Polymer Nanocomposites: An Advanced Material for Functional Fibers

M. Joshi

Department of Textile Technology
Indian Institute of Technology, IIT Delhi 110016, India
Email: mangala@textile.iitd.ernet.in
Tel. No. 91 11 26596623, Fax No. 91 11 26581103

ABSTRACT

Polymer nanocomposites have recently gained a great deal of attention because of the much superior properties in terms of increased strength and modulus, improved heat resistance, decreased gas permeability and flame retardance at very low loadings of < 5-wt % of nanofillers**,** as compared to conventional composites. Nanocomposite fibres that contain nanoscale embedded rigid particles as reinforcements show improved high temperature mechanical property, thermal stability, useful optical, electrical, barrier or other functionality such as improved dyeability, flame retardance, antimicrobial property etc. This paper discusses the recent developments in this area and also presents some highlights of the research and development activity undertaken at Textile Department, IIT Delhi, in this area.

Key words: polymer nanocomposites, functional fibers, nanoclay, POSS

1 INTRODUCTION

Textile Industry is likely to be hugely impacted by Nanotechnology, as research involving nanotechnology based finishes and coatings to improve performances or to create new functionality on textile materials has gained a big impetus / momentum across the globe. The current R&D trends show a clear shift to nanomaterials as a new tool to improve properties and gain multifunctionalities for textile materials. Organized nanostructures as exhibited by either fibers, nanocoatings, nanofinishing, nanofibers and nanocomposites seem to have the potential to revolutionize the textile industry with new functionality such as self cleaning surfaces, conducting textiles, antimicrobial properties, controlled hydrophilicity or hydrophobicity, protection against fire, UV radiation, etc. All this can be achieved without affecting the bulk properties of fibers and fabrics. The market for textiles based on nanotechnology is expected to reach US$115 billion by 2012 [1].

Polymer nanocomposites are the advanced new class of materials with an ultrafine dispersion of nanofillers or nanoparticles in a polymeric matrix, where at least one dimension of nanofillers is smaller than about 10nm. The volume and influence of the interfacial interactions increases exponentially with decreasing filler /reinforcement size and thus forms an additional separate phase known as interphase, which is distinct from the dispersed and continuous phases and hence influences the composite properties to a much greater extent even at low nanofiller loading (< 5%). Therefore, their properties are much superior to conventional composites. The interest in polymer nanocomposites further arises from the fact that, they are light weight as compared to conventional composites because of the low filler loadings, are usually transparent as scattering is minimized because of the nanoscale dimension involved and are still processable in many different ways including production of fibers with nanoscale fillers embedded in the polymer matrix. With these improved set of properties, they show promising applications in developing advanced textile materials such as Nanocomposite fibers, nanofibers and other nanomaterial incorporated coated textiles for applications in medical, defense, aerospace and other technical textile applications such as filtration, protective clothing besides a range of smart and intelligent textiles.

Polymers nanocomposites thus offer tremendous potential when produced in fiber form and offer properties that leapfrog those of currently known commodity synthetic fibres. Nanocomposite fibres that contain nanoscale embedded rigid particles as reinforcements show improved high temperature mechanical property, thermal stability, useful optical, electrical, barrier or other functionality such as improved dyeability, flame retardance, antimicrobial property, etc. These novel biphasic nanocomposites fibres in which dispersed phase is of nanoscale dimension, will make a major impact in tire reinforcement, electro-optical devices and other applications such as medical textiles, protective clothing etc. The work on spinning of nanocomposites started about seven years ago and several research groups across the world are exploring the synthesis, fiber processing, structure- property characterization and correlation and molecular modeling of these unique new composites fibers. Polymeric nanocomposite fibres have been mostly spun through three basic methods of fiber spinning - Melt spinning, Solution spinning and Electrospinning. Although, most of the research reports on polymeric nanocomposites is where it has been studied in form of films or moulded specimens and very few reports on their spinning into fiber form [1, 2-4].

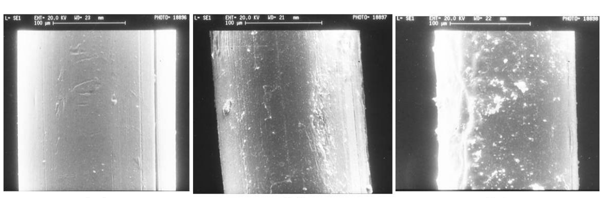
2 RESEARCH AT IIT DELHI

2.1 Nanocomposite Fibers

At Textile Department at IIT Delhi, India we have investigated nanocomposite fibers based on all the three major types of nanofillers viz layered silicate nanoclays (MMT), carbon nanotubes (CNT), nanofibers/ nanographite as well as hybrid nanostructured materials such as POSS.

2.1.1Polypropylene/NanoclayNanocom-posite Fibers

Compatibilized polypropylene/nanoclay composite filaments were produced by melt intercalation route using twin screw compounder coupled to a fiber take up device and drawing machine and characterized to study the effect of the compatibilizer and the role of nanoclay in improving the properties. The compatibilizer used was maleic anhydride grafted Polypropylene (PP-g-MA).



(a) (b) (c)

Figure1: Scanning Electron Micrographs of polypropylene/nanoclay composite filaments (a) Neat PP (b) 0.5% clay loading (c) 1 % clay loading (surface view)

Clay loadings of up to 1 wt % with up to 3 wt % of the compatibilizer were studied. The dyeability properties of these filaments showed that nanocomposite filaments took up disperse dyes unlike the neat PP filaments which have to be dope dyed. There was a significant improvement in tensile, thermal, dynamic mechanical and creep resistance properties of PP/nanoclay composite filaments over neat PP filaments at very low loadings of the organomodified clay [5, 6].

2.1.2 HDPE/ POSS Nanocomposite Fibers

Another development was making high performance fibers based on polymeric nanocomposites based on a novel class of hybrid nanostructured filler, Polyhedral Oligomeric Silsesquioxane (POSS). The system chosen for the study is the simple ‘octamethyl POSS’, a molecular silica as the nanofiller and HDPE as the polymeric matrix. At comparatively very low loadings (0.25-0.5 wt %), molecularly dispersed POSS actually gives a lubricating effect and facilitates the drawing of filaments, which results in higher tensile strength and modulus. With increase in POSS concentration beyond 1 wt %, POSS existing as nanocrystals/aggregates starts hindering the orientation of HDPE chains leading to a gradual fall in tensile strength and modulus. Incorporation of POSS also modifies the thermal degradation behaviour of HDPE and broadens the temperature range of thermal degradation. The HDPE-POSS nanocomposite filaments also exhibit better UV resistance than neat HDPE filaments, which may be attributed to the scattering/reflective action of POSS [7, 8].

2.1.3 Polyurethane/Nanoclay Nano-composite Fibers

An attempt to explore the feasibility of producing filaments from polyurethane (PU) /clay nanocomposites and compare their structure and properties vis-a-vis neat PU filaments has been carried out as a part of doctoral thesis by our research group. This work reports the production of filaments from neat polyurethane and polyurethane/clay nanocomposite by dry-jet-wet spinning; a technique being used for the first time for this system [9, 10]. An organomodified nanoclay was used as a filler and thermoplastic polyurethane as the matrix. Dispersed nanoclay in PU matrix has induced both external morphological changes as well as internal micromorphology. Nanoclay dispersion reduces the stretchability by enhancing the void content of the nanocomposite filaments. Modulus and tenacity are enhanced significantly in the presence of nanoclay at low concentrations; nevertheless elongation and elastic recovery are marginally affected. Thermal studies suggest that a significant improvement in thermal stability of PU/clay nanocomposites filaments is due to hybridization with inorganic nanoclay. High thermal shrinkage at low clay concentration indicated high orientation due to good dispersion and exfoliation of clay in filaments. Boiling water shrinkage and water swelling also indicated high orientation and reduced swelling due to incorporation of clay. Fire retardant properties studied by cone calorimetry shows excellent fire retardant properties at low clay content (0.25 wt %). Dyeability properties of nanocomposite fibres also get significantly enhanced in the presence of nanoclay. Weatherability resistance of PU/clay filaments are significant only at higher clay concentration (> 1 wt %).

2.2 Future Trends

Nanotechnology has thus emerged as the 'key' technology, which has revitalized the material science and has the potential for development and evolution of a new range of improved materials including polymers and textiles. However there are many challenges in the development of these products, which need to be intensively researched so that the wide range of applications envisaged can become a commercial reality. An excellent dispersion and stabilization of the nanoparticles in the polymer matrix is crucial to achieving the desired nano effects. The tendency to agglomerate due to extremely high surface area is the major problem facing the effective incorporation of nanoadditives in coatings/finishing as well as in nanocomposite preparation. Surface engineering of nanoparticles and combining them with functional surface-active polymers can bring the nanoparticles onto fibers/textiles without loosing their superb, nanoscopic properties.

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