Conclusions and future directions

Highlight

This chapter mainly summarizes the entire work of the thesis. The chapter wise major achievements and conclusions are highlighted here. Finally, the future directions or scopes of the present work are also mentioned.

6.1. Summery and conclusions

The thesis highlights on the development of hyperbranched epoxy nanocomposites with high toughness and new set of properties for their potential applications to overcome the shortcomings of conventional epoxy thermosets as well as to increase the area of applications. The first chapter describes the general introduction and brief review on epoxies with special emphasis on hyperbranched architecture and their nanocomposites with different nanomaterials. The chapter mainly emphasizes the importance, preparation and characterization techniques, properties and applications of epoxies and their nanocomposites. The scopes, objectives and plans of the present work are also mentioned at the end of this chapter.

The second chapter of the thesis describes synthesis of hyperbranched epoxy resins by polycondensation reaction using three different multifunctional moieties (pentaerythritol, triethanol amine and castor oil based polyester polyol) along with other conventional reactants in three subsequent sub-chapters. It also deals with characterization and property evaluation of the synthesized hyperbranched epoxies. The desired toughness along with high performance of the hyperbranched epoxy thermosets was achieved through judicious molecular engineering.

Again, to address the advanced demands of such polymers different nanocomposites with various types of nanomaterials were fabricated. These works are presented in Chapter 3, 4 and 5. Third chapter deals with fabrication, characterization and property evaluation of hyperbranched epoxy nanocomposites with modified nanoclays. This chapter contains two sub-chapters, where, the first sub-chapter demonstrates a tough and highly flexible nanocomposite of hyperbranched epoxy with first generation of poly(amido-amine) dendrimer modified bentonite nanoclay. In the second sub-chapter, the fabrication as well as significant improvements in tensile strength, elongation at break, toughness and thermal stability along with antimicrobial activity of hyperbranched epoxy nanocomposites with neem oil modified OMMT nanoclay is described.

The spectrum of hyperbranched epoxy nanocomposites was further expanded by incorporation of a bio-based carbon dot, obtained both by *ex-situ* and *in-situ* techniques. The works on these nanocomposites are described in forth chapter. This chapter is divided into three sub-chapters. The first sub-chapter described a water soluble high polar functional group containing carbon dot with fluorescent property, which was synthesized from banana juice by simply heating. This carbon dots based hyperbranched epoxy nanocomposites obtained through solution technique demonstrated not only high performance including outstanding toughness, but the material also enjoyed interesting optical properties and it is reported in the second sub-chapter. Again, the hyperbranched epoxy/carbon dot nanocomposite obtained through *in-situ* technique, exhibited superior performance including mechanical, thermal and optical properties compared to the *ex-situ* fabricated nanocomposite as presented in the last sub-chapter.

Furthermore, hyperbranched epoxy nanocomposites with carbon dot reduced Cu_2O nanohybrids are reported in two sub-chapters of fifth chapter. Carbon dot reduced Cu_2O nanohybrid was fabricated for obtaining high performance hyperbranched epoxy nanocomposites as heterogeneous photocatalyst for the degradation of organophosphate pesticide under solar light as mentioned in its first sub-chapter. The second sub-chapter describes the biocide immobilized OMMT-carbon dot reduced Cu_2O/hyperbranched epoxy nanocomposites, which exhibited high overall performance with excellent antimicrobial activity towards bacteria and a fungus.

Thus, from the present work following conclusions can be briefed.

(i) The unique hyperbranched architecture with unison of aromatic-aliphatic moieties can offer high performance tough epoxy thermosets to overcome the shortcomings of commercial epoxy thermosets.

(ii) The nature and amount of branch generating moiety of the hyperbranched epoxy strongly influence the ultimate performance of the thermosets.

(iii) The toughness and flexibility of the hyperbranched epoxy was highly influenced by the formation of nanocomposites with first generation of aliphatic poly(amido-amine) dendrimer modified bentonite and neem oil modified OMMT nanoclays.

(iv) Neem oil immobilized OMMT nanoclay offered high performance as well as strong antimicrobial activity to the hyperbranched epoxy nanocomposite against bacteria and a fungus.

(v) Incorporation of a very small amount of carbon dots in hyperbranched epoxy resulted a photo-luminescent transparent nanocomposite with outstanding toughness and elasticity.

(vi) Superior mechanical, thermal and optical properties can be obtained by *in-situ* prepared hyperbranched epoxy/carbon dot nanocomposites compared to the *ex-situ* prepared nanocomposite.

(vii) Carbon dot reduced Cu_2O nanohybrid can strongly influence the performance and photocatalytic activity to the hyperbranched epoxy nanocomposites.

(viii) Excellent performance and interesting optical properties along with significant antimicrobial activity can be achieved by incorporation of biocide immobilized OMMT-carbon dot reduced Cu_2O nanohybrid system in hyperbranched epoxy.

Therefore, it can be concluded from this investigation that the studied nanocomposites have strong potential to be used as active functional materials for different advanced applications.

6.2. Future directions

Although, the thesis presented a comprehensive and systematic study on development of tough hyperbranched epoxy nanocomposites. However, still there are many future scopes for further studies. Some of these scopes are highlighted below.

(i) High performance hyperbranched epoxy nanocomposites can be fabricated with graphene and CNT based nanomaterials. The study of special properties like optical, electrical, catalytic, etc. of these nanocomposites is also an interesting research area.

(ii) The biomedical applications of the tough hyperbranched epoxy thermosets and their nanocomposites based on carbon dot and clay can also be further studied. Especially, the carbon dot based nanocomposites can be utilized in the field of tissue engineering as well as bio-imaging.

(iii) The extensive study on antimicrobial, optical and photo-catalytic properties of the nanocomposites can be carried out. Different metal and metal oxide nanoparticles like silver, gold, iron, titanium dioxide, zinc oxide, etc. can also be utilized in this regards to increase the spectrum of their applications.

(iv) Different mechanical models and theoretical studies can be performed to understand the reinforcing mechanism for the hyperbranched epoxy nanocomposites.