Nanotechnology in the Textile Industry

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Introduction

Nobel Prize winning physicist, Richard Feynman, is recognized as one of the first to realize the numerous opportunities associated with the manipulation and control of particles on a small level. In 1959, Feynman gave a pivotal presentation entitled "There is *Plenty* of Room at the Bottom." In the presentation, Feynman introduced the "bottom up" approach which is now synonymous with nanotechnology—building structures atom-by-atom. He implored his colleagues to break out of their conventional thought process, enticing them with challenges—"Why cannot we write the entire 24 volumes of the Encyclopedia Britannica on the head of a pin?" Feynman's unique approach was a sober divergence from the traditional "top down" practice.

Nanotechnology is defined as the precise manipulation of individual atoms and molecules to create layered structures. Nanosize particles can exhibit unexpected properties— different from those of the bulk material. The basic premise is that properties can dramatically change when a substance's size is reduced to the nanometer range. For example, ceramics which are normally brittle can be deformable when their size is reduced. In bulk form, gold is inert, however, once broken down into small clusters of atoms it becomes highly reactive. Incorporating nanomaterials into a textile can affect a host of properties, including shrinkage, strength, electrical conductivity and flammability.

A broad definition of a nanomaterial is a material in which at least one of its dimensions is less than 100nm. Various nano-entities have been reviewed in literature. The most common are nanofibers, nanocomposite fibers and nanocoated fibers.

Nanofibers

Nanofibers can be defined as fibers with a diameter of less than 1mm or 1000nm. The majority of nanofibers are produced by the electrospinning process—a process that has been used to spin fibers since the early 1930's. In this process a charged polymer melt is extruded through a small nozzle. The charged solution is drawn toward a grounded collecting plate. As the jet of charged melt travels, the solvent evaporates, leaving a non-woven nanofiber mat on a substratum. The process can be altered to produce fibers with different diameters. Nanofibers are characterized as having a high surface area to volume ratio and a small pore size in fabric form.

There are numerous applications in which nanofibers could be suited. The high surface area to volume ratio and small pore size allows viruses and spore-forming bacterium such as Anthrax to be trapped. Filtration devices and wound dressings are just some of the applications in which nanofibers could be utilized.

In the electrospinning process, nanofibers with diameters as small as 4nm can be produced. Researchers are investigating the possibility of using nanofibers with diameters in the 4nm range as a replacement for a diseased or damaged artery, capable of emulating some of the natural biological processes of the arterial wall.

Other potential applications for nanofibers include drug delivery devices and sensors.

Nanocomposite Fibers

A composite is a material that combines one or more separate components. Composites are designed to exhibit the best properties of each component. One of the most challenging aspects of current research is to obtain an even and thorough dispersion of the nanomaterial within the composite.

Nanocomposite fibers are produced by dispersing nanosize fillers into a fiber matrix. Nanofillers can be distributed in a polymer matrix through either a mechanical or chemical process. Common fillers include nanoparticles, graphite nanofibers (GNF) or carbon nanotubes (CNT) into a fiber matrix. Depending on the kind of nanomaterial used and the amount and distribution of the nanomaterial—the mechanical, electrical, optical or biological properties of the textile can be altered.

Nanoparticles
Nanoparticles include clay, metal oxides and carbon black. Although some of these materials have been utilized in the textile industry for decades, reducing them to the nanosize is recent and has resulted in fibers with better performance properties than in the past.

Clay nanoparticles are resistant to heat, chemicals and electricity, and have the ability to block UV light. Incorporating clay nanoparticles into a textile can result in a fabric with improved tensile strength, tensile modulus, flexural strength and flexural modulus. Nanocomposite fibers which utilize clay nanoparticles can be engineered to be flame, UV light resistant and anti-corrosive.

Producing flame resistant fabric has been an ongoing challenge in the textile industry. If untreated, synthetic fibers melt and drip when exposed to high heat. Although there have been a number of flame retardant finishes available since the 1970's, the emission of toxic gasses when set ablaze make them somewhat hazardous. Clay nanoparticles have been incorporated into nylon to impart flame retardant characteristics to the textile without the emission of toxic gas.

Clay nanoparticles have been used to improve the dyeabilty of polypropylene. Polypropylene is notoriously difficult to dye. The lack of dye attracting sites within the fiber makes it difficult to dye using traditional dyeing procedures and dyes; however, the addition of clay nanoparticles has made polypropylene dyeable. Before extrusion, clay nanoparticles treated with ammonium salt are mixed with polypropylene. The resulting composite fiber has dye attracting sites with dye holding space, allowing the fiber to be dyed.

Other nanoparticles include metal oxides such as TiO2, Al2O3, ZnO, and MgO. Once in the nanosize range, metal oxides are inherently photocatalytic, electrically conductive, UV absorptive, and photo-oxidizing against chemical and biological species. Swimwear fabric has been developed by incorporating ZnO into nylon to produce composite fibers that shield UV light and have anti-static properties. Composite fibers incorporating nanoparticles of both TiO2 and MgO have produced fabrics that are self-sterilizing.

Carbon Black Nanoparticles and Graphite Nanofibers (GNF)
Carbon black nanoparticles and GNFs are some of the most commonly used nanofillers in the textile industry. Carbon black nanoparticles improve the resulting composite fiber's abrasion resistance and toughness. Composite fibers which incorporate GNFs have improved tensile strength. Polyester, nylon and polyethylene have been used as the matrices for both of these nanofillers.

Carbon Nanotubes (CNT)
CNTs consist of tiny shells of graphite rolled into cylinders. There are both single-walled carbon nanotubes (SWNT) and multi-walled carbon nanotubes (MWNT).

CNTs are some of the most remarkable nanostructures—having 100 times the strength of steel and one sixth the weight. CNTs have a thermal conductivity better than the purest diamond and electrical conductivity similar to copper; however, with the ability to carry much higher currents than copper. Carbon nanotubes are suited to applications in which high strength, low weight and high electrical conductivity are needed. Possible applications include screen displays, sensors, aircraft structures, explosion-proof blankets and electromagnetic shielding.

Because of the excellent electrical conductivity, nanotubes could also be used in the burgeoning field of electronic textiles. Having the feel and drape of traditional textiles, nanotubes could be used in the construction of clothing which incorporates electronic devices or wearable computers. Unlike the current products that incorporate electronic devices into apparel, apparel which utilizes nanotubes could withstand multiple home launderings.

Specially engineered CNTs have been incorporated into polyvinylalcohol to produce a composite fiber with diameters in the micrometer range. The composite fiber is two times the stiffness and strength and twenty times the toughness of steel wire.

Nanocoated Fibers
Nanocoated fibers are produced by depositing layers of a coating onto the surface of a fiber. The thickness of each

layer is in the nanometer range. A number of methods have been used to apply a nanocoating to the fiber surface. Each method has its own set of advantages and disadvantages.

Commercially Available Products

Nano-Tex

Nano-Tex, founded in 1998, has been one of the leaders in nano-treatments designed specifically for textiles. The first commercially available products debuted in December of 2000. Today, more than eighty textile mills around the world are utilizing Nanotex's patented nanotreatments.

Nano-Tex treatments are applied to a fabric in a "bath." As the fabric goes through the bath, nanoparticles come in contact with the fibers of the fabric. When the fabric is cured or heated – the nanoparticles spread out evenly and bond to the fibers. Treatments are permanent and do not jeopardize the aesthetic characteristics or mechanical properties of the fabric. Treatments can be applied to a number of fibers including cotton, polyester, silk and wool. A variety of enhancing characteristics can be imparted to the fabric through the application of special treatments. Nanotreated fabrics can be spill resistant, stain proof, wrinkle resistant and static proof.

Resists Spills

Resists Spills was one of the first nanotreatments offered by Nano-Tex. It can be applied to cotton, polyester, wool, silk or rayon. Stain release was designed to mimic the natural characteristics of a plant's leaves. The surface of most leaves is hydrophobic. In a rain shower, water droplets roll off the leaf's surface—carrying away contaminants. A leaf's surface is also rough, decreasing the surface's ability to soak up water. Like a leaf's surface, treatments have been developed to make the fabric ultra-hydrophobic. Self-cleaning fibers might eventually replace conventional fluorochemical based finishes currently used to provide water repellency.

After applying the Resists Spills treatment, the fabric becomes both liquid repellent and stain resistant. Without ever penetrating the fabric, liquids such as coffee, wine, water and salad oil bead up and roll off the fabric.

Coolest Comfort

Coolest Comfort was released in December 2000. It was initially designed for synthetics. A Coolest Comfort treatment imparts superior wicking properties to a previously hydrophobic synthetic. The treated fabric pulls away perspiration from the body allowing the wearer to stay dry and comfortable.

Coolest Comfort is now being applied to resin treated cotton. Resins are applied to cotton fabric to make them wrinkle free. Unfortunately, the resin treatment blocks cotton's natural ability to absorb moisture. Coolest Comfort has been specially formulated to restore the natural wicking properties of resin treated cotton.

Resists Static

Resists Static is the first permanent anti-static treatment for synthetic fibers. Not only does it repel static, but the treatment also repels statically attractive substances such as dog hair, lint and dust. Resists Static can be applied to a variety of fabric constructions including rough textured fleece and slick suit linings.

Repels and Releases Stains

Repels and Releases Stains is applied to cotton and polyester/cotton blends. As the name implies, Repels and Releases Stains has a built-in dual treatment. Once liquid comes in contact with the fabric, it beads up and rolls off. If liquids get around this barrier and into the fabric, the patented release technology frees it from the fibers during a typical home laundering cycle.

Products which utilize Nano-Tex treatments meet environmental, health and safety standards mandated by the U.S. Environmental Protection Agency, the Occupational Safety & Health Administration and the Consumer Product Safety Commission.

Future Applications

An extremely hydrophobic textile surface could have other potential uses other than for stain release. A fabric that repels liquids could also be used to direct liquids. Fabrics treated with nano stain release finishes could potentially be used in the construction of a liquid superconductor to transport fluids through and over materials, membranes, pipes and capillaries.

Nanotechnologists are working on nanocoatings that could possibly have the ability to self heal. Textile surfaces which can remove surface scratches and scuff marks; repel insects; and decolorize red wine spills are under development.

Nanotechnology is being used to develop “sensorized” garments. Prototype garments with the ability to monitor functions such as body temperature and vital signs have already been developed. Sensorized garments could potentially be used in a wide variety of applications including hospital gowns and military uniforms.

Self ironing suits are being developed using nanomaterials that respond to heat. A heat source, such as a blow dryer, is applied to the wrinkled area. After reaching a specific temperature the nanomaterial is thermally activated—removing the creases.

Research is focused on developing bioreactive plastic coatings which protect the wearer against biological and chemical attacks. The coating, embedded with antibodies and enzymes, decontaminates the textile surface as soon as pathogens or toxins are present. Scientists are also investigating ways to equip the coating with an alarm system which would alert the wearer to the invisible attack.

Other research is focused on developing military uniforms that can change colors on command to camouflage the wearer.

Bringing Nanotechnology to Fruition

In the last five years, nanotechnology has catapulted from obscurity to a promising scientific and industrial enterprise. However, taking the small scale production of nanostructures from the laboratory to an industrial scale is not without challenges. To further compound the risks of commercial production, few studies have been published on the adverse effects of nanomaterials.

Possible explosions and toxic hazards are just some of the concerns. If handled incorrectly nanomaterials can spontaneously burst into flames when exposed to air.

Some scientists have expressed concerns over possible pollution. Nanoparticles released from coatings could become a new type of chemical pollution.

Nanoparticles can pose a risk to bacteria and mammals. Studies have shown that carbon nanotubes can agglomerate, causing tissue damage, respiratory problems and in some cases death in rats. It has been shown that nanocrystals dissolved in water can devastate an existing bacteria population—an extremely effective antibiotic. Other studies have demonstrated that the lung tissue of mice can be damaged by breathing in nanotubes and nanosized iron particles.

Although there has been an effort to make nanoprocessing compatible with conventional textile equipment it is inevitable that investments will have to be made. New equipment for making nanomaterials will be required. In addition, nanomaterials can be very expensive.

Conclusion

There is tremendous potential in the field of nanoscience. In the next 10-20 years nanotechnology is expected to greatly impact the textile industry. There are numerous products that are already commercially available and limitless products that could be developed utilizing nanotechnology. However, with recent technological advances, science will not be the major obstacle to bringing nanotechnology to fruition—money and risk will.

January 2009