Review Article

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New materials and their application in the design and production of high-performance textile products

Abstract

This paper provides a comprehensive description of the performance materials employed in a select group of high- performance textiles that are designed for a range of nontraditional applications. It also covers some design aspects of the individual products and explains the principles governing the specially engineered functional performance built into the products through the use of special materials and product design features. Among the applications covered is critical life saving applications falling under healthcare and personal protection categories.

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Introduction

Textiles are mostly two-dimensional flexible structures constructed with fibers, and they are a part of the everyday life of people in the form of apparel.[1] In recent years, however, fabrics and other miscellaneous fiber products have started playing a much more expanded role than that of providing modesty to the wearers. High-performance textiles are now providing a wide range of performance measures required in dozens of non-apparel end uses. The measures include protecting the user from harm or improving the ability of the end-user to perform by enhancing comfort. High-performance textiles are also becoming increasingly smart, and they are now being used in life-saving and life enhancing applications. Chemical processing of textile fibers, yarns and fabrics is one way of adding desired functionality to textile products used in non-traditional applications. Nanofinishing which emerged in recent years in the form of nanocoating, nanocomposite coating and nanodyeing, has vastly enhanced the range of performance measures that can be added to structured fiber products. Thus, nanomaterials added to textiles in textile finishing and processing are expected to yield a new generation of high performance textile products with superior performance properties for a wider range of end uses that are not known today.

Individual applications, materials used and their functional mechansims

Biomedical applications

Textiles have become a common and important part of the biomedical field. Many types of high-performance fabrics are being used in a range of procedures to protect all participants from the potential cross contamination hazards associated with medicine. This is done through the fabrics that are used in non-implantable as well as implantable methods. The importance and sensitivity of health makes biomedical applications of high-performance textiles a critical area for research.

Non-implantable medical textiles: Non-implantable medical textiles refer to those that are applied externally to the body. These textiles can be used to regulate hygiene or fight the spread of bacteria. Hospital fabrics, including surgical gowns, bed linens, and patient dresses are some important uses of non-implantable high-performance textiles. These textiles and any others used in healthcare serve as important barriers to protect healthcare workers, patients, and visitors from cross-contamination and the spread of diseases. Figure 1 illustrates the abundance and commonality of the use of barrier textiles in surgical procedures. Their importance is amplified by the close contact and extended wear time dictated by the end use. These fabrics are usually imparted with permanent antimicrobial materials and dyes that can help protect against the spread of bacteria.[2]

Figure 1 In most surgical procedures, surgical gowns, face masks, caps, gloves, and linens are used by multiple individuals and surgical platforms.[23]

New research has vastly improved the antimicrobial performance of biocidal materials used in medical textiles. These materials have replaced the previous generation materials because they have the ability to completely and quickly inactivate micro-organisms. Traditionally used biostatic materials could only inhibit further growth of micro-organisms and bacteria after they come into contact with the textile. Even if the treatment can block penetration of liquids into the fabric, they cannot fully protect from infection and disease, as the micro-organisms survive and live on the fabric for months. The new antimicrobial treatments are either chemically bonded or permanently coated to the textiles. This gives new biocidal materials the advantage of being durable against laundering by implementing a slow release mechanism over time. Biocidal materials also permitted the compatibility needed to make the fabrics waterproof and antistatic.[3] The textiles were also made superhydrophobic to help prevent the entrance of harmful liquids to the body while also improving wash durability. This is accomplished by providing for a high-water contact angle that creates a "lotus effect" where liquids run off the fabric and, in the process, provide a self-cleaning function for the textile.[4] These functions would also be useful as coating to various surfaces in and out of a healthcare environment to eliminate the spread and growth of harmful micro-organisms.

The ability to instantly kill harmful bacteria and microorganisms provided by the new advances is beneficial for all biomedical textiles including hospital gowns worn by patients, bedding used on hospital beds, linens used in medical procedures, face masks, gloves, scrubs, and surgical caps and gowns. Having these materials possess biocidal qualities is important to protect a patient's already weakened immune system from outside bacteria carried by hospital workers and visitors, and it is also important in protecting healthcare workers from the harmful bacteria that they are exposed to from the sick patients. These non-implantable medical textiles, therefore, are a key factor in keeping hospitals and clinics clean and safe.

Another non-implantable medical textile that must have functions beyond those provided by biostatic materials is the wound dressing material used for surface wounds on the body. In contrast to gowns and linens, the bandages used for wounds are applied to the body's surface for not only hygiene and decontamination but also for their healing properties. Wound dressings are tasked with providing a suitable environment around a wound in order to help the body's natural processes to be able to clean and heal. Figure 2 demonstrates the ideal healing process for wounds that is aided by proper bandages. Creating this environment means providing a sealed, moist, and absorbent covering in order to keep the wound clean and allow the body's tissue to regrow. These dressings can come in a lot of different forms, from traditional gauzes to semipermeable foams and films to hydrogels. Different wounds are treated with different dressings based on how they need to heal. For example, gauze is best suited for chronic wound because it is absorbent and can maintain a moist environment, and it also has elastic properties that allow for better mobility while worn. Recent developments have also introduced dressings that act as skin substitutes by restoring chemical balance through stimulating cytokines as a growth factor while also removing bad proteins in the wound to help it heal healthier and quicker than what was possible through previous generation products.[5] Proper bandages are essential in allowing the healing process to proceed quickly by facilitating a desirable environment while keeping out harmful bacteria. Wound dressings, like the previously mentioned protective hospital wear, have the important function of keeping bad organisms from entering the body and causing infection while also protecting others from the potentially harmful bacteria that emanates from ill or injured persons.

Implantable medical textiles: Implantable medical textiles work inside the body to help aid in the body's functioning. Because these textiles work in conjunction with the body's natural processes, biological recognition is crucial to their ability to perform. Biocompatibility of a material is what allows the body to accept a given textiles that has been implanted. Biocompatibility requires the textile to be non-toxic, permeable to normal bodily fluids, porous, and biodegradable. This has created new work in designing implantable materials to have a biologically active component that allows the textiles to more successfully integrate into the body. The functionality is added through compounds such as proteins, lipids, carbohydrates, and peptides because they have the ability to maintain their functionality after they are bound to a fiber.[5] These compounds naturally exist in the body, so fabrics integrated with them are more compatible and thus more likely to successfully integrate into the body's natural processes in order to accomplish the desired functions.

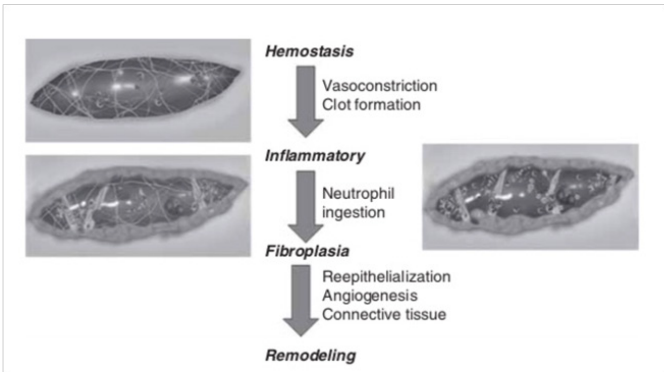

Figure 2 The main steps that occur in a typical wound while it undergoes the healing process.[6]

Synthetic polymers have become a predominant material to make implantable medical textiles because the rich carbon base allows the textiles to biodegrade. Biodegradation is important in implantables because it helps to eliminate need for maintenance through further surgical procedures to extract an implanted device. This saves time and money while also improving safety. For example, biodegradable stitching is used in wound closures inside the body to eliminate the need for further surgery and procedures. Synthetic polymers also are designed with particular mechanical properties that allow them to be strong for reinforcement applications while also maintaining a natural flexibility. Synthetic polymers have various biomedical applications, from orthopedic implants to vascular grafts to ophthalmology to dentistry and many others. Often, they are used as coatings instead of as bulk materials because of their ability to respond and adapt to their environment, a property that helps improve biocompatibility.[6] Synthetic polymers are integrated into implantable biomedical textiles because their properties improve the performance of textiles.

Implantable medical textiles can be used in many ways in the body; one of those applications is as an artificial organ. Artificial lungs, kidneys, bladders, and many other organs that experience common failure are important applications of high-performance biomedical textiles. Hemodialyzers are used in implantable devices to help purify the blood passing through which aids in the biocompatibility of the system. Biomaterial scaffolds have also been developed through tissue engineering in order to help repair damaged organs. They function as grafts that work to repair misfunctioning inside organs, arteries, or any other damaged part of the body. Biomaterials have become popular as implantable textiles because they can easily adhere to the cells and the body's tissue to help regulate functioning and blood flow. This allows them to be useful in wound closure and replacement surgery because of their biocompatibility and biodegradable properties.[5]

Hydrogels

Hydrogels have found use in medical textiles to transport drugs into the body. These hydrogels are networks of cross-linked water-soluble polymers that can be administered either through implantable or non-implantable methods. The high-water content of hydrogels gives them good biocompatibility. Drugs are loaded into hydrogels' porous regions and then they release the drugs over time through diffusion. The ability for the release upon implantation occurs because hydrogels are constructed from thermo-responsive polymers. These materials can change their solvation states after entering the body and undergoing the accompanying temperature change. The phase changes that thermo-responsive polymers experience from room temperature into the body allows for the release of the drugs carried in the hydrogel.[7] Figure 3 demonstrates the change in structure that hydrogels experience with changes in temperature that stimulate drug release. The material becomes less gelatinous and more soluble which allows drugs to begin diffusing into the body. This release is often a highly concentrated and highly localized process. Most research on this topic surrounds enhancing the drug's interaction with the hydrogel or introducing a diffusion barrier in order to make the drug release duration of this process longer and in more moderated dosages.[8]

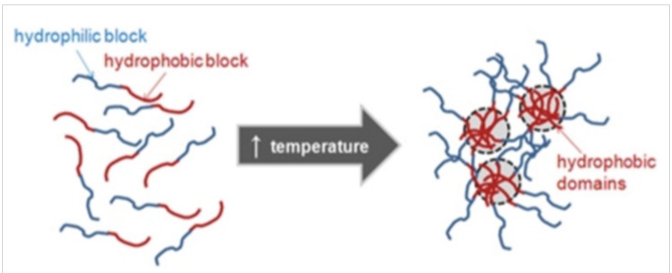

Figure 3 As temperature increases, the surface area of hydrophobic material decreases and allows the hydrogel to become more soluble, allowing the drugs to permeate through the body.[10]

As opposed to implantable hydrogels, non-implantable drug delivery occurs through transdermal permeation of the body. In this method, the hydrogel is adhered to the skin and allowed to permeate into the body to begin the drug's action. This allows slightly more control over the drug release and does not require any sort of surgery or invasive procedure. Transdermal permeation also provides an advantage over traditional oral methods of drug-taking in through the elimination of some of the side effects. This is most predominately seen in estrogen, often taken to balance hormonal deficiencies in the body. Taking estrogen pills orally can increase hepatic protein levels and cause an abnormally high fluctuation in hormones in the blood. These adverse reactions of ingesting drugs are minimized or erased through using hydrogels and transdermal permeation to deliver the drug into the blood stream.[9] Hydrogels, which can by non-implantable or implantable textiles, have important functions in delivering drugs efficiently and effectively into the body.

Thermal applications

Fire and heat can have positive or negative attributes to situations. These thermal sources can provide safety and comfort but also present the potential for danger. Heat plays in important role in maintaining a comfortable temperature for the body but fire can be harmful on the body. High performance textiles find applications to help regulate these interactions. Fabrics are used to enhance safety and comfort and this makes them applicable in various situations where heat and fire are involved.

Thermal comfort: One of the most traditional function of clothing is to maintain thermal comfort of the body. Traditionally, people add and remove layers of garments in response to the surrounding temperature in order to maintain their core body temperature. However, phase-change materials (PCMs) are being implemented as a new method that allows textiles to respond to both the surrounding temperature and the body's temperature to eliminate thermal discomfort. This prevents the constant need for adjustment of clothing and layers because PCMs are able to accommodate the desired warmth. PCMs do this by absorbing latent heat from the body and the surroundings and then releasing it in response to temperature changes. The change in temperature prompts an accompanying phase change which is how the heat is absorbed and released. This phase changing process is demonstrated by Figure 4.[10] This allows the release of heat to keep the body warm as the material changes to a solid in cold weather. PCM fibers are also able to absorb heat stored in the material. This occurs when the body's skin temperature is high indicating an elevated body temperature or when there is a warm surrounding environment from a hot day or a warm room. These PCMs can be manufactured into textiles in a variety of ways, but there are a few standard processes that are used. They can be manufactured by impregnating textile fibers with PCMs, coating fibers to encapsulate them with PCMS, or spinning the fibers together with the PCMS.[11] These processes each exhibit advantages and disadvantages based on their laundering and wear durability as well as their effectiveness. Because of this, the process used often varies with the type of application. PCMs are able to maintain comfort in the user, and they do this in a renewable way that utilizes the body's natural releases of heat. Because of this, high performance textiles that integrate PCMS provide the opportunity to reduce the number of layers needed in cold weather situations. Traditional cold weather clothing is bulky and insulating. The use of PCMs allows reducing the weight and number of layers needed.

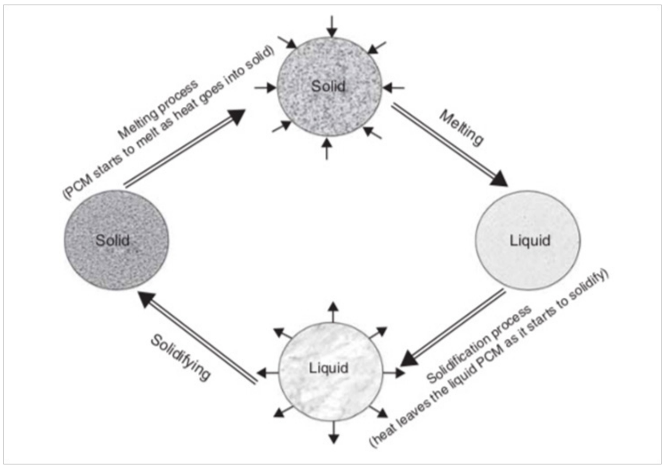

Figure 4 Phase changes that occur in PCMs in response to temperature changes.[16]

PCMs were first researched and utilized for their ability to be used in aerospace textiles like space suits because of the drastic cold temperatures experienced in space. However, they are also applicable in active wear clothing for both cold and hot weather sports and outdoor activities. This includes coats, socks, hats, and pants for cooler applications as well as athletic wear for warmer conditions. In cold weather, PCM laden clothing provides warmth in order to maintain better functioning and comfort of the user, and in warmer conditions, clothing with the PCMs allow less heat to be trapped by clothing. Instead, the textiles are able to wick away heat when the body is experiencing too much warmth. Bedding is also an applicable field for these textiles because it regulates a comfortable sleeping environment to improve sleep quality. Even firefighter's uniforms can implement PCMs in order to relieve firefighters from the burden of bulky clothing in extremely hot environments.[10] The ability of PCMs in textiles to create thermal comfort for the user in a variety of conditions provides a lot of advantages. The beneficial performance is applicable to highly specialized textiles as well as to common everyday use textiles.

Infrared textiles

Multilayered fabric structures achieve warmth by trapping air and body heat between the fabric's layers, and this provides insulation.[12]

This method of multiple layers in textile's structure explains why cold weather textiles and clothing, like ski jackets are thick and heavy. A more recently developed approach to warming and insulation is through the use of infrared textiles. These fabrics provide increased warmth retention over traditional fabrics because of their ability to absorb thermal energy released by the body and redirect it into the body as far infrared rays. Infrared rays are non-visible light rays within the electromagnetic spectrum illustrated in Figure 5. The wavelength of these emitted rays helps stimulate an increase in blood circulation that in turn is able to warm the body. In this way, the warm up function of the infrared textile is enabled by the wearers themselves, and the fabric's warming effects can adapt to the wearers body temperature by responding to the amount of thermal energy the body releases. Although these provide warmth in response to the body's temperature, they differ from PCMs in their mechanism for warming. Infrared textiles also differ in that they don't respond to environmental stimuli, and they don't have functions to release heat to suit warm weather situations. This is why infrared textiles are just considered as insulators. However, the rays radiated into the body by far-infrared textiles do provide the advantage of a quicker warming effect than traditional insulating fabrics.[13] Infrared textiles also go above traditional insulating and warming actions provided by sun's radiation in that they contribute to increased warming retention for the benefit of the user. This makes them more suitable for use in any cold weather clothing and textiles where warmth retention is important. This includes sleeping bags and blankets as well as clothing articles such as gloves, jackets, hats, and other linings.

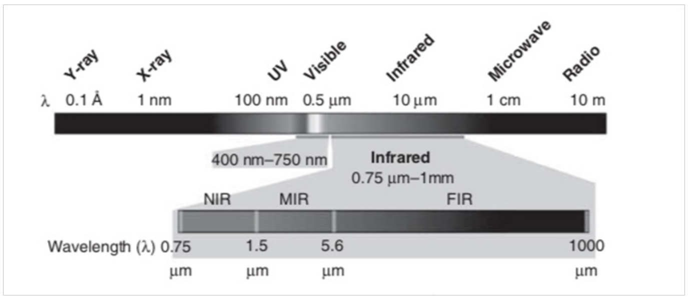

Figure 5 Far Infrared rays used in infrared materials typically fall between 8 and 25 µm in wave length within the electromagnetic spectrum.[5]

Flame retardant textiles

The ability of textiles to resist fire is also an important thermally related application of high-performance textiles. This is a property that can keep people and objects protected from the hazards of fire. The flammability of a textile can depend on many properties, including polymer type, fabric structure, and chemical treatments applied to the fabrics. For example, an open porous structure of fabric allows the increased presence and flow of oxygen, and this makes combustion more likely. A textile can be made flame retardant through inflammable fibers or through an active surface treatment. Among the few flame-retardant polymers are wool and synthetic aramids. The downside of fabrics such as wool which were traditionally used in firefighters' uniforms is that they are also insulating, and this makes them less hospitable under elevated temperature conditions. A better way to achieve flame-retardant functionality in textiles is through coatings and finishes, for which many different materials and application modes are available. The ability to coat light-weight textiles with a flame-retardant coating make the textile to function without any limitations to its mobility and flexibility.

Flame retardant textiles are appropriate for any application that carries the risk of fire and combustion. One of the most obvious applications, of course is firefighters' uniform. Flame resistance and retardance properties are also important for clothing used by industrial workers or for lab coats because of the potential fire risk involved in these applications. Additionally, installers of high friction brake pads, metal workers and others operating in similar spots of intense heat and flame generation need the protection offered by flame-proof clothing. Textiles that surround electrical wiring and equipment is also an area where fire is a hazard; housing insulation is an area where flame-retardant fibers have been instrumental in reducing the number of house fires cause by home electrical systems. Bedding and carpet are also textiles that provide benefit by being inflammable, and that function could prevent fires. Flame retardant textiles work to protect and limit the damage to people and objects that fires can damage.[14] Dangerous fires can very easily and accidentally be started in all kinds of environments and can be caused by seemingly harmless sources, like candles, cigarettes, ovens, electrical cords, or any source of heat radiation. For the risks associated with many of these sources, flame retardant textiles can serve as important precautionary and protective tools to prevent and contain fire damage.

Protective applications

Textiles used in military applications have experienced major iterations throughout history. As war tactics and needs evolved, the number of potential threats faced by the soldiers also grew. Because of this, the fabrics used in military uniforms have had to evolve as well. In today's modern warfare, important functions of high-performance textiles in military applications include armor, chemical resistance, and camouflage. Soldiers' uniforms have also become increasingly digitized, but this development will be discussed in the section on electronic textiles. These functions of military textiles have also become applicable in other areas, such as in the uniforms of law enforcement personnel and first responders. The function of all of these textiles is to provide protection from the common and harmful threats faced in individual occupations.

Ballistic protection: Structured ballistic fabric materials are often used as inserts in uniforms to protect the soldiers from the penetration of bullets as well as from potentially harmful projectiles that result from blasts or explosions. The most prevalent type of ballistic protection is through soft-rigid armor that involves layering ceramics and polymers in a fabric to make a strong but still flexible structure. Ceramics are a favorable component in these soft-rigid systems and are implemented as plates placed inside fabric layers. These plates are what are used to protect against bullets or other projectiles; the special properties of ceramics namely, high level of hardness, elastic modulus, and rigidity give them the ability to stop the penetration of bullets by dispersing the kinetic force of the projectile without rupturing or deforming the ceramic plate. These ceramics are then implemented into polymer structures that are woven in orthogonal directions. These polymers also possess high modulus of elasticity which adds further ballistic protection while also allowing the textile to maintain flexibility which enhances functionality in the actual usage field.[15] The most common example of soft-rigid armor is the bullet-proof vest made of Kevlar fiber. These are worn by soldiers in the battle field as well as by police officers or other first-responders in danger of experiencing gunfire. Figure 6 shows the layering of ceramic and polymer materials in these systems that are able to stop the penetration of ballistic projectiles. Beyond soft-rigid systems, there is a lot of research into developing new completely soft armor that provides protection through only polymer fibers. Specifically, the company Magellan Systems International LLC has been working to produce a fiber designated as M-5™, which is known to perform as well as and better than soft-rigid systems. Its enhanced performance is attributed to its ability to form lateral hydrogen bonds. Combining these fabrics with shear-thickening fluids also increases the fabric's ability to withstand ballistics.[16] Although these soft armor systems are not commercially available yet, the research surrounding them has provided new materials that could improve the wearability and functionality of current soft-rigid armor.

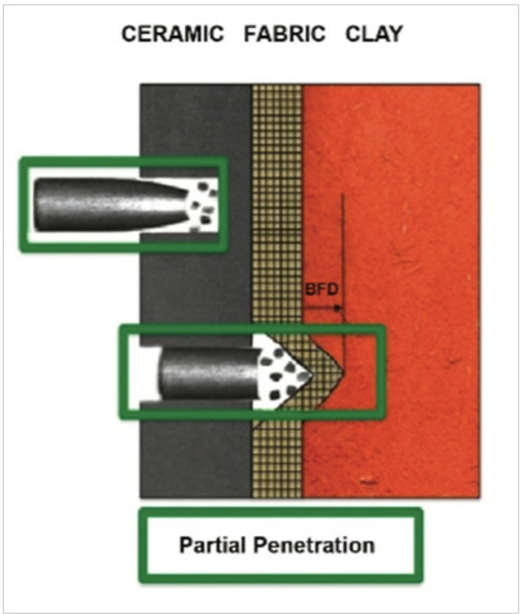

Figure 6 A layered ceramic-fabric-clay composite in soldiers' armor prevents the bullet from fully penetrating by absorbing and redistributing the forces from the projectile.[17]

Ballistic fabrics have the ability to save the life of an individual who is shot. In fact, these fabrics go beyond bullet proof vests when it comes to protection. The fabrics are also used in boots and helmets of soldiers. The development of fully flexible soft armor would allow these fabrics to be integrated into soldiers' uniforms such as pants and jackets. This development would also create new commercial applications for ballistic protection fabrics. High-performance ballistic textiles can save the lives of soldiers and law enforcement personnel without hindering their ability to perform their jobs.

Chemical protection

Scientific advancements in the last century have led to more sophisticated and deadly chemical warfare tactics. This emergence of chemical warfare as a threat has created a need for fabrics that can protect people from liquids, oils, and gases. Protection from aerosols, which can come from radioactive dust and other threat agents, is best achieved through encapsulation and filtration processes. Encapsulation traps the aerosols before they penetrate the fabric, and then a fibrous membrane is used to mechanically filter the particles. However, toxic gases and vapors are too small to use this method of protection. The most effective form of protection against toxic gases and vapors is adsorption, which forces the chemicals to accumulate on the fabric's surface and form a film rather than penetrate it. This is accomplished through the use of fabrics with activated carbon, silica, alumina and zeolites. These are commercially available and effective absorbents that can be most effectively integrated into fabrics.[16]

High performance textiles with function for chemical protections can protect and even save the lives of soldiers that are attacked with chemical weapons. With the increasing use of chemical and biological warfare, it is imperative that these technologies be implemented to protect soldiers in harm's way. Outside of military applications, these functions are also applicable in laboratories that experiment with toxic gases and deadly chemicals. Availability of appropriate protective tools would make research involving hazardous chemicals more accessible and safer.

Camouflage

Camouflage is an often neglected but important form of protection. In military applications, camouflage is the first line of defense for a solider in battle because he or she is safe until detected. In the past, camouflage was just in the form of a fabric that had patterns printed on it to help blend into the surroundings. Figure 7 shows a traditional military camouflage pattern used in most environments. However, new technologies now allow enemies to detect soldiers though infrared signatures and electromagnetic frequencies. To address this, new research has gone into improving camouflage. Passive camouflage has been developed to allow the masking of a body's infrared signature. However, active active camouflage is what is needed to become virtually invisible. New fabrics are being researched which use light-emission and electromagnetic scattering to mimic the iridescence exhibited by the bio cephalopods which accomplish invisibility biologically.[16] The materials being researched would allow wearers to become invisible to enemies, protecting them from detection. This can also be used in tents, tarps, or other fabrics to provide camouflage to more aspects of a soldier's life. Additionally, camouflage is often commercially used in hunting, and these improvements could further make it difficult for animals to detect humans operating in their vicinity.

Figure 7 A modern camouflage worn by soldiers in the U.S. military to limit detection in most environments.[18]

Electronic textiles

Electronic textiles are a form of active smart textiles with capability to sense and react to various stimuli from the wearer or the environment. They use microelectronics that are interwoven into textiles thus turning the fabric into a technological device.[17] This development has become increasingly popular because of the vast technological advancements made in microelectronics. These high-performance electronic textiles have important applications in energy storage, communication, and sensing applications.

Conductive Textiles: In order for high performance textiles to be functional, they have to possess many of the qualities of standard electronic devices. One of those qualities is conductivity, which allows voltage to move throughout the textile in order to power various devices. Carbon nanotubes have becoming increasingly popular as a means to satisfy this need. Carbon nanotubes are created by the rolling of graphene sheets into seamless microscopic cylinders seen in Figure 8. These nanotubes are the stiffest, strongest, and most conductive known fiber materials.[18] However, it has been found that by coating textiles with carbon nanotubes, the textile can maintain its flexible and stretchable properties for comfortable wear while making the fabric instantly more conductive for high-power performance.[19] This makes the material more wearable, and the coating is an easier and cheaper process. Using carbon nanofiller has also become an option. This method increases the strength, roughness, and conductivity of the textile it is integrated with in order to increase its performance without sacrificing wearability.[20] This method of creating conductive textiles provides a more durable option for retaining conductivity through laundering. However, all methods have been shown to work to establishing conductivity in a textile. The method used is often dependent on the application and how microelectronics is integrating into the fabric. Conductive textiles created with carbon nanotubes are inexpensive and have become the ideal substrate for microelectronics in high performance textiles. These conductive textiles provide a good platform for the various uses of electronic textiles.

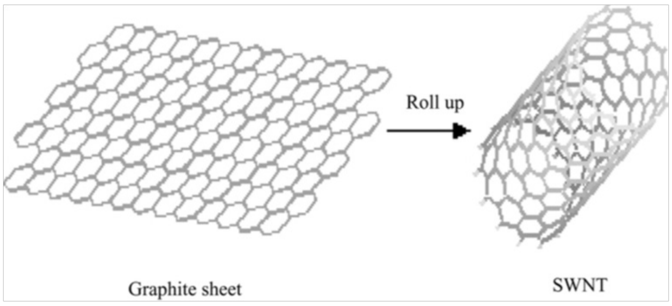

Figure 8 Illustration of the formation of single walled carbon nanotubes (SWNTs) from flat sheets.[12]

Energy collecting and harvesting

In order to power the microelectronics in e-texiles, it is important to have a viable power source. Traditional lithium-ion batteries are too bulky and rigid to integrate into textiles. This has created a need for a flexible and wearable way to collect and store energy for use in the functions of e-textiles.[21] Using ambient sources of energy, like the body's natural movements and the surrounding environmental forces can provide a renewable way to collect power for electronic textiles.[22] This is not only an environmentally friendly option of capturing renewable energy, but also an easy and effective method of energy collection that requires little or no extra work from the user.

Piezoelectric materials have emerged as a new and viable way of collecting mechanical energy arising from everyday activities and movements. These materials are able to capture energy as voltage created through ambient movements. A schematic of energy harvesting piezoelectric structure is shown in Figure 9. Piezoelectric materials, which can be used in ceramic and polymer forms can store energy from vibrations created by breathing, walking, and other kinetic movements. They can also collect energy from environmental vibrations created by wind and by the impact of raindrops on a fabric.[23] This allows constant energy collection from natural and renewable sources.

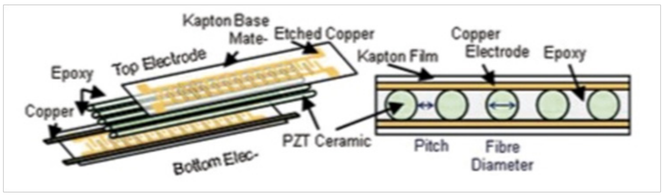

Figure 9 Schematic of a piezoelectric fiber composite.[25]

Piezoelectric textiles were first implemented as high-performance e-textiles into tremor suppression gloves. These gloves have the ability to measure the frequency of vibrations made by the body and identify frequencies associated with tremors. It can then feed the collected energy it has stored back into the wearer at certain frequencies that help suppress the tremors. In this way, piezoelectric textiles can act as both a sensor and an actuator. Figure 10 shows how piezoelectric composites are aligned in the gloves. These gloves were specifically designed for people suffering from Parkinson's disease, but have the ability to find applications for other tremor related issues.[24] Beyond tremor suppression, the renewable energy collection that piezoelectric textiles provide gives the ability to harvest energy and then use it to help power any device. This can be used in any environment, and it could prove extremely useful in allowing people who are camping or in situations without power to be able to power small devices. Piezoelectric materials provide the ability for energy collection from everyday activities that creates an environmentally friendly energy source, and even can have medical benefits against conditions associated with tremors.

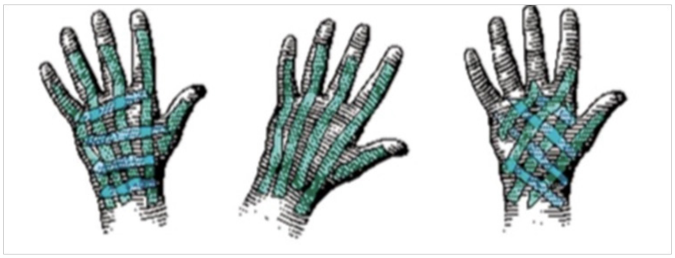

Figure 10 The alignment of piezoelectric composites in tremor suppression gloves.[25]

Sensors

Sensing technology essentially served as the driver research activity in the field of electronic textiles. The microelectronics in electronic textiles provide the ability to use sensors to collect information about both the wearer as well as the surrounding environment. ProeTEX is a recent project that was aimed at accomplishing this goal by creating a uniform of smart textiles for first responders. The uniform possesses many sensing functions that allow the health vitals of the wearer to be monitored while also integrating sensors that monitor the environmental conditions in order to be aware of and assess potential risks. The numerous locations of sensors, monitors, and displays integrated in the fabrics can be seen Figure 11. This ProeTEX project also designed a "victim patch" that could be adhered to a potential victim in order to assess their injuries immediately.[25] The sensing ability of textiles like these can be accomplished in many ways. There are traditional electronic sensors that are primarily used for environmental sensing. For instance, boots can be integrated with sensors that detect oxygen levels, track location, or do any other function.[26] This is an advantage because it eliminates the need to carry around a traditional device. Additionally, some smart textiles experience changes in response to temperature, pressure, pH levels, biochemical fluids, or stress. These stimuli-sensitive polymers experience shape and phase changes that can be measured as another method of sensing.[1]

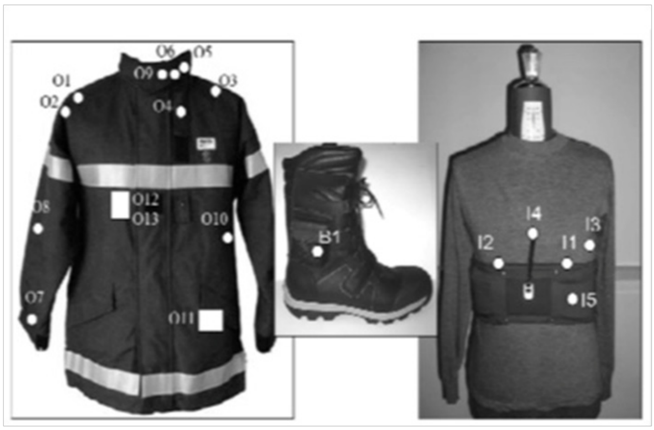

Figure 11 Illustration of the ProeTEX uniform developed for use by emergency responders.

The sensing capabilities of smart electronic textiles have many potentially commercial and noncommercial applications. The ability to monitor conditions of the surrounding environment can have applications for first responders and soldiers. The ProeTex uniform was originally developed for firefighters but it demonstrates the applicability of sensing in electronic textiles for any person going into dangerous and unknown conditions. For instance, an oxygen level sensor could be advantageous for firefighters going into burning buildings where oxygen level is a critical indicator of trouble.[25]

The ability to monitor the vitals of the wearer is also an important medical application of high-performance electronic textiles. Whether through electronic sensors or smart textiles that respond to stimuli, electronic textiles can provide the ability to monitor the heath of a person. For instance, there is research into using electroactive polymers in wearable contact sensors that can come as patches, bandages, or any other textile that touches the body. These non-invasive devices have the ability to monitor biochemical fluids that are released through sweat, saliva, tears, or even blood. These fluids can reveal levels of dehydration and monitor their vital levels in the body.[27] This illustrates how fabrics can be used to monitor all types of health-related information coming from the body as well as from invasive sensors that monitor internal functions of the body. The technology has applications for soldiers, first responders, space suits, and injured personnel as a way to get and monitor quick information about their health. It can also help monitor long term health of elderly or disabled patients. Electronic textiles provide the benefit of being able to continuously monitor and capture information on patients without requiring them to come into a hospital or clinic.[28] This could also be beneficial for athletes wishing to track themselves in order to help improve their performance. The ability to know and monitor the health of a person is an important application of sensing in electronic textiles.

Communication

The information that electronic textiles collect is only beneficial if the textile also has the ability to communicate that information. Recent advancements have allowed fiber optics to be embedded into textiles in order to carry and transmit the collected data.[26] This transmission could feed the information directly back to the user, but it could also transmit the data to external facilities. It allows hospitals to monitor their patients remotely or it could allow the location and health status of soldiers or first responders to be monitored from a base.

The wireless communication network created in the textiles also allows it to receive information from external systems as well. This could prompt an electronic response from a device in the electronic textiles, and it could also allow the textiles to display that information to the user. For instance, electronic textiles could receive and display information in the same way a television set might play the news. Although there is no current system to make it as interactive as a smart phone, the microelectronics and microprocessors embedded into the fabric can permit electronic textiles to serve as two-way communicators of information way that receive and transmit information.[22] This could have applications in many fields in everyday life as well as in specialized fields. For instance, with the digitization of battle field, high performance electronic textiles offer the ability to give and receive information that could help soldiers be more aware and informed in order to better protect themselves. Beyond that, the abilities of electronic textiles as communication centers give it the potential to be commercially applicable.[29]

Summary and conclusions

High performance textiles have a variety of functions applicable to different fields and applications. Work to innovate or create these new and better textiles in order to better serve society is continuously happening. There is always an aim for more efficient, cheaper, and more durable textiles in all fields. There has been work to provide better applications in the biomedical, thermal, and protective fields. However, much of recent research is aimed at the field of smart electronic textiles. This is due in large part to the technological advancements and rapid digitization taking place in the modern world. As society continues to digitize, electronic textiles have emerged as a way to mirror the trend. Textiles field is a continuously developing field that is growing to serve emerging needs in a wide range of nontraditional application areas.

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Conflicts of interest

The authors declare there is no conflict of interest in publishing the article.

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