the weight percentage of fly ash inclusion.

- the FA-PUF core CFRP (face sheet) sandwich composites exhibit higher flexural strength and stiffness characteristics in comparison to GFRP sandwich composites.
- The mechanical test showed a 10% increase in the peak load for the 20% FA-PUF GFRP sandwich composites in comparison to the neat PUF GFRP sandwich composites, while in contrast 25% reduction in deflection at peak load was observed.
- Similarly, for the 20% FA-PUF CFRP sandwiched composites, there was 5% increase in peak load and 25% reduction in deflection at peak compared to those for the neat PUF CFRP sandwich composites.
- Finding from the compression testing state that, in comparison to neat PUF, the 20% FA-PUF shows an increase of almost 120% in young's modulus and 37% in Yield stress. However, the increase in stiffness causes a reduction in yield strain of around 48% for the fly ash included PUF foam core.
- Tearing, crushing and shearing are observed to be the three dominant damage mechanism of indentation for the failure and fracture of FA-PUF core. The PUF core exhibited the maximum indentation resistance to the flat-circular indenter, followed by that to the hemispherical and conical indenters.
- The compression curve aligns to the flat-circular indenter's curve properties. PUF core curve characteristics under hemispheric indenter are bi-linear, followed by a densification surge. In comparison, curve characteristics under conical indenter are parabolic.
- The damage analyses employing optical images reveal that the damage area gets reduced with the increase in fly ash reinforcement for the flat-circular and hemispherical indentation. Contrastingly the damage mechanism is more localized for the conical indentation without any significant change in the damage zone.

- The reinforced FA-PUF core performs better under a flat-circular and hemispherical indenter. But the neat PUF responds quite well under conical shape indenter rather than reinforced FA-PUF.
- With FA inclusion the cell density increases, on contrary the cell wall thickness gets reduced. Hence, the performance under compression of 5 wt. % FA-PUF is lower than the neat PUF. However, with further increase in FA inclusion, the mechanical performance is significantly enhanced.
- The study using scanning electron microscopy concluded that the neat PUF displays more flexibility and elastic behavior whereas reinforced PUF exhibits brittle characteristics under loading. The fly ash infused PUF has higher stiffness and rigidity to compensate the loss of flexibility.
- Each indenter has a unique impact on sandwich structure. The mode of failure in sandwich composite's upper face sheet under flat circular indenter is matrix cracking, delamination, fiber breakage and shear plugging around the circumference of indenter.
- The failure is localized at the contact site in case of hemispherical indenter. The matrix cracking and initiation of the delamination due to shear stresses generated in the upper face sheet, which later on leads to the fiber breakage at the contact site of the indenter.
- Here, damage is more localized at the point of contact between the conical tip indenter and sandwich specimen. The conical indenter engendered even higher contact stresses which tries to pierce the upper face sheet.
- The response of the CFRP sandwich composite is better than the GFRP sandwich composite under indentation. This improvement is due to the superior stiffness of the CFRP laminated face sheet in comparison to GFRP laminated face sheet. This

conforms the CFRP is having higher first peak, and slope is also higher in the plastic crushing region.

- The response of the FA reinforcement to PUF core sandwich composite has been captured in the study. It has been observed that the elastic performance of the sandwich composite is surely enhance due to FA reinforcement. But, indentation resistance of the sandwich composite in plastic region is deteriorating for 5% FA-PUF sandwich composite. While, the performance in plastic region also improves with increment in FA reinforcement.
- The improvement in shear, compression, bending and indentation properties of PUF foam core and sandwich composite by employing a low-cost thermal power plant industry by-product. Fly ash seems to be an attractive alternative for future structural applications. This also has the advantage of reducing environmental hazards and corrosive pollution.

7.2. Future Scope

Based on the present results, the future scope of this research work is:

1. The fabricated sandwich composite can be investigated for change in mechanical properties and deformation behaviour under hygrothermal conditions.
2. The residual stress carrying capacity of sandwich composite after indentation can be evaluate as future work.
3. The effect of fly ash reinforcement on PUF foam and sandwich composite can be tested for its sound and thermal insulating properties.
4. The present study showed improved mechanical properties by utilising FA in PUF sandwich composites. Further, the investigation can be extended on the utilisation of industrial and agricultural wastes such as egg shell ash, coconut shell ash, bagasse shell ash, red mud etc. as reinforcements in the PUF core.