SYNOPSIS

Nonwoven fabric technology is the most modern branch of the textile industry and it embodies both old and very new processing techniques and materials. Nonwoven fabric is essentially an assemblage of fibers held together by mechanical or chemical means, resulting in a mechanically stable, self-supporting and flexible, web-like structure. Nonwoven fabrics find numerous end-use applications from luxury automobiles to familiar tea bag. The diversity and growth possibilities of new product lie principally in the area of apparel and durable applications. The nonwoven fabric alone is unsatisfactory for many durable applications (gaskets, automotive trims, etc.,) because of poor mechanical strength and stiffness. Hence, the fabrication of composites by incorporating polymer or copolymer is essential to obtain the satisfactory performance. The end-use of the composites decides the use of certain additives like flame-retardants, conducting fillers, etc., in polymer or copolymer. The ease of fabrication, cost effectiveness and versatility make the nonwoven fabric impregnated polymer composites popular for many industries such as automotive, filtration, medical and home furnishing.

Among the different types of nonwoven fabrics, the low density of the needle punched nonwoven fabric creates an advantage to produce light-weight and tailor-made composites from stiff to soft type. The light weight is an essential feature required for a product to be used in automobile industries to achieve positive impact on fuel economy. The use of highly porous structure of needle punched nonwoven fabric allows better matrix penetration. The furniture industry can make use of these composite to produce light-weight products. The absorption and desorption characteristics (breathability) of nonwoven fabric impregnated polymer composite helps the shoe and packaging industries. The composites can be made electrically conductive or fire resistant by the incorporation of necessary polymer or additives during the fabrication. The biodegradation of the composite is very important from an environmental life cycle perspective and the same can be imparted with the use of natural fillers or fibers in the formulation.

The thesis entitled, “Studies on The Nonwoven Fabric Reinforced Polymer Composites” encompass the results of investigation on the aforementioned research topic. The
thesis has been divided into nine chapters and the contents of each chapter are briefly highlighted. The present research work has the following salient features:

(i) The fabrication of light weight nonwoven fabric composites using simple and straight forward impregnation method.

(ii) Fabrication of biodegradable composites using natural fibre (jute) based nonwoven fabric.

(iii) Characterisation of the molded composites in order to generate the data useful to the automobile and shoe manufacturing industries.

(iv) Sorption and diffusion studies of different penetrants into the composites

(v) Fabrication of composites using the reaction mixture of castor oil and different diisocyanates

(vi) Fabrication of flame retardant (FR) incorporated composites and their study by cone calorimeter.

(vii) Fabrication of conductive composites using polyaniline filled poly vinyl acetate and polyester nonwoven fabric.


Chapter 1 gives a brief introduction to composites and nonwoven fabrics. The method of making, classification and application of nonwoven fabrics has been discussed. It also concentrates on the advantages of the nonwoven fabrics. The scope and objective of the present research work is highlighted at the end of this chapter.

Chapter 2 deals with the materials, methods and experimental procedures adopted in the present research work. This chapter is divided into two major parts namely; Part A - Materials and Equipments and Part B - Theory and Techniques. Part A deals with the materials used in the research work, which includes the chemistry and properties. The specifications of analytical equipments used to characterize the composites are enlisted in this part. The equipments used to fabricate the composites are included in this section. Part B explains the theory and techniques adopted for characterisation and preparation of different latex blend. The analytical instruments used for the characterisation are; Fourier transform infrared (FTIR) spectroscopy, universal testing machine (UTM), differential scanning calorimeter (DSC), thermogravimetric analyzer (TGA) and scanning electron microscope (SEM). The theory and techniques of the above testing equipments with their ASTM
specifications are described briefly in this chapter. The characterisation of the molded composite articles for physico-mechanical properties as per Shoe and Allied Trade Research Association (SATRA) standards has been briefly discussed.

Chapter 3 is divided into two parts; Part A deals with the fabrication of polyester nonwoven fabric impregnated poly (styrene-co-butyl acrylate) composites and their characterisation. Part B describes the effect of carbon black (CB) content on the mechanical and electrical properties of the composites. Part A covers the synthesis of poly (styrene-co-butyl acrylate) latex having different compositions and its characterisation. The characterisation of the latex is performed using FTIR and SEM. The SEM revealed that the domain size increased with increase in the butyl acrylate. A series of composites are fabricated by impregnating the needle punched nonwoven fabric in poly (styrene-co-butyl acrylate) latex having different weight ratio of St/BA from 100/0 to 50/50. The fabricated composites are characterized for density, tensile behavior, stiffness, specific tensile strength, reinforcement factor, burst and stitch tear strength. The composites are molded and characterized as per SATRA standards by measuring the hardness, area shape retention and resilience. Highest percentage area shape retention of 76.6 and 77 is noticed for 80/20 and 70/30 (St/BA) composites respectively. Chemical resistance of the composites has been studied by exposing them into different chemical environments. To know the response of the composites to different relative humidities, composites are subjected to cyclic humidity test.

The thermal stability of the fabricated composites is studied using thermogravimetric analyzer (TGA). TGA data revealed that there is no systematic improvement in thermal stability with varying copolymer composition. All the composites are found to be stable up to 350°C. Thermal parameters such as integral procedural decomposition temperature (IPDT), oxygen index (OI) and transition temperatures are evaluated from TGA curves. The kinetics of thermal degradation of composites revealed that the first step degradation requires low activation energy compared to final step. The scanning electron microscope (SEM) studies revealed that, the incorporation of poly (styrene-co-butyl acrylate) latex into polyester nonwoven fabric enhances the mechanical properties. Ultimately, the optimized compositions of St/BA is noticed for 80/20 and 70/30.

Part B briefly describes the preparation and characterisation of different amount of carbon black (CB) filled poly (styrene-co-butyl acrylate) latex. The composites are fabricated by impregnating the polyester nonwoven fabric in CB filled latex. The effect of different amount of CB on the mechanical and electrical properties has been studied. An abrupt phase...
transition from insulating to semi-conducting behavior was noticed at about 8% CB loading. The volume resistivity of the composites reduced from $1.54 \times 10^{12} \, \Omega \cdot \text{cm}$ to $5.06 \times 10^7 \, \Omega \cdot \text{cm}$ with increase in the CB content from 0 to 10%. A marginal reduction in mechanical properties with increasing the CB content is noticed.

Chapter 4 is divided into two sections. Part A - deals with the effect of different amount of corn starch filled poly (styrene-co-butyl acrylate) latex on the performance of polyester nonwoven fabric impregnated composites. The surface morphology of corn starch filled latex is studied by SEM. The fabricated composites are characterized for physico-mechanical properties and chemical resistance. The tensile strength of the composites retained up to 20% starch incorporation. The values for 0, 10 and 20% starch loading are 8.0, 8.1 and 7.8 MPa respectively. The area shape retention of molded composites have been studied as per SATRA standards. The effect of water immersion on the absorption, swelling and mechanical properties of composites have been studied. The effect of salt water and cyclic humidity on the performance of the composites has been explored. The thermal stability of the composites has been assessed by TGA and surface morphology of tensile fractured specimens by SEM. The soil burial biodegradation test of the composites showed a maximum of 35% mass loss.

Part B describes the moisture sorption behavior of starch filled poly (styrene-co-butyl acrylate) – polyester nonwoven fabric impregnated composites after exposing to different relative humidities. About five sorption models are used for all the composites to assess the range of water activity ($a_w$) and their applicability using sorption isotherm data. This study revealed that the properties of the composites could be retained upto 20 wt% starch loading into copolymer latex. The data obtained from sorption isotherm models reveal that, with increase in the starch content, the moisture sorption of the composites has been increased. This data helps to select and assess the shelf life of the composite material for biodegradable packaging applications.

Chapter 5 is divided into two sections. Part A describes the effect of different amount of acrylonitrile-butadiene (NBR) latex to jute nonwoven fabric on the physico-mechanical properties, heat ageing and chemical resistance. The effect of different relative humidities and salt water on the mechanical properties has been studied. The specific tensile strength of the composites increased drastically from 3.8 to 13.96 N m/g with increase in the NBR to jute pickup ratio from 0.5:1 to 2:1. The cyclic humidity test is performed to know the ability of composites to withstand at 30 and 60% relative humidity alternatively. The TGA
studies of composites showed a two-step degradation mechanism in the temperature range 300-
394°C and 394-510°C. It is found that the incorporation of NBR into jute nonwoven fabric
eenhanced the thermal stability by 36°C. With increase in the NBR pickup ratio, a slight
increase in the thermal stability of the composites was noticed. The thermal degradation
kinetics of composites are studied using TGA data by adopting three different models namely
Broido, Coats-Redfern and Horowitz-Metzger methods. The tensile fractured specimens are
analyzed by SEM to know the fiber-polymer bonding.

Part B briefly describes the molecular transport behavior of water into the
composites. The sorption and diffusion behavior of water is studied at different temperatures
viz., 30, 50 and 70°C. Determining the empirical parameters like n and K from the sorption
curves assesses the mode of transport behavior. The temperature dependence of the transport
coefficients has been used to estimate the activation energy for diffusion (E_D) and permeation
(E_P) processes from simple Arrhenius plots. The incorporation of NBR enhanced the
performance of jute nonwoven fabric composites. The diffusion coefficient of water at 70°C
reduced drastically from 17.14 x 10^5 cm²/sec to 4.92 x 10^5 cm²/sec with increase in the pickup
ratio of NBR to jute nonwoven fabric from 0.5:1 to 2.5:1. A similar behavior was noticed at
30 and 50°C.

Chapter 6 has been divided into three parts. Part A - deals with the fabrication and
characterisation of polyurethane (PU) - polyester nonwoven fabric composites. Composites are
fabricated by impregnating the needle punched polyester nonwoven fabric in a reaction
mixture of isocyanate and a polyol. The effect of different isocyanates such as toluene-2, 4-
diisocyanate (TDI) and hexamethylene diisocyanate (HMDI) on the physico-mechanical
properties of both reinforced and unreinforced PUs has been studied. The TDI and HMDI
based PUs showed a specific tensile strength of 1.2 and 1.1 N m/g and their corresponding
composites showed 9.1 and 11.1 N m/g. The assessment of the composites for chemical
resistance revealed that the composites are more resistant to acids than alkali. Heat ageing,
cyclic water soaking, water absorption and cyclic humidity test of the composites are
performed. Compared to neat PUs, the TDI and HMDI based PU composites exhibited an
improved thermal stability by 22 and 54°C. The TGA thermograms showed two-step
degradation for neat PUs, whereas their composites showed three step degradation. The SEM
studies revealed that there is a good interaction between PU matrix and polyester nonwoven
fabric.
Part B describes the molecular transport behavior of n-alkane penetrants into TDI and HMDI based PUs and their composites. The penetration velocity (v), sorption (S), diffusion (D) and permeation (P) coefficients have been calculated for PU-alkane system. The n and K values have been determined to know the transport mechanism of alkanes. The thermodynamic parameters such as enthalpy (ΔH) and entropy (ΔS) have been determined using vant Hoff’s relation. The activation energy for the process of diffusion (E_D) and permeation (E_P) has been calculated from Arrhenius plots of ln D versus 1/T and ln P versus 1/T. The S and D values increased with increase in the molecular volume of the alkane penetrants and temperature. Higher S and D values are noticed in reinforced composites compared to unreinforced PUs. An inverse relationship is found between the pore size and the activation energy.

Part C deals with the water transport behavior at different temperatures into both unreinforced and reinforced PU composites. The obtained activation energy is high for neat PUs compared to their composites.

Chapter 7 is divided into two parts. Part A describes the fabrication and characterisation of melamine-formaldehyde (MF) incorporated PVAc-polyester nonwoven fabric composites. The effects of different amount of MF cross linker from 0 to 20- % by weight into PVAc on the physico-mechanical properties, heat ageing and chemical resistance have been studied. The tensile modulus of the composites lies in the range 33- 87 MPa. The effect of salt water on the mechanical properties of the composites has been studied. The vertical flammability test of the composites showed reduced char length with increasing the MF content. The water absorption studies and cyclic water-soaking test are performed to know the behavior of the composites with water. The thermal stability and thermal degradation kinetics are studied from TGA scans. The activation energies are determined to know the energy required for the process of thermal decomposition. The relationship between the percentage weight loss and the activation energy is established. The morphology of tensile fractured composites studied by SEM. The optimized composition of MF/PVAc is 10/100 dry, weight by weight.

Part B describes the sorption and diffusion of water into the MF/PVAc-polyester nonwoven fabric composites. The S, D and P values are drastically reduced with increasing the MF content in PVAc. The E_D and E_P values increased from 11 to 82 kJ/mole and 14 to 77 kJ/mole respectively with increasing the MF content.
Chapter 8 briefly describes the fabrication of composites by impregnating the needle punched nonwoven fabric in synergistic flame retardant (FR) system filled PVAc/MF (90/10) latex composites. The effects of different amount of FR on mechanical properties and combustion behavior of the composites have been studied by cone calorimeter. The parameters such as percentage mass loss, total heat released (THR), heat release rate (HRR), peak heat release rate (PHRR), smoke release rate (SMR), total smoke released (TSR), total oxygen consumed (TOC) and effective heat of combustion (EHC) have been determined. The PHRR of the composites reduced from 620 to 255 kW/m² with increasing the FR from 0 to 40% by weight. A linear relation ship is found between the total oxygen consumed and peak heat release rate. This study showed that, with increase in the FR content, the mechanical properties have been reduced, whereas the flame resistance nature of the composites have been increased.

Chapter 9 deals with the fabrication of composites by impregnating polyester nonwoven fabric in poly vinyl acetate/polyaniline (PVAc/Pani) latex blends. This chapter also reveals the synthesis and its characterisation by UV-visible spectroscopy and elemental analyser. The effect of different amounts of polyaniline in PVAc on the mechanical and electrical properties of the composites has been studied. It is observed that the mechanical properties such as tensile strength, surface hardness and burst strength increased marginally with increase in the Pani content and their values lie in the range 7.5-7.8 MPa, 75-76 ShoreA and 2.8-3.0 MPa. A conductive percolation threshold is noticed at about 4 % by weight of polyaniline incorporation. The conductivity of the composites increased from 2.2 x 10⁻¹⁵ to 6.4 x10⁻⁶ S/cm with increase in the Pani content.

Conclusions and references are cited at the end of each chapter

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### List of Publications in International Journals


16. M.N. Satheesh Kumar and Siddaramaiah, Mechanical and Electrical properties of Polyester Nonwoven Fabric Impregnated Polyvinyl acetate/Polyaniline (PVAc/Pani) Composites, Polymer Composites, (Communicated).

Papers Presented at Conferences


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