



Fly ash mediated epoxy composites: A Review

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Fly ash utilization has always been a major concern because of pollution aspects and requirement of large area of land for disposal. Construction industry use fly ash partly for cement and bricks. Polymer composites are the novel material which can utilize fly ash as a potential material for filler in manufacturing of cost-effective epoxy composites for diverse applications. Researchers has shown that this material may be utilized to improve the thermal and mechanical characteristics of epoxy composites which can be employed in different sectors like automotive, aeronautical, semi-structural etc. Proper surface modification of fly ash can significantly improves the adhesion between matrix and filler and properties of epoxy composites reinforced with fly ash. This work reviews the recent developments in surface treatment and utilization of fly ash mediated Epoxy composites.

Keywords: Fly ash, epoxy, reinforced, composites.

Introduction

Nowadays, due to the expanding need of better infrastructures in industries, buildings as well as constructional materials, household materials, and materials used in different sectors worldwide demand of lightweight and eco-friendly materials having good physical, mechanical and chemical properties is increasing which leads to increasing numerous ongoing researches for developing new materials. The basic lightweight and eco-friendly concept came up with filler-polymer composites for lightweight with different eco-friendly fillers. Fly ash can be utilized as filler materials because of its density and good dispersion properties (Yang *et al.*)¹.

Goh *et al.*² did the research work on fly ash obtained from incineration of Municipal solid waste (MSWI) as reinforcing filler in epoxy composite to check mechanical strength enhancement. Zacco *et al.*³ also suggested that, may MSWI fly ash, cause environmental problem while disposing in landfills as fly ash carries harmful metals mainly Zn, Pb which classified it in the category of hazardous waste. So, it is better to use MSWI fly ash in composite developments. Fly ash as industrial waste can be used to make polymeric composite (Saxena *et al.*)⁴.

It is reported that during 2014-2015, in India alone, 2400 lakhs tons of fly ash was generated in different thermal power stations (Pappu and Thakur)⁵. Fly ash can be used to make composites to maximize the fly ash consumption and safe management. Some of the fly ash/epoxy composites are made and studied for different characteristics are given in Table 1. Polymer composites reinforced with fly ash are getting importance due to diverse applications and cost-effectiveness. Srekanth *et al.*⁶ observed that fly ash from coal improves thermal and mechanical properties of developed composites. The improvement in compressive strength shown by increased fly ash in recycled polymer (Li *et al.*)⁷. (Baccaro *et al.*)⁸ showed that because of irradiation flexure strength decreases but impact, compressive strength, and hardness increases. Zacco *et al.*³ reported that, fly ash containing minerals are able to improve the performance of composites. Dey and Pandey⁹ illustrated that performance of polymer composite materials reinforced by fly ash depends on its size geometry and distribution of filler particles along with interfacial adhesion property between filler and matrix. Stimoniaris *et al.*¹⁰ suggested for focusing on dispersion of fly ash in composite either by using mechanical stirring or ultrasonication. This review paper aims to study the proper-

Table 1. Studies done on fly ash based epoxy composites

Sr. No.	Filler	Property studied	Reference
1.	MSWI fly ash	Tensile	Goh <i>et al.</i> ²
2.	Fly ash with sisal fiber	Tensile	Pappu and Thakur ⁵
3.	Fly ash	Mechanical	Pattanaik <i>et al.</i> ¹¹
4.	Fly ash and silica fumes	Tensile	Ravishankar <i>et al.</i> ¹²
5.	Fly ash and glass fiber	Compressive	Kulkarni and Kishore ¹⁴
6.	Fly ash	Flexural property	Dharmalingam <i>et al.</i> ¹³
7.	Fly ash and glass fiber	Damping property	Shubham and Tiwari ¹⁵
8.	Fly ash	Tensile and impact strength	Shubham and Tiwari ¹⁶
9.	Fly ash	Impact strength	Raja <i>et al.</i> ¹⁷
10.	Fly ash	Mechanical	Sreekanth <i>et al.</i> ⁶
11.	Fly ash	Mechanical	Thongsang and Sombatsompop. ¹⁸
12.	Fly ash	Compressive and flexure strength	Qin <i>et al.</i> ¹⁹

ties of fly ash-epoxy composite, different methods for surface modification of fly ash particles, and effect of surface treated fly ash on epoxy composite along with recent developments in this field.

Epoxy

The excellent characteristics of epoxy like good mechanical performance, minimum shrinkage, make it the preferred matrix material for composites (Faruk *et al.*)²⁰. Epoxy based polymer composites had diverse applications such as aerospace, defense automobile and manufacturing sector (Goh *et al.*)². Epoxy could be cured easily within 24–48 h at ambient temperature (Pattanaik *et al.*)¹¹.

Fly ash

Power and incineration plants produce fly ash as a byproduct may have specific surface area greater than 0.1038 m²/g run produced from different sources like coal based, biomass based (Asokan *et al.*)²¹. Advancement in technology meets the demand of energy requirements globally, which followed a considerable increase in thermal power plants increasing ash residue respectively termed as fly ash (Asokan *et al.*)²². Fly ash is assumed to be world's fifth largest material resource because of its high production (Zacco *et al.*)³. It is reported by Blissett and Rowson²³ that, constituents of coal fly ash based on geographical location. The chemical constituents of coal fly ash in India majorly contains silicon dioxide in the range of 50.2–59.7%, aluminium oxide 14.0–32.4%, iron oxide 2.7–14.4% and other metal oxides²³. Fly

ash also consists of few spherical particles hollow in nature, the less density for composite considerable for weight specific applications.

Surface treatment/modification of fly ash

There are basically two method to treat surface of fly ash i.e. physical treatment and chemical treatment (Thongsang and Sombatsompop)¹⁸. Reducing fly ash particle up to micro and nano size is done by Dharmalingam *et al.*¹³ to make fly ash-epoxy composite. Fly ash, with inorganic minerals has been utilized as filler material in epoxy matrix. Degradation in mechanical characteristics because of to poor compatibility and adhesion with the epoxy matrix has been reported and to improve the adhesion surfactant sodium lauryl sulfate and silane coupling agent was used for treatment. The surface improvement of fly ash promotes the adhesion and crosslink in organic matrix (Parvaiz *et al.*)²⁴. As Alkadasi *et al.*²⁵ stated that, the composites of polymeric material (hydrophobic nature) and fly ash particles (hydrophilic nature) are irreconcilable, leading poor interfacial bonding and lower mechanical properties and it is also reported that, surface improved fly ash with silanes or surfactants is capable to improve the mechanical properties of composite by affecting their chemical structure and by introducing covalent bonds. Surface treatment mechanism of fly ash using silane (bis(3-triethoxy silyl) propyl tetrasulfide) is shown in Fig. 1. Surface treated fly ash with surfactant avoids particle-particle interaction between fly ash particulates, enhances physical properties.

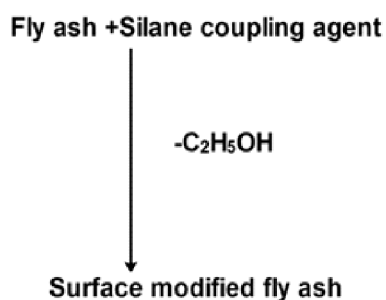
Surface modification of fly ash by chemical method:

Fig. 1. The reaction silane and fly ash particle surface (Alkadasi *et al.*)²⁵.

Coupling agent like silane are served as chemical bridge for polymeric matrix like epoxy and inorganic substrate like fly ash and improves adhesion between them (Culler *et al.*)²⁶. Coupling agents are chemical treatment method and Si-69 as coupling agent is used to treat fly ash (Thongang and Sombatsompop)¹⁸. Silane acts as a bonding bridge between the two dissimilar materials to improve the adhesion (Chaudhury *et al.*)²⁰. Silane coupling agent gamma-aminopropyltriethoxysilane (Silquest A1100), is used to treat surface of Municipal solid fly ash for comparative study between modified and unmodified fly ash and reported that silane coupling agents are able to improve the interfacial adhesion between the filler and matrix (Goh *et al.*)². Glycidoxy propyl trimethoxysilane and surfactant sodium lauryl sulphate is used to modify coal fly ash to make composite with epoxy (Dharmalingam *et al.*)¹³. Gamma-aminopropyltriethoxysilane is also used as coupling agent to modify fly ash by Shubham and Tiwari¹⁶, and reported that treated fly ash has good compatibility with epoxy resin and inorganic fly ash substrate. Similarly, determination of mechanical characteristics of fly ash-reinforced polybutadiene composite was done using coupling agent, Si-69 named as bis(3-triethoxysilyl)propyl tetrasulfide (Alkadasi *et al.*)²⁵. 3-Glycidoxypropyltrimethoxy silane (GPTMS) is used as coupling agent to modify fly ash, aimed to improve mechanical characteristics of composites (Qin *et al.*)¹⁹. It is also depicted that with the crosslink mechanism the coupling agent changes the hydrophilicity. The alkoxy group of molecule hydrolysed to form silanol when interacted by GPTMS. Mesoporous silica in colloidal form (CMS) is used as physical method of treatment for fly ash surface to reduce agglomeration among fly ash particles

because of interaction within the particles. CMS enhance the compatibility of fly ash in epoxy matrix (Besco *et al.*)²⁷. Surface modification of fly ash is done using alkaline activating solutions i.e. combination of 10 M NaOH solution with Na₂SiO₃ to make composites (Messina *et al.*)²⁸. NaOH solution for treating fly ash resulted rougher physical surfaces (Thongang and Sombatsompop)¹⁸. Xie *et al.*²⁹ studied the effect of surface modified fly ash with the help silane coupling agent and mixed with asphalt.

Mechanical behaviour of composites

Shubham and Tiwari¹⁶ analyzed that, silanized fly ash observed increment in tensile characteristic and toughness in comparison to unsilanized fly ash filled epoxy composite. They concluded that, increasing fly ash intrusion in epoxy composite decreases overall property. The tensile properties and the fracture toughness measured to show the effect of fly ash content and coupling agent (Wong *et al.*)¹⁰. Gupta *et al.*³⁰ checked compressive property and impact property of glass fiber reinforced fly ash-epoxy composite. Goh *et al.*² made the samples of fly ash-epoxy composite varying fly ash content 0–30% and tested for flexure and tensile strength. Samples showed the result that, increasing fly ash content decreases overall performance but, comparatively strength of composite while mesoporous silica treated fly ash has improved properties as compare to silane treated fly ash composites and silane treated fly ash composites have better characteristics as compared to untreated fly ash composites. The density (g/cc) of fly ash-epoxy composite was observed 1.46 and fly ash based polyester composite was 1.68 and comparative tensile strength (MPa) of fly ash-epoxy composite and fly ash polyester composite was 31.57 and 22 respectively (Pappu and Thakur)⁵.

The mechanical behavior also changes with curing conditions and mixing time (Pattanaik *et al.*)¹¹. They reported that fly ash based epoxy composite when kept for different curing situations like an ambient curing or natural curing, oven curing, and micro oven curing, the tensile, flexural, and impact strength of composite cured by microwave oven > oven curing > ambient curing. Comparative study microwave curing with thermal curing of epoxy resins are done by Yarlagadda and Hsu³¹ and Tanrattanakul and Saetiauw³². The internal heat generates in microwave oven within the material accelerating cross linking reaction and polymerization very fast. While similar phenomenon occurred in oven curing would

be in much slower rate (Mijović *et al.*)³³.

Ravishankar *et al.*¹² illustrated the comparison in mechanical characteristics of fly ash based epoxy composites and silica fumes based epoxy composites and reported that fly ash based epoxy composites had better compression and tensile strength than silica fumes based epoxy composite. Singla and Chawla³⁴ studied the mechanical characteristics of glass fiber/fly ash based epoxy composites. Dharmalingam *et al.*¹³ determined the flexure and impact properties of fly ash based epoxy composites in their research work and concluded that, surface modification with silane improves the overall mechanical behavior compared to sodium lauryl sulphate modified fly ash. The effect of filler particle size on compressive and flexural behavior studied by Nakamura *et al.*³⁵ and impact strength by Baheti *et al.*³⁶. Raja *et al.*¹⁷ reported that, the size of filler particles affects mechanical behavior of developed composites. It was found that impact energy (Joule) in fly ash mediated epoxy composite of fly ash particle size 300 nm < 350 nm < 480 nm < 50 micron. Baheti *et al.*³⁷ studied thermo-mechanical behavior of pulverized fly ash particle up to 500 nm in epoxy composite.

Conclusion

Fly ash mediated epoxy composites have great potential to use them as a new material due to its non-corrosive property, lower density and better mechanical properties. It is also a new way to reduce and reuse fly ash making eco-friendly material. Due to better physical and mechanical property composite can be used to make tiles, bricks, window and door frames, may help to reduce dead load of buildings. But, economically accessibility may be a major concern, which needs leads for some more research. Various researchers did different modification on fly ash particle surface to enhance overall property of fly ash-epoxy composite.

References

1. Y. F. Yang, G. S. Gai, Z. F. Cai and Q. R. hen, *J. of Hazardous Materials*, 2006, **133**, 276.
2. C. K. Goh, S. E. Valvan, T. K. Low and L. H. Tang, *Waste Management*, 2016, **58**, 309.
3. A. Zaco, L. Borgse, A. Gianonclli, R. P. Strus, L. Depero and E. Bontempi, *Environmental Chemistry Letters*, 2014, **12**, 153.
4. M. Saxena, R. Morchale, P. Ashokan and B. K. Prasad, *J. of Composite Materials*, 2008, **42**, 367.
5. A. Pappu and V. K. Thakur, *Vacuum*, 2017, **146**, 375.
6. M. S. Sreekanth, V. A. Bambole, S. T. Mhaske and P. A. Mahanwar, *Journal of Minerals & Materials Characterization & Engineering*, 2009, **8**, 237.
7. Y. Li, D. White and R. Peyton, *Resources, Conservation and Recycling*, 1998, **24**, 87.
8. S. Bacaro, B. Bianchili, C. Casdio and G. Rinaldi, *Radiation Physics and Chemistry*, 1998, **52**, 187.
9. A. Dey and K. M. Pandey, *Reviews on Advanced Materials Science*, 2016, **44**, 168.
10. A. Stimoniris, E. Skoura, D. Gounis, M. Karakasides and C. Delides, *J. of Mat. Engineering and Performance*, 2019, **28**, 4620.
11. A. Pattanaik, M. Mukherjee and S. B. Mishra, *Composites Part B: Engineering*, 2019, **176**, 107301.
12. K. S. Ravishankr and S. M. Kulkarni, "Materials Science and Engineering (IOP Conference Series)", 2017, **225**, 012299.
13. U. Dharmalingam, M. Dhanasekran, K. Balasubramanian and R. Kandsamy, *Polimeros*, 2015, **25**, 540.
14. S. M. Kulkarni, *Journal of Applied Polymer Science*, 2003, **87**, 836.
15. P. Subham and S. K. Tiwari, *Proc. of AME*, 2012, **105**, 978.
16. P. Subham and S. K. Tiwari, *IJSER*, 2013, **4**, 1173.
17. R. S. Raja, K. Manisekar and V. Manikandan, *International J. of Mining, Metallurgy and Mechanical Engineering*, 2013, **1**, 2320.
18. S. Thongsang and N. Sombatsompop, *Polymer Composites*, 2006, **27**, 30.
19. C. Qin, W. Lu, Z. He, G. Qi, J. Li and X. Hu, *Polymers*, 2019, **11**, 741.
20. M. K. Chaudhry, T. M. Gen le and E. P. Plueddmann, *Journal of Adhesion Science and Technology*, 1987, **1**, 29.
21. P. Ashokan, M. Saxena, A. Aparna and S. Asoletar, *Waste Mgmt. & Research*, 2004, **22**, 265.
22. P. Ashokan, M. Saxena, A. Aparna and R. Asoletar, *Materials Characterization*, 2010, **61**, 1342.
23. R. S. Blissett and N. A. Rowson, *Fuel*, 2012, **97**, 1.
24. M. R. Purvaiz, S. Mohanty, S. Nayak and P. Mahanwar, *Materials Science and Engineering: A*, 2011, **528**, 4277.
25. N. A. Alkads, D. Hundiwale and U. Kapadi, *Journal of Applied Polymer Science*, 2004, **91**, 1322.
26. S. Culler, H. Ishida and J. Koenig, *J. of Colloids and Interface Science*, 1986, **109**, 1.
27. S. Besco, M. Brisotto, A. Gianoncelli, L. E. Depero, E. Bontempi, A. Lorenzetti and M. Modesti, *Journal of Applied Polymer Science*, 2013, **130**, 4157.
28. Messina, Ferone, Colangelo, Roviello and Cioffi, *Composites Part B: Engineering*, 2018, **132**, 161.
29. J. Xie, L. Pan, J. Lin and Z. Zhu, *Construction and Building Materials*, 2012, **30**, 340.

30. N. Gupta, B. Brar and E. Woldesebet, *Bulletin of Mat. Science*, 2001, **24**, 219.
31. K. P. Yarlagadda and S. H. Hsu, *Journal of Materials Processing Technology*, 2004, **155**, 1532.
32. V. Tanrattanakul and K. Sae Tiaw, *Journal of Applied Polymer Science*, 2005, **97**, 1442.
33. J. Mijovic and J. Wijaya, *Polymer Composites*, 1990, **11**, 184.
34. M. Singla and V. Chawla, *J. of Minerals & Mat. Characterization & Engineering*, 2010, **9**, 199.
35. Y. Nakamra, M. Yamaguchi, M. Okobo and T. Matsumoto, *J. of Applied Polymer Science*, 1992, **44**, 151.
36. Y. Nakmra, M. Yamguchi, M. Okobo and T. Matsumoto, *Polymer*, 1991, **32**, 2976.
37. V. Baheti, Jiry Militky, R. Mishra and B. Behera, *Composites Part B: Engineering*, 2016, **85**, 268.
38. P. Chindapasirt and U. Rattanasak, *International Journal of Greenhouse Gas Control*, 2019, **85**, 30.
39. O. Faruk, A. K. Bldzki, H. Fink and M. Sain, *Progress in Polymer Science*, 2012, **37**, 1552.
40. K. Y. Wong and R. W. Truss, *Composites Science and Technology*, 1994, **52**, 361.
41. M. Ahmaruzaman, *Progress in Energy and Comb. Science*, 2010, **36**, 327.