CHAPTER 9

(i) SUMMARY AND CONCLUSION

RESULTS OF THE PRESENT STUDY

The present study reveals the systematic efforts that are put in developing FA/GPR composites with improved properties. GPR was chosen because of its functional end advantages in composite industry and FA because of its low cost.

Chapter I comprises of brief introduction on various types of fillers and their properties; effect of mineral fillers on both thermoplastics and thermosets; source and properties of FA; commercially available GPR; filled polymers and their characteristics; various methods of toughening of GPR along with literature survey on the work done in GPR followed by the scope of the present investigation.

The materials used, methods of preparation and testing of particulate composites developed in this study and the various modification techniques that are employed in the present investigation along with their notations are given in chapter II.

Chapter III covers the mechanical and thermal properties of FA/GPR and surface treated FA/GPR composites. The data are compared with those of conventional CaCO₃ filled GPR composite. A suitable mechanism is proposed for the chemical reaction taking place at the interface in the presence of CAs. An enhancement in tensile, flexural and impact strength and decrease in tensile elongation were observed when FA
was surface treated with CA. Hardness also increases with CA treated FA/GPR. Morphological properties were also studied by using SEM.

Chapter IV explains the formation of tercomponent interpenetrating polymer network (IPN) from castor oil (the renewable resource) based polyurethane, polyacrylonitrile and polyester. The formation of this IPN was confirmed by Fourier Transform Infrared Spectroscopy (FTIR). The mechanical properties like tensile, flexural, impact and hardness were studied. Thermal stability was studied using thermogravimetric analysis (TGA). Morphological studies using scanning electron microscopy (SEM) were also carried out. The prepolymer formation, IPN formation and GPR curing mechanism are described in network schemes.

In Chapter V, the properties of surface modified FA (elastomeric encapsulation by coagulation of SBR latex and acrylic copolymer latex containing filler)/ polyester composites are presented and compared with those of elastomer encapsulated CaCO₃ filled GPR composites. The mechanical properties like tensile strength, tensile modulus, tensile elongation, flexural strength, flexural modulus, impact strength and hardness of both filled polymers are discussed and compared. Tensile fractured surfaces were studied using SEM.

In Chapter VI, use of sequential emulsion polymerisation to prepare toughening particles comprising of two radially alternative rubbery and glassy layers is described. The conditions which lead to controlled particle size and morphology are discussed. The particles were crosslinked during their formation in order to ensure that they retain their size and morphology during blending with GPR. In this way, toughened GPR composites with multilayered core shell particles of predefined particle size and morphology were produced and the formation of multiple layers is confirmed by transmission electron microscopy (TEM). The mechanical properties like, tensile, flexural, impact and hardness of the toughened GPR are discussed. The tensile fractured surfaces were studied by SEM analysis.
In chapter VII, the properties of all the toughened fly-ash/polyester systems were compared and the optimum formulations with maximum properties are discussed.

Chapter VIII gives the responses to the various environmental stresses on the mechanical properties of all the modified FA filled GPR systems. The composites were left exposed to various adverse environmental conditions such as water, boiling water, salt water, acid, alkali, toluene, weather and freezing-thawing cycles for 30 days. The results indicate that the mechanical properties of FA/GPR composites are improved by all modification procedures and that their resistance to the various environmental stresses is also enhanced substantially.

Through careful analysis of properties, the following conclusions were drawn:

From the processability point of view, 40% filler loading was optimised for all the filled systems.

- The tensile, flexural and impact strengths of the FA/GPR composites were found to be inferior to those of CaCO₃/GPR composites and neat GPR.

- The tensile and flexural modulus were increased and tensile elongation decreased on addition of FA.

- Treatment of FA with silane coupling agents resulted in an increase in the tensile, flexural and impact strengths and hardness of the composites.

- An increase in the tensile and flexural moduli of FA/CA/GPR was observed when FA was surface treated with silane CAs.
The mechanical properties were enhanced when the content of both CAs was increased from 0.5 to 2.0 wt%.

Treatment of fly-ash with 2% CA makes the FA/GPR composites to have properties comparable to those of CaCO₃ filled GPR.

Among the two silane CAs, AMP was found to be better than VES in modifying the properties of FA/GPR composites.

These results reveal that FA can be used as filler in GPR just like the conventional CaCO₃ filler, if it is surface treated with 2% silane CA.

Castor oil - a renewable resource has been used in the novel synthesis of IPNs.

The FTIR spectra of the PU/PAN and PU/PAN/GPR IPNs were used to confirm the formation of IPNs.

Increasing the PU/PAN content in the GPR matrix generally improves the mechanical properties.

The tensile strength of GPR matrix was decreased on incorporating PU/PAN networks in GPR matrix.

The flexural strengths of IPNs were found to be higher than that of pure GPR. The tensile elongation was found to decrease.

The flexural modulus for the IPNs decreased with increasing PU content. But an increased modulus was observed at higher PAN contents.
The impact strength of IPNs were found to be higher than that of the pure GPR resin.

IPNs and the pure GPR were found to have comparable hardness values. The morphologies of the IPNs show better compatibility and improved phase distribution in IPN10.

FA filled IPN shows decreased tensile strength and elongation whereas impact strength, tensile, and flexural modulus increased considerably. But FA filled IPN exhibits almost equal flexural strength compared to GPR.

IPN modified FA/GPR shows substantial improvement in all mechanical properties considerably, compared to untreated FA/GPR composites.

Elastomer encapsulation of filler(s) both CaCO₃ and FA results in improved tensile and flexural strength and modulus, impact strength and hardness of FA/GPR and CaCO₃/GPR significantly. Tensile elongation was found to decrease on increasing elastomer content from 2 to 15% by weight in GPR matrix.

FA/SBR/GPR has higher tensile and flexural strength than FA/AC/GPR composites. But impact strength for both systems are comparatively equal.

Comparing CaCO₃/SBR/GPR and CaCO₃/AC/GPR composites AC encapsulated CaCO₃/GPR shows higher tensile and flexural properties whereas impact strengths are almost equal.
2% SBR encapsulated CaCO₃/GPR has higher tensile elongation than all other elastomer encapsulated filled systems. But 15% SBR encapsulated FA/GPR has higher tensile and flexural properties.

Impact strength and hardness properties of both SBR and AC encapsulated FA and CaCO₃/GPR are comparable.

Tensile strength and modulus increased slightly while incorporating 2, 5 and 10% by weight of multilayered core shell particles in GPR matrix.

Flexural strength was decreased appreciably and the modulus increased enormously on adding the multilayered core shell particles.

Better improvements in the impact strength and hardness was observed for multilayered core shell particle toughened FA/GPR compared to FA/GPR systems.

Hence toughened particles can be added up to 10% by weight to GPR system without much affecting the ease of processing and mechanical properties with better toughness.

AMP based surface treated FATP/GPR was found to be the best system with improved toughness while comparing with all other particle toughened systems.

The thermal stability were found to be almost unaffected on inclusion of toughened particles.
It can be concluded that the various FA/GPR modifications result in better mechanical properties as

- FA/SBR15/GPR shows higher tensile strength than all other FA/GPR modified systems.
- FA.AMPcore10/GPR has best tensile modulus than all other modified systems.
- Unmodified GPR has the best tensile elongation compared to FA/GPR, and modified FA/GPR composite systems.
- IPN modified GPR (IPN D) shows both highest flexural strength and impact tolerance than all other modified FA/GPR composites.
- AMP based surface treated FA/GPR composite shows highest flexural modulus and hardness than GPR and other modified systems.

From the above conclusions, it is evident that each one of the modification method improves only one or two properties of the composite tremendously while the other properties are not that much improved. But a good composite material should be light weight and have better toughness while maintaining all other mechanical properties. Hence, from the toughness point of view, IPN modified GPR composite system is the best one among all the composites systems studied.

Treatment with silane coupling agents improves the adhesion between FA and GPR appreciably. Matrix modifications (IPN formation, elastomeric coating, and particle toughening) give better improvement in all mechanical properties especially impact strength. Thus FA can be used as acceptable filler for unsaturated polyester resin. So FA can be called as
eco-friendly filler and hence they could stand as a convenient alternative to conventional CaCO₃ for composite applications and this is one best way to utilise FA and a way to dispose the waste FA.

(ii) SCOPE FOR FURTHER RESEARCH AND GLOBAL TREND

Polymer composite is a fascinating engineering structural plastic material to work with. Based on the study conducted, an insight into the material science aspect in formulating good composites will bring a lot of scope wherever structural metallic components need replacement.

In extension of this work, studies on matrix substitution with various filler/fibre in composites by formulating and fabricating under ideal conditions, would prove to be meaningful and can solve many of the design and fabrication problems in the steel industry and high temperature composite technology. From the study conducted, the composite developed is an environmentally friendly (ecofriendly) and a technically and commercially viable material. Procedural simplification is the important aspect from the point of view of fabrication. A very detailed microstructural and macro level analysis in understanding the physico-chemical mechanisms which cause the improvement in the various properties, is inevitable.

The matrix material may be replaced by epoxy, vinyl ester, phenolic, cyanate ester etc. and suitable formulations may be tailored for electrical, high and low temperature applications viz. lightening arrestor, high voltage insulators and components for use at cryogenic temperatures. Detailed long term thermal aging with endurance test needs to be conducted for electrical applications which require thermal properties. Girth weld joint filling material for laying offshore pipes, production of machine tool bases, lightweight insulating panels for DYKE insulation at Liquified and natural
gas storage facilities and architectural precast granite and marble like panels for flooring and exterior cladding etc. could be thought of.

Studies may be conducted to develop new polyester composite systems with structural advantages over the conventional polyester systems, by forming new interpenetrating polymer networks (IPNs) and new crosslinks. For instance, in the development of leather adhesives, some new ideas have been developed for heat resistance and better adhesion of the shoe soles by introduction of the synthetic rubber neoprene into polyester, polyester polyol, polyurethane-polyol and epoxy-polyol which gives good prospects for developing the best adhesive with excellent freeze-thaw resistance.

Lead mineral may be grafted and then homogenized with the systems investigated in the present study. The attenuation experiment, based on neutron flux and dose reduction experiment done with broad polymer composites, could be extended to study the applications and shielding materials.

According to literature, polymer composites were first developed in the United States in the mid 1960's, by the Bureau of Reclamation and Brookhaven National Laboratories under the auspices of a large interagency program sponsored by Atomic Energy Commission. They were conceived first as high strength construction with ease of material processing. They have excellent erosion resistance needed in spillways and stilling basins of dams, corrosion resistance needed in desalination plants and the ability to withstand several severe freeze-thaw cycles in bridge decks and pavements, where conventional concrete has suffered deterioration. Many researchers are known to be using it for all types of constructions, including concrete floor with decorative terrazzo effects, architectural facades, curbstones, bridge deck surfacing and containers for corrosive chemical storage.
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