CHAPTER 5
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This part of the thesis describes comprehensive summary of the work incorporated in the thesis.

CHAPTER-1: The classification of natural fibers, their chemical constitution, mechanical properties physical and chemical treatment of natural fibers, scope of natural fibers in various fields, etc. described in this chapter. The classification of polymers and polymer composites are also included in this chapter. The up to date literature survey on syntheses of bisphenols, epoxy and vinyl ester resins, fabrication of fiber reinforced composites their characterization and applications, etc. described in brief.

CHAPTER-2: Syntheses of 1,1'-bis(4-hydroxyphenyl) cyclohexane, liquid epoxy resins, vinyl ester resin, determination of epoxy equivalent weight of liquid epoxy resin, acid value and hydroxyl value, density and viscosity of EBCMASt are well described in this chapter.

CHAPTER-3: Introduction and thermal analyses (DSC and TG) of EBCMA and EBCMASt at the heating rate of 10\(^\circ\)C in nitrogen atmosphere is described in detail. EBCMA and EBCMASt followed two and three steps degradation reactions, and are thermally stable up to 326 \(^\circ\)C and 322 \(^\circ\)C, respectively. The associated kinetic parameters namely energy of activation (\(E_a\)), frequency factor (A), order of the reaction (n) and entropy change (\(\Delta S^*\)) were derived according to Anderson-Freeman method and discussed in light of nature and structure of the resins synthesized. Both the compounds were found to possess good thermal stability and followed multistep degradation with fractional/integral order of degradation kinetics.

CHAPTER-4: This chapter describes literature survey on fiber reinforced composites, their fabrication and evaluation of mechanical and electrical properties; chemical resistance against different environments. Glass, jute and hybridized composites of different biofibers like white coir, banana, brown coir,
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groundnut, beetelnut, palmyrah, cane sugar, pine apple leaf fibre, rice husk, wheat husk, wild almond, bamboo are fabricated by compression molding technique and evaluated their mechanical properties like tensile strength, flexural strength, flexural modulus, impact strength, Barcol hardness and electrical properties such as dielectric strength and volume resistivity according to standard test methods. Water absorption behavior of all composites was studied in different environments like 10% NaCl, 10% NaOH, 10% HCl, water and 10% H$_2$SO$_4$ at room temperature.

The tensile strength, flexural strength, flexural modulus and impact strength of EBCMASt-MMT-5 are decreased, while Barcol hardness is increased to some extent as compared to EBCMASt indicating increase of rigidity of the cross-linked EBCMASt, which is further supported by very low flexural modulus. As compared to Aeropol-7105, MMT filled and unfilled EBCMASt showed considerably better above mentioned properties. For MMT filled and unfilled Aeropol-7105 tensile strength, impact strength, and Barcol harness decreased to some extent, while flexural strength and flexural modulus remained unchanged.

As compared to EBCMASt, flexural strength, impact strength and flexural modulus (~43 times) of EBCMASt-J are increased considerably, while tensile strength and Barcol hardness are decreased to some extent indicating improved stiffness and decrease in rigidity of the jute composite. The tensile strength, flexural strength, flexural modulus (~2 times), impact strength and Barcol hardness EBCMASt-TJ are increased as compared to EBCMASt-J because of improved wetting property of treated jute and increase of crosslinking density. As compared to EBCMASt-TJ, Barcol hardness, tensile strength, flexural strength and flexural modulus of EBCMASt-TJ-MMT-5 are improved to some extent, while impact strength decreased considerably confirming improved interfacial adhesion.

As compared to EBCMASt-G, EBCMASt-G-MMT-5 showed improved tensile strength and flexural strength, while flexural modulus and impact strength are decreased to some extent and Barcol hardness remained unchanged. As compared to filled and unfilled Aeropol-7105, MMT filled and
unfilled treated and untreated jute and glass composites revealed better above mentioned properties. Thus, EBCMASt find its industrial impact as that of commercial Aeropol-7105 resin.

As compared to EBCMASt-G, EBCMASt-G-NF showed considerably decrease in studied physical properties except flexural strength of EBCMASt-G-BM, which revealed better flexural strength indicating improved stiffness of the composite, decrease of the physical properties are mainly due to random orientation of natural fibers and poor interaction with glass fibers. Among natural fibers filled glass composites EBCMASt-G-B showed inferior tensile strength as compared to other natural fibers. Comparatively EBCMASt-G-WC, EBCMASt-G-GN, EBCMASt-G-BN, EBCMASt-G-PA, and EBCMASt-G-BM showed better physical properties indicating good interfacial adhesion among natural fibers, glass fibers and matrix. EBCMASt-G-C composites showed much better studied properties as compared to polyester fabric based hybrid composites.

The jute hybrid composites showed about 1.2 to 1.9 times improved tensile properties except EBCMASt-J-B. EBCMASt-J-PA, and EBCMASt -J-PM showed comparatively same tensile properties. Hybrid composites showed ~1.2 to 1.5 times improved flexural strength except EBCMASt-J-GN and EBCMASt-J-PE. Improved flexural strength indicated improved stiffness of the composites by randomly oriented chopped fibers, but flexural modulus is decreased considerably except J-PA. The improved stiffness is also reflected in the impact strength and Barcol hardness. Hybrid composites showed lower impact strength and Barcol hardness as compared to EBCMASt-J.

The tensile properties of EBCMASt-TJ-NF hybrid composites (Table 4.13) showed improved tensile strength of ~1.2 to 1.5 times as compared to EBCMASt-TJ except EBCMASt-TJ-B, EBCMASt-GN, EBCMASt-PM, EBCMASt-CS, EBCMASt-BN and EBCMASt-PA indicating poor adhesion among matrix and reinforcing fibers. Flexural strength is improved to some extent in case of EBCMASt-TJ-WC, EBCMASt-TJ-BN and EBCMASt-TJ-C, while in other cases it is considerably decreased. Hybridization caused
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decrease in flexural modulus except EBCMASt-PE. Much reduction in flexural modulus of EBCMASt-TJ-GN is observed due to rigid property of the composite. Improved flexural properties suggested improved stiffness of the NF filled composites. All the hybrid composites showed comparatively somewhat poor mechanical properties as compared to EBCMASt- TJ except EBCMASt-TJ-C. The lowering in impact strength indicated flexible nature of hybrid composites.

Filler fibers caused decrease of above mentioned properties as compared to Aeropol-7105. Treated jute composites showed better properties as compared to untreated jute composites. Similar observation is also observed for filled composites. In the case of hybrid composites some of the filler fibers showed improved properties as compared to treated and untreated jute composites, but glass hybrid composites showed inferior properties as compared to their counterpart EBCMASt-G. Looking to the improved physical properties fiber filled treated and untreated hybrid composites showed considerably better physical properties in some cases especially tensile and flexural properties depending upon their nature and cross linking tendency among matrix and reinforcement. Thus jute hybrid composites showed better physical properties as compared to their counter parts indicating their usefulness as low load bearing applications especially for housing applications. The use of agriculture waste may cause cheaper production of the composites and can prevent the depletion of forest and other environmental related problems.

The dielectric strength of EBCMASt- MMT-5 and Aeropol-7105 (Table 4.14) decreased to some extent. EBCMASt possess ~ 1.4 times dielectric strength and ~ 5 times volume resistivity as compared to Aeropol-7105 indicating better dielectric and volume resistivity due to less polar nature of EBCMASt. EBCMASt-TJ possesses ~2 times dielectric strength and volume resistivity as compared to EBCMASt-J. Fiber treatment caused considerable improvement in dielectric strength and volume resistivity. Dielectric strength and volume resistivity (~11 times) of EBCMASt-MMT-5 are improved as compared to EBCMASt-J. In case of glass composites dielectric strength is
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decreased to ~1.3 times and no effect of filler is observed on volume resistivity. Thus, neat EBCMASt possesses better dielectric strength and volume resistivity as compared to Aeropol-7105 signifying its superior industrial applications.

EBCMASt-G-NF hybrid composites (Table 4.15) showed decrease in dielectric strength considerably and volume resistivity is improved to greater extent in some cases. Comparatively EBCMASt-G-B, EBCMASt-G-PM, EBCMASt-G-PA and EBCMASt-G-BM showed better dielectric strength as compared to EBCMASt-G-WC, EBCMASt-G-BC EBCMASt-G-GN, EBCMASt-G-CS, EBCMASt-G-RH, EBCMASt-G-WH, EBCMASt-G-C and EBCMASt-G-PE. Dielectric strength and volume resistivity of EBCMASt-G-C decreased to a greater extent as compared to EBCMASt-G. Similarly EBCMASt-G-PE showed ~2 times reduction in dielectric strength and 96 times improvement in volume resistivity due to polar nature of carbon and polyester fibers. EBCMASt-G-PM, EBCMASt-G-PA and EBCMASt-G-BM showed ~ 208 to 253 times improvement in volume resistivity as compared to EBCMASt-G due to neutralization of partial charges among glass, filler fibers and matrix and hence better interfacial adhesion.

EBCMASt-G-BC, EBCMASt-G-BN, and EBCMASt-G-WH showed ~42 to 167 times improvement in volume resistivity, while EBCMASt-G-CS and EBCMASt-G-WA showed ~13 to 15 times improvement in volume resistivity. EBCMASt-G-WC, EBCMASt-G-GN, and EBCMASt-G-RH showed reduction in volume resistivity of ~ 6 to 48 times due to more polar nature of reinforcing filler fibers as compared to EBCMASt-G. Better dielectric strength and volume resistivity signify their industrial applications as insulating materials. Good dielectric strength (6 to 11.5 kv/mm) and good to excellent volume resistivity (1 x 10^{14} to 2.8 x 10^{15} \, \Omega.cm) of EBCMASt-G-BC, EBCMASt-G-BN, EBCMASt-G-PM, EBCMASt-G-PA, EBCMASt-G-WH and BM signifying their industrial applications as an insulating materials. Use of glass fibers in combination with natural fibers may cause overall production cost and also solve some environmental related problems.
EBCMASt-J hybrid composites (Table 4.16) showed improvement in dielectric strength (6.6 to 9.3 kV/mm) and volume resistivity (3 $\times$ $10^{12}$ to 3 $\times$ $10^{13}$ $\Omega$.cm) as compared to EBCMASt-J. Dielectric strength and volume resistivity of hybrid composites especially EBCMASt-J-WC, EBCMASt-J-GN, EBCMASt-J-BN, EBCMASt-J-PM, EBCMASt-J-PA, EBCMASt-J-RH, EBCMASt-J-WH, EBCMASt-J-WA are improved, while those of EBCMASt-J-B and EBCMASt-J-CS are decreased (2 to 4.4 kV/mm and 4 $\times$ $10^{10}$ to 5 $\times$ $10^{10}$ $\Omega$.cm). EBCMASt-J-BN showed comparable dielectric strength and much improvement in volume resistivity as compared to EBCMASt-J. EBCMASt-J-BC showed good dielectric strength, but slightly lowering in volume resistivity. EBCMASt-J-C showed decrease in dielectric strength (14 times) and volume resistivity (1.3 times) as compared to EBCMASt-J. The improvement in electrical properties may be due to better adhesion and cancellation of partial charges present on matrix and reinforcing fiber surfaces. EBCMASt-TJ hybrid composites (Table 4.17) showed decrease in dielectric strength and improved volume resistivity. EBCMASt-TJ-WC and EBCMASt-TJ-CS showed decrease of volume resistivity as compared to EBCMASt-TJ. Comparatively natural fiber filled treated jute composites showed inferior dielectric strength and volume resistivity as compared to untreated hybrid composites due to more polar nature of treated jute fibers. As compared to EBCMASt-J hybrid composites, EBCMASt-TJ-B, EBCMASt-TJ-BN, EBCMASt-TJ-PM, EBCMASt-TJ-PA, EBCMASt-TJ-RH, EBCMASt-TJ-WH and EBCMASt-TJ-BM showed better dielectric strength and volume resistivity (5.8 $\times$ $10^{11}$ to 2.5 $\times$ $10^{14}$ $\Omega$.cm) except EBCMASt-TJ-BC and EBCMASt-TJ-GN.

The neat filled and unfilled EBCMASt and Aeropol-7105 (Table 4.18) showed 1.1 to 1.3 % water absorption. In case of filled composites water absorbed is negligibly decreased, but equilibrium time decreased by 18 to 33 h. Equilibrium time of EBCMASt is smaller than that of Aeropol-7105. Thus, EBCMASt has comparable water absorption behavior as that of Aeropol-7105. Jute and glass composites absorbed about 2 to 3 % water in various environments. Observed trend is $H_2SO_4$ > HCl > NaOH > $H_2O$ > NaCl. Jute and glass composites showed somewhat higher water absorption as
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compared to unfilled glass and jute composites. Fiber treatment showed ~ 3 to 4 % reductions in water absorption in various environments.

Water absorption varied ~ 2 to 3 % in various environments (Tables 4.19-4.21). The hybrid composites followed similar trend as that of treated and untreated jute and glass composites in various environments and water absorption increased ~2 to 3 % as compared to EBCMASt-G and ~2 to 3 % variation is observed for different fiber filled glass composites in individual environments. Somewhat increase in water absorption in hybrid composites is mainly due to hydrophilic fiber fillers. In case of treated and untreated jute fiber hybrid composites similar observation is observed as that of glass hybrid composites. Treated jute hybrid composites showed ~1 to 2 % more water absorption tendency as compared to EBCMASt-TJ. Somewhat increase of water absorption by the filler in hybrid composites is due to variation in hydrolytic cellulosic and lignin content in different fibers. The jute, glass and hybrid composites possess excellent hydrolytic stability even in harsh acidic and saline environments indicating their usefulness in the field of marine application. The addition of electrolyte affected the water structure and hence water absorption behavior as reflected in the diffusivity (Tables 4.22-4.25) in different environments and no systematic trend is observed due to different nature of electrolyte activity on water structure.
Seminar/Conferences attended / papers presented