CHAPTER 9

SUMMARY AND CONCLUSION

The development and characterization of epoxy based nanocomposites with detailed studies on the Mechanical, Wear, Electrical and Thermal properties have been conducted in detailed in this thesis.

The development, classification and advantages of nanocomposites, the importance of resin systems epoxy, Unsaturated Polyester, Glass and Kevlar fibre and iron (III) oxide nanoparticles, preparation of nanocomposites, fabrication of fibre reinforced nanocomposites have been reviewed in Chapter 1.

The scope of the present work is the development of epoxy based nanocomposites. The epoxy was toughened with Unsaturated Polyester (UP) and reinforced with iron (III) oxide and siliconized iron (III) oxide nanoparticles. The Glass and Kevlar fibre reinforced UP toughened epoxy nanocomposites were prepared, each using eight layers of Glass/Kevlar fiber reinforced UP toughened epoxy filled with silane modified iron (III) oxide nanoparticles.

Development of siliconized iron (III) oxide nanoparticles has been described. Preparation of UP toughened epoxy, nanoparticles (iron (III) oxide, siliconized iron (III) oxide nanoparticles) reinforced UP toughened epoxy and Glass/Kevlar fibre reinforced nanocomposites are explained in Chapter 2. Also the experimental procedure for the studies of physico-chemical, X-ray diffraction analysis, tensile, flexural, impact studies, electrical properties,
thermal, wear, hardness and water absorption properties of nanocomposites are presented in Chapter 2.

The reaction mechanism of epoxy with UP and siliconized iron (III) oxide nanoparticles with UP toughened epoxy are discussed in Chapter 3. The formation of intercrosslinked network structure between epoxy and UP was confirmed by FT-IR spectra. The formation of intermolecular hydrogen bonding between the carbonyl group on the polyester and the epoxide ring were confirmed by FT-IR spectral studies. The interaction between amino group of siliconized iron (III) oxide nanoparticles and epoxy resin was ascertained by FT-IR. The iron (III) oxide nanoparticles, siliconized iron (III) oxide nanoparticles, size and structure were confirmed by XRD and TEM. The size of iron (III) oxide nanoparticles are not affected by surface modification which are confirmed by XRD.

The tensile properties like tensile strength, tensile modulus, elongation at break and Poisson’s ratio of the epoxy, UP toughened epoxy composites, UP toughened epoxy as a function of weight percentage of iron (III) oxide, siliconized iron (III) oxide nanoparticles, Glass and Kevlar fibre reinforced with UP epoxy nanocomposites were studied as per the ASTM standards. The introduction of UP into epoxy resin decreased the tensile strength and tensile modulus, when compared with those of unmodified epoxy resin. This is due to the formation of chain entanglement in the UP epoxy matrix system. However, elongations of the UP toughened epoxy matrix system there is no significant changes as compared to neat epoxy. The incorporation of siliconized iron (III) oxide nanoparticles into UP toughened epoxy hybrid matrix, enhances the value of tensile strength and tensile modulus due to the nanocomposite formation.

The incorporation of siliconized iron (III) oxide nanoparticles into Glass fibre reinforced UP toughened epoxy composites increases the tensile properties, however the tensile strength and modulus decreases with the
addition of above 3 wt % of nanoparticles due to the agglomeration of nanoparticles in the epoxy matrix.

The tensile properties of the Kevlar fibre reinforced, siliconized iron (III) oxide nanoparticles filled UP/epoxy nanocomposites increases with nanoparticle loading. When compared to the base composite, the siliconized iron (III) oxide nanoparticles reinforced composite, shows significant improvement in the tensile properties up to loadings \( \leq 1.5 \) wt%. With higher loadings the tensile strength shows a rapid decrease until at high iron (III) oxide concentration.

The introduction of UP into epoxy decreased the flexural properties. However, the increase in impact strength is due to the formation of entangled network structure developed due to unsaturated active sites of polyester toughened epoxy system. The addition of siliconized iron (III) oxide nanoparticles into UP toughened epoxy hybrid matrix increases the flexural and impact properties. This is attributed to the improved nanoparticles dispersion and enhanced interaction between nanoparticles and polymer matrix.

Thermal degradation of epoxy, UP, UP toughened epoxy and siliconized iron (III) oxide nanoparticles reinforced UP toughened epoxy nanocomposites were studied by TGA. The incorporation of UP into epoxy increased the thermal stability and enhances degradation temperature. The delay in degradation caused by UP moiety is attributed to its cross-linked network structure of UP toughened epoxy system. The resistance to initial thermal degradation was improved after siliconized iron (III) oxide nanoparticles reinforcement, indicating a strong interaction between nanoparticles and UP toughened epoxy system.
The glass transition temperature ($T_g$) of epoxy, UP, UP toughened epoxy and siliconized iron (III) oxide nanoparticles reinforced UP toughened epoxy nanocomposites has been studied by DSC. The addition of UP into epoxy decreases the $T_g$ values. This is due to the chain lengthening and flexibility behavior of unsaturated polyester resin, which in turn decreases the effective crosslink density and accelerates the reaction rate and reduces the curing temperature. However, the addition of Si-$\text{Fe}_2\text{O}_3$ nano particles increased the $T_g$ values due to the crosslink density and mobility of matrix.

The incorporation of UP into epoxy increased the electrical properties like dielectric strength, volume resistivity, surface resistivity, and arc resistance. The improvement in these values of electrical properties of UP toughened epoxy is due to the presence of rigid and alicyclic ring structure. The introduction of siliconized iron (III) oxide nanoparticles into UP toughened epoxy, increases the electrical properties according to their percentage content. This is due to the presence of the siloxane linkages present in the nano reinforcements that may be responsible for the enhanced insulating properties.

The wear properties of siliconized iron (III) oxide nanoparticles reinforced UP toughened epoxy nanocomposites has better improvement as compared to unmodified iron (III) oxide nanoparticles reinforced nanocomposites, which is due to the higher dispersion state of siliconized iron (III) oxide nanoparticles in the composites.

The hardness of UP toughened epoxy systems were decreased due to the flexible ether group formation by the reaction of hydroxyl group of unsaturated polyester resin and the epoxy group of resin. The introduction of siliconized iron (III) oxide nanoparticles into UP toughened epoxy, there is significant improvement in the values of hardness, which is due to the effective network formation.
The introduction of UP into epoxy increases the water absorption values which is due to the presence of more polar groups and possibility for hydrogen bonding. The water uptake properties decreased for siliconized iron (III) oxide nanoparticles by incorporation of UP toughened epoxy. The decrease in percentage water uptake for siliconized iron (III) oxide nanoparticles incorporated system which is due to the inherent hydrophobic nature of the silane.

The result from various studies indicates that the UP toughened epoxy, the siliconized iron (III) oxide nanoparticles reinforced with UP toughened epoxy nanocomposites and Glass and Kevlar fibre reinforced with siliconized iron (III) oxide nanoparticles contain UP toughened epoxy nanocomposites can be used for the fabrication of aerospace, military components, wind turbine blade and automobile components. In addition these can be used for wear resistance applications, electrical insulating applications under high temperature and humidity environment.

9.1 Scope of the Future Research

1. Different metal oxide nanoparticles like (ZnO, TiO\textsubscript{2}) can be siliconized and that can improve the mechanical and thermal properties of epoxy nanocomposites.

2. The siliconized metal nanoparticles can be reinforced with various natural fiber epoxy composites which can improve mechanical properties.

3. In the present work the other tribological properties like wear rate, wear mechanism and effect of friction can be considered for future research.