

FY 2008 Project Proposal

Project No.

ADAN-08

Nanoparticle Reinforced Hybrid Fibers and Films

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Objective:

The objective of the proposed research is to combine traditional polymeric materials with nanoparticles (carbon nanotubes and nanoclays) to engineer new hybrid micro/nano fiber and film properties for nontraditional industries such as fuel cells, electronics, using injection molding, extrusion and electrospinning processes.

The majority of currently available polymeric fibers and films are dielectric materials with limited applications in electronics, optics and other industries such as safety and protection. This proposal addresses the limitation of the properties of current polymers to be used in these areas.

Relevance:

The reinforcement of micro/nano fibers and films using nanofillers, represents a new approach for enhancing the performance of these materials. Incorporation of nano reinforcements into fibers and films is expected to yield performance enhancements (such as elastic modulus) at small nanoparticle loadings (~1-5 wt%). Thus, new combinations of properties derived from the nanoscale structure of polymeric nanocomposites provide opportunities to circumvent traditional performance trade-offs associated with conventional fibers, films and membranes, epitomizing the promise of nano-engineered materials.

The incorporation of carbon nanotubes and nanoclays into nano/micro scale fibers and films has the potential to launch numerous new applications for smart and high performance textiles. Potential applications include smart textiles for medical and military applications, tissue scaffolds, electronic devices and textiles with better mechanical properties and flame retardancy than can be achieved with current materials. Electrospinning of the composite fibers is of particular interest because of the small fiber diameters that can be achieved to form fibers, films and membranes. In addition, elongation along streamlines facilitates alignment of both the matrix and the nanomaterial, particularly carbon nanotubes.

The proposed research will expand the knowledge base of the textile industry making it possible to introduce new types of hybrid fibrous materials and films to be used in fast growing non-textile industries such as electronics and mobile communications. These markets require further miniaturization for inductive components installed in various devices. The proposed work will lay the ground work for fibers, films and membranes to penetrate into these new areas.

State of the Art:

Considering the development of major textile fibers over the years, it is obvious that there has been a stagnation in recent years in new fiber commercialization. Embedding nanoparticles in polymeric matrix is an inexpensive but effective way to modify the properties of neat polymers. Multicomponent structures in the range of 1-100 nanometer (nm) would have unusual electrical, chemical, mechanical, optical and magnetic properties. These properties include single-electron hopping, tunneling, percolation at low loadings, optical absorption, superparamagnetism, and magnatoresistance. Fibers and films embedded with optically functional nanoparticles can act as thin color filters. Some studies were reported in the literature regarding nanocomposites involving polymers and organic/inorganic particles such as nanoclays. However, these studies have not been geared towards obtaining textile fibers with improved properties [1-4]. Tsai and Cheng reported that inclusion of clay in nylon 6 improves not only the mechanical and thermal properties, but also functional properties such as gas and moisture barrier, and UV resistance [5].

There has been significant interest and progress in electrospinning polymer nanocomposite fibers in the last three years. The existing research demonstrates the promise of electrospun nanocomposite fibers based on a range of polymer matrices including PVA, PEO, PLA, PU, PC, PMMA, and PA [6-12]. However, as for many other polymer nanocomposite systems three key challenges remain 1) dispersion of the nanomaterial in the matrix, 2) optimization of the processing conditions, and 3) achieving close interaction between the nanomaterial and the matrix in the final fiber. This proposal will address these challenges through 1) quantitative measurement of dispersion quality and the impact of nanomaterial functionalization and mixing technique on the dispersion 2) optimization of the processing conditions based on the viscoelastic properties of the dispersion and 3)

measurement of load transfer and thermal stability enhancement in the final fiber using mechanical testing, electron microscopy, differential scanning calorimetry, thermal gravimetric analysis and flame resistance.

With the earlier NTC project (M02-MD08), we developed scientific know-how as well as built equipment to produce electrospun fibers [13-16]. We studied the effect of Laponite® nanoclay in electrospun PVA fibers in terms of weight loss at 300 and 800° C. The results showed that including 1-3% nanoclay in the fiber decreased the weight loss at high temperatures as shown in Figure 1. The temperature difference of the modified and unmodified fibers for 5% weight loss was significant. We will build on this expertise for the newly proposed work.

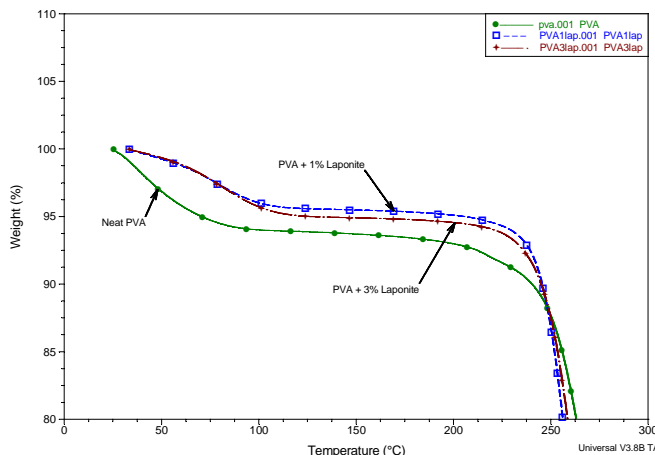


Figure 1. Weight loss comparison by thermogravimetric analysis (TGA) up to 300 °C among three samples: Pure 12 wt % PVA, 12 wt % PVA+ 1 wt % Laponite®, and 12 wt % PVA + 3 wt % Laponite® [Adanur and Ascioğlu].

Approach:

The simplest way to include nanoparticles in fibers is to add the nano reinforcement to the polymer precursor, a melt or a solution. The mixing is critical and should disperse the particles uniformly. Agglomeration and uneven distribution of particles are known to adversely affect the final properties of the material.

Good dispersion and bonding between the nano particles and polymer is critical. The particles may be functionalized to improve the adhesion between the particles and the matrix as well as their dispersion. Melt flow index (MFI) and rheological properties of the polymer-nano systems will be characterized to determine the processability.

The nanocomposite material will be spun into fibers using an extruder and electrospinning apparatus. The deposition rates will be monitored and the fibers' physical and structural properties will be studied. The compatibility between the selected polymers and nano particles will be determined. The effect of loading, particle size and density will be investigated. Constant strain rate tensile tests will be performed on the resulting hybrid fibers. The change of modulus with the amount of nanoparticles will be determined. The heavier nano particles may improve the molecular orientation because of the acceleration in the field. The rigidity of the fibers will also be determined as a function of nanoparticle content. The relationships between temperature/heat flux versus nanoparticle content will be determined. In electrospinning, particles are field responsive to orient them along the direction of stretching. This internal orientation of the particle can be determined by transmission electron microscope (TEM).

Electrical, rheological, mechanical and thermo-physical characterization will be conducted for the newly developed fibers and films. Differential Scanning Calorimetry (DSC) analysis will be done to study the crystallization behavior. We expect that surface treated particles may act as nucleating agents increasing the crystallinity. Scanning electron microscopy (SEM) will be performed to identify the microstructural origin of strength and toughness of the newly produced fibers and films.

Initial work will focus on the evaluation of dispersion quality by quantitative rheological and qualitative morphological (optical, scanning electron, transmission electron, and atomic force microscopy) techniques. The study of structure and morphologies of nanocomposite materials in micro and nanoscale fibers using nanotubes and nanoclays in conjunction with different types of polymeric matrices will be done.

A fundamental understanding of the manufacturing process to produce nanoclay and carbon nanotube reinforced hybrid fibers and films will be established. The polymer materials will be selected to act as matrix (e.g. PVA, PET, epoxy, unsaturated polyester) and nanoparticles will be embedded in fiber matrix to impart various

properties. Particle surface modification and characterization using XeCl (308 nm) pulsed excimer laser technique will be performed.

Based on the results of the proposed work, full scale proposals will be submitted to NSF and other funding agencies.

Outreach to Industry:

Microfibers have been around for quite some time. However, design, development and manufacturing of nano textile fibers is still in its infancy. There are many start up companies that deal with nanocomposites. From the contacts with these companies in various recent conferences, they showed an interest in the development and characterization of nano fibers. Several companies are interested in the proposed work. The topic of the project was discussed with the following people who showed strong interest:

- Dr. John Lever, Business Development Director, Milliken & Co., Spartanburg, SC, Ph: 864 494-8013, e-mail: John.Lever@milliken.com
- Dr. John N. Randall, Chief Technical Officer, Zyvex Corporation, Richardson, TX. Ph: 469 877-6579, e-mail: jrandall@zyvex.com
- Mr. David Offord, Chief Scientific Officer, Nano-Tex, LLC., Emeryville, CA, Ph: 510 594-8983, e-mail: offord.david@nano-tex.com
- Mr. Todd Hobbs, Sales and Marketing Coordinator, Polystrand, Inc., Montrose, CO, Ph: 970 240-2213, e-mail: todd@polystrand.com, www.polystrand.com

New Resources Required:

We have the electrospinning system in place at Auburn University, Department of Polymer and Fiber Engineering to successfully produce nanofibers. The newly acquired injection molding and extrusion machines will be used to produce fibers and films of various thickness. All of the synthesis, testing, analysis and characterization equipment is in place. Three graduate students are needed to work on this project.

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