Chapter 7

Conclusions and future directions

Highlights

In this chapter, an effort has been made to re-scrutinize and critically analyse the preparation and properties including shape memory behaviors of hyperbranched polyurethane and its nanocomposites, reported in the thesis. The major achievements and the future prospects of the reported work are highlighted.
7.1. Summary and conclusions

The thesis highlights the synthesis, characterization, properties evaluation including shape memory behaviors of *Mesua ferrea* L. seed oil based hyperbranched polyurethanes and their nanocomposites with different types of nanomaterials. The first chapter of this thesis describes a general introduction and brief review on the vegetable oil based shape memory polyurethane nanocomposites emphasizing the importance, general techniques of preparation, characterization, properties and applications. The scopes, objectives and plans of work for the present investigation are also focused here. The entire technical work of the present investigation is divided into ten subchapters in five consecutive chapters.

In the second chapter, the synthesis, characterization and properties evaluation including shape memory behaviors of vegetable oil based hyperbranched polyurethanes are described. The first subchapter of this technical part describes the hyperbranched polyurethanes with three different vegetable oils, whereas the second subchapter deals with the variation of the amount of monoglyceride of *Mesua ferrea* L. seed oil for the same polymer. However the third subchapter presented the hyperbranched polyurethane with varying amount of multifunctional moiety, triethanolamine. All the above hyperbranched polyurethanes were prepared by the prepolymerization technique. The *Mesua ferrea* L. seed oil based hyperbranched polyurethane exhibited good thermal stability and shape memory behaviors among the other vegetable oils based polyurethane.

The third chapter deals with the study on modification, characterization, properties evaluation of monoglyceride (10 wt%) of *Mesua ferrea* L. seed oil based hyperbranched polyurethane. This polyurethane was modified with the commercially available glycidyl ether of bisphenol-A based epoxy resin in the presence of cycloaliphatic amine. The modified systems showed the enhanced performance including shape memory behaviors compared to the pristine system.

The fourth chapter consists of two subchapters. The study on Fe$_3$O$_4$ based hyperbranched polyurethane thermoplastic nanocomposites is described in the first subchapter. The second subchapter deals with the thermosetting nanocomposites of the same. The prepared nanocomposites showed improved mechanical, thermal and microwave induced shape memory
behaviors compared to the pristine systems. The study showed the thermosetting nanocomposites exhibited better performance compared to the thermoplastic one.

The fifth chapter described MWCNT based hyperbranched polyurethane thermoplastic (first subchapter) and thermosetting (second subchapter) nanocomposites. The triethanolamine modified MWCNT plays an important role for enhancing the mechanical, thermal and shape memory behaviors of the pristine polyurethane. Moreover the thermosetting one exhibited enhanced performance as compared to the thermoplastic one.

Similarly the sixth chapter consists of two subchapters, where the first subchapter deals with preparation, characterization and properties evaluation including shape memory behaviors of hyperbranched polyurethane/Fe$_3$O$_4$ decorated MWCNT thermoplastic nanocomposites. The second subchapter demonstrated on the same for the thermosetting nanocomposites. Fe$_3$O$_4$ nanoparticles were successfully decorated on the surface of MWCNT by the wet chemical technique. The nanocomposites showed enhanced mechanical, thermal stability and shape memory behaviors as compared to pristine system for both the cases. The shape recovery time was found to be decreased in the nanocomposites under the microwave irradiation. However thermosetting one exhibited better mechanical, thermal and shape memory behaviors compared to thermoplastic one.

From the present investigation the following conclusions have been drawn.

(i) The high potential non-edible *Mesua ferrea* L. seed oil, industrially important castor oil and dual purpose sunflower oil were successfully utilized for the preparation of shape memory hyperbranched polyurethanes. The monoglyceride of *Mesua ferrea* L. seed oil based shape memory hyperbranched polyurethane exhibited overall good performance as compared to the other. Thus structure and composition of oil can tune the ultimate properties of the polymer.

(ii) The study showed that the amount of monoglyceride of oil as well as the multifunctional moiety has strong influence on the performance including shape memory behaviors of hyperbranched polyurethanes.

(iii) The modified hyperbranched polyurethane with commercially available glycidyl ether of bisphenol-A based epoxy resin exhibited better mechanical, thermal and shape memory behaviors compared to the pristine polyurethane.
(iv) The Fe$_3$O$_4$/hyperbranched polyurethane thermoplastic and thermosetting nanocomposites were successfully prepared. The thermosetting one exhibited better performance as compared to the thermoplastic one. The shape recovery time was found to be decreased in the thermosetting nanocomposite as compared to the thermoplastic one under microwave irradiation.

(v) The mechanical, thermal stability and shape memory behaviors were strongly influenced by triethanolamine modified MWCNT in hyperbranched polyurethane thermoplastic and thermosetting nanocomposites. However, the thermosetting nanocomposites exhibited better performance including faster shape recovery compared to the thermoplastic one.

(vi) The Fe$_3$O$_4$ nanoparticles were utilized to decorate the surface of MWCNT for improving compatibility and to achieve unique properties. The hyperbranched polyurethane/Fe$_3$O$_4$ decorated MWCNT thermoplastic and thermosetting nanocomposites, thus showed better performance including microwave stimulated shape memory behavior compared to their respective pristine systems. The thermosetting nanocomposite exhibited better performance including faster shape recovery compared to the thermoplastic one.

7.2. Future directions

The thesis, even though presented a comprehensive and systematic study on vegetable oil based hyperbranched polyurethanes and their nanocomposites as advanced shape memory materials, still there are a few future scopes for further studies. Some of these are:

(i) Vegetable oil based hyperbranched polyurethane with other nanomaterials such as graphene, carbon dot etc. can be studied as shape memory materials.

(ii) The theoretical study of such nanocomposites can be conducted to understand the reinforcing mechanism as well as shape memory behavior.

(iii) The shape memory behaviors of such nanocomposites can be conducted using other types of contact and noncontact stimuli.

(iv) The biomedical applications of such bio-based hyperbranched polyurethane nanocomposites can be delved into.