GT9 - DESIGNING NANOFIBRES: A DESIGNER´S POINT OF VIEW OF NANOTECHNOLOGY

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Resumo: A nova fronteira em tecnologia de vestimentas são as fibras funcionais feitas por meio de nanoengenharia que podem criar novas funcionalidades sem alterar as características básicas do material têxtil. Combinar moda com avanços tecnológicos é um dos desafios a serem observados quando se projeta nanofibras para uma funcionalidade.

Palavras chave: Nanofibras; design têxtil; nanotecnologia.

Abstract: The new frontier in clothing technology is nanoengineered functional textiles that can create new functions without altering the basic characteristics of a fabric material. Combining fashion with advances in technology is one of the challenges to be addressed in designing nanofibres for function.

Keywords: Nanofibers; textile design; nanotechnology.

Introduction

Technology has already become pervasive in everyday life. There are vast possibilities to add and extend the functionalities and performance of textiles to meet those demands (COYLE et al., 2007). Individuals constantly check their mobiles for updates on social networking, listening to music or even taking pictures. Traffic lights are monitored by a remote centrals and sensors to work according the local traffic. Something one can recognize is the high presence of technology on several aspects of our daily lives. But what is the next step of this technological revolution? Future indicates that the ´concept of clothing is undergoing a transformation through innovation in wearable technologies.` (YETISEN et al., 2016). McCann, Hurford and Martin (2005) defined smart clothing as ‘a product that should look good and be appropriate for the culture of the end-user, with garment functionality enhanced by embedding technologies such as electronics and computing into the clothing.`

Not only the addition of computational systems to clothing can be considered technology when talking about wearable, but the worn material development also play a pivotal role in this context. Smart textiles concept fulfils very well this gap. While conventional fabrics are made of passive materials such as cotton, wool or nylon, smart textiles have the ability of reacting to stimuli (mechanical, electrical, thermal, etc.) and respond (sense, interact, communicate, adapt, etc.) to their environment (HARJUNIEMI, 2016; HU et al., 2010; LAI et al., 2017; STOPPA; CHIOLERIO, 2014; WU et al., 2017; YANG et al., 2017). They challenge the concept of what fabrics are and inspire us to re-think our clothing.

Textiles are a ubiquitous media; it is present everywhere in the world as individuals wear it every day of our lives. It is only natural that this second skin can become part of this revolution. ‘Smart textiles are envisioned to make a paradigm shift in wearable technologies to directly impart functionality into the fibres(…)’ (YANG et al., 2017). Combining fashion with advances in technology is one of the challenges to be addressed in designing wearables´. Besides being comfortable and washable, clothing needs to please aesthetically. Pieces presented on a catwalk can be really interesting but usually their solemn purpose is to communicate a concept. Once commercial production is applicable, a “downgrade” of the concept needs to take place, bringing this garment to be reproducible, more mainstream and trendy. Another challenge presented in designing smart clothing is to have the components truly embedded in to the fabric. Batteries, microchips and common wires are not washable neither comfortable to be worn.

The misconception of what defines wearable happens when it is understood as anything technological that can be attached to a piece of clothing. The definition can be better explained by “embedded technology into a piece of clothing, but keeping its original proprieties. When perceiving smart textiles as components, its applications can range from sensors, actuators and control units. Those components are intended to be fully lodged in the textile material. Meanwhile the textile material must retain its original shape and flexibility, light weight, washability and comfort of clothing in order for smart materials being considered practical. Much work developed on smart textiles have been presented with conventional electronics layered on a textile base, presenting problems of connections, bulkiness and discomfort to the user, among others. Nanotechnology can be considered a key component to achieve true wearability, enabling the incorporation of functionalities to textiles in various production stages — at the fibre-spinning level, during yarn/fabric formation, or at the finishing stage (COYLE et al., 2007; SUH, 2010).

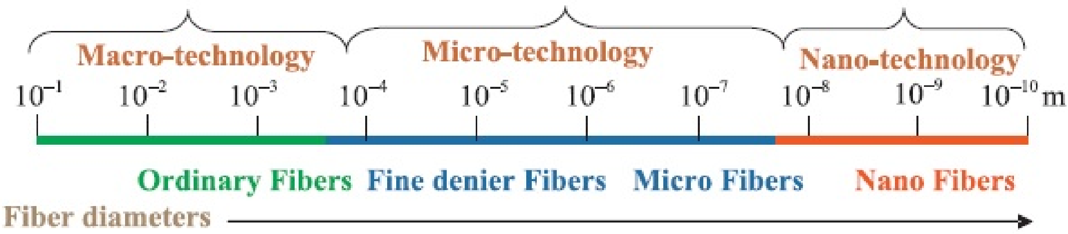
This article describes current materials developments for smart nanotextiles, more specifically for nanofibres and some of the many applications where these innovative textiles proved to be effective.

Nanofibres

Nanothis, nanothat, nanoevertyhing. Is the world getting nanosized? Is not uncommon to read news about new researches and hear “nanosomething” in the middle of presented information. Nanotechnology has become a big topic when reflecting on latter research trends. The reason behind that is the number of possibilities that this technology can present to mankind. Being able to discover, produce, manipulate and apply materials and components in such small scale allows researchers a whole new broad of alternatives and choices. Any material able to be nanosized changes its proprieties. This happens because once you work with a material in a molecular level, it does not react in the same way as when all its molecules are gathered in big quantities.

A nanometre (nm) is the measurement unit for length that is below micrometre (µm). It is one billion of a metre, or 1×10^{-9} m (fig 1). The prefix Nano comes from Ancient Greek “Nanos” which means dwarf. It is used as a prefix of a substantive to indicate that something is happening in the nanometric scale or that has relation with nanotechnology (SAWHNEY et al., 2008). But how such small measurement, invisible to the naked eye, can be understood? For instance, a man’s beard grows one nanometre between the time he gets a razor from a surface and touch his face for shaving. Taking into consideration the earth’s diameter, one football can be considered as one nanometre. On average, our nails grow one nanometre per second. In order to be seen nanometric, materials need to be analysed under special equipments such as an electronic microscope.

Fig 1: Scale of fibre material sizes



Source: SAWHNEY et al., (2008)

Nanofibres are fibres which diameter is smaller than 1000 nm or 1 μm. They represent a bridge between nanoscale and macroscale worlds, since its diameter is nanometric and its length can extend up to kilometres (FRENOT; CHRONAKIS, 2003). Nanofibres have countless applications, which makes them an attractive material. In order to understand the material, one needs to be able to understand different production methods. Utilizing the methods according to the required application plays an important role on product development. There are many ways to produce nanofibres such as self-assembly, drawing, centrifugal, phase separation, template synthesis, electroblowing, drawing and electrospinning(KIYAK; CAKMAK, 2014).

When polymeric fibrous material are reduced from micrometric size (e.g. 10–100 μm) to sub-micrometric or nanometres (e.g. $10x10^{-3}$-$100x10^{-3}$ μm), many different enhanced characteristics can be noticed ´such as very large surface area to volume ratio[1], flexibility in the surface functionalities, and superior mechanical performance (e.g. stiffness and tensile strength) compared to any other of know forms of that same material` (HUANG et al., 2003). Nanofibres present unique chemical, mechanical and electrical proprieties therefore they are acknowledge as advanced materials. Nanofibrous mats are also recognized as nanomaterials because they can be intentionally produced in chosen desired conditions (KIYAK; CAKMAK, 2014). The fibres can be

[1] This ratio for a nanofibre can be as large as 10 times compared to the one of a microfibre.

collected in different ways with the intention of the resulting mat having different deposition layouts. For example, if nanofibres are produced aligned, unique functional nanostructures such as nanowires and nanotubes can be formed (FRENOT; CHRONAKIS, 2003).

In this present research electrospinning was the chosen method. Great interest arises from this technique because it can produce solid fibres utilizing a polymeric fluid stream (solutions or melts) (FRENOT; CHRONAKIS, 2003) with a very small size, ranging from a few micrometers until 100 nanometres (FRENOT; CHRONAKIS, 2003; KIM et al., 2011; RUTLEDGE; FRIDRIKH, 2007). It is a ´simple, elegant and scalable technique` (PANT et al., 2011), cost effective and straight forward method (KILIC; ORUC; DEMIR, 2008) to produce micro/nanofibres from polymers when compared to other techniques like drawing, template synthesis and phase separation method. This technique can also produce fibres from metals, metals oxides and ceramics. Different from conventional fibre spinning systems like melt spinning and melt spinning, the electrospinning process instead of utilizing mechanical force to draw and stretch a polymer jet, it makes use of an electrical field force (KILIC; ORUC; DEMIR, 2008). Electrospinning is recognizably and efficient technique for the fabrication of polymer nanofibres (THIYAGARAJAN; SAHU, 2014).

Electrospinning is a technique of spinning[2] a solution or melt of polymers through an input of voltage. The most basic and usual setup (fig 2) composes of a syringe filled with a solution or melt of polymers, pushed by a pump. This solution then is delivered towards a needle. A high electric input of energy added to this needle makes the solution charged; the fluid than becomes charged with this high potential (positive or negative depending on the generator´s polarity). The electrostatic forces role is to replace or add to conventional mechanical sources normally used to form the jet and reduce the size of the fibres (RUTLEDGE; FRIDRIKH, 2007). Bellow the needle a collector is placed and grounded to attract charged substances coming out of the needle

[2] Spinning, in this research context, ´is a textile term that derives from the early use of spinning wheels to form natural fibre staples like cotton and is commonly used to identify fibre-forming processes for synthetic fibres as well`(RUTLEDGE; FRIDRIKH, 2007).

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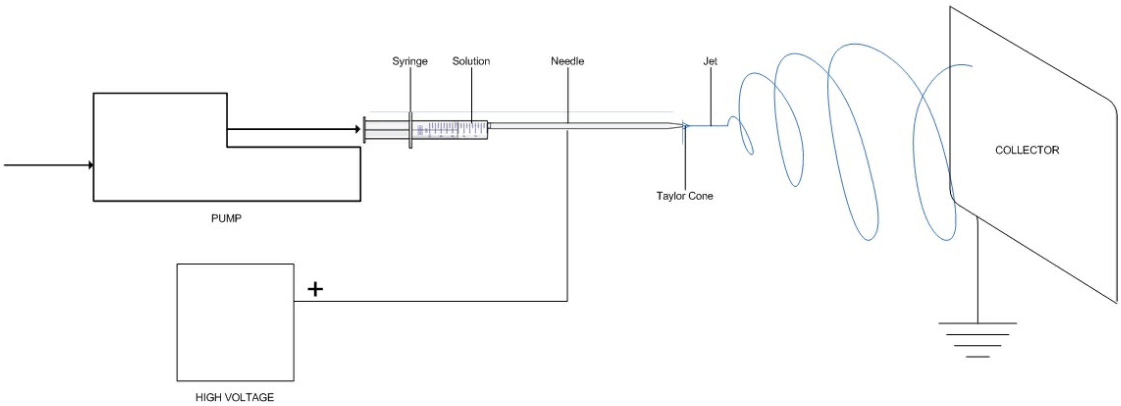
to be deposited in a specific area. “Electrospinning occurs when the electrical forces at the surface of a polymer solution overcome the surface tension and cause an electrically charged jet to be ejected” (KILIC; ORUC; DEMIR, 2008). When the voltage applied is increased, a conical meniscus forms at the tip of the needle; this formation refers to Taylor´s cone (ref3ofP4). A single jet ejects from the cone. The combination of Coulomb´s forces in high electrical fields results in transporting the polymer jet from the needle to the collector by reducing its diameter to nanoscale. In the collector it can be found fibres of micro or nanosize (KILIC; ORUC; DEMIR, 2008). Again, note that this is a basic setup and many different adaptations can be done to alter parameters and therefore have a different final deposited product. As a matter of fact, electrospinning technique can be much more complex than it looks like. Many parameters can influence on the process, not only on the formation of the fibre, but on its conformity and shape, volume and area of deposition, among others.

Fig 2 – Electrospinning setup



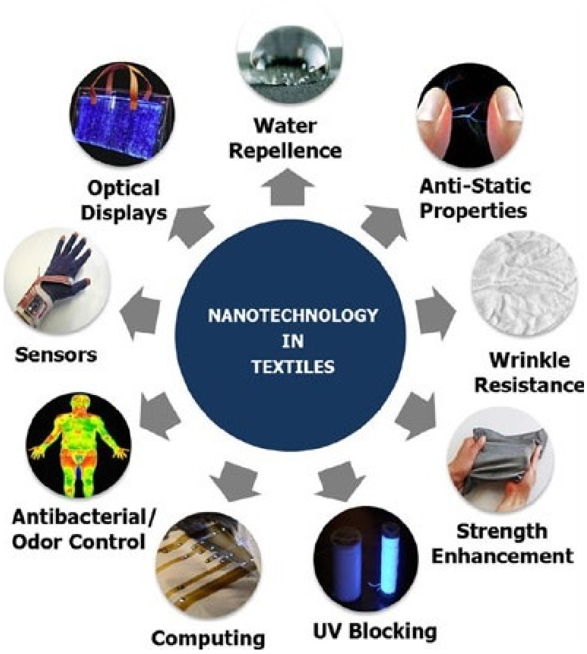
Source: Elaborated by the author

Applications of Nanotechnology in Textiles

Nanotechnology is a pathway for textile development to add new and more complex functionalities while enhancing the already existing qualities, such as durability, without losing the fabric comfort, feel and texture. These technologies can be on the finishing of an existent fabric, on adding nanomaterials to fibres, or even producing nanofibres by themselves. Many nanotechnologies are already commercially available. For example, Nano-tex has a nanofinishing that binds a functional chemical directly to the applied fibre; different from previous products that bound those chemicals as a side polymeric compound. This characteristic will improve the durability of these chemicals over the fabric, without altering its texture or feel. Another example is NanoSphere[R] from Schoeller Textil, a finish for fabrics inspired in the hydrophobicity of leaves as the base of self-cleaning. It is an oil and water repellent stain protection. Yet thinking about self-cleaning clothes, scientists from the Hong Kong Polytechnic University developed an efficient way to coat cotton cloth with titanium dioxide nanoparticles. Those particles act as catalysts, when exposed to sun-light, breaks down carbon-based molecules, being able to tackle harmful microorganisms, dust and pollutants. This barrier against bacteria and other pathogens can also be embedded to textiles by adding nanoparticles of gold, palladium, silver, cooper, gallium, carbon nanotubes or even creating a physical barrier with nanofibres. “A large number of functionalities can be imparted to textiles by the application of nanoparticles and nanostructured materials.”(GULRAJANI, 2013)

Besides attaching functionality directly to the fibres to act on the environment, nanomaterials can be added to fabrics or created as a fabric per se, with the intention of integrating emerging communication devices in to wearable flexible electronics. The advantage of nanomaterials is the ability of creating function without altering the comfort proprieties of the substrate where is deposited (AVILA; HINESTROZA, 2008). Other proprieties can also be achieved in textiles through nanotechnology (fig 3), such as easy care fabrics, stronger materials, anti-static, etc. The array of utilities only grows with new researches being published on this area every day. It is a buzzing field with many perspectives and possibilities yet to be explored.

Fig 3: Nanotechnology in textiles



Source: YETISEN et al., (2016)

Other examples of smart nanomaterials are inherently conductive polymers (ICPs). They can conduct electricity and act as sensors and actuators. They are highly sensitive and its actuation response can be 20 times of the ones generated from natural muscles (DELLA SANTA; DE ROSSI; MAZZOLDI, 1997). Composite fibres is not the future, it is already present. Traditionally made with microfibres, reinforced fabrics can present superior structural properties, such as high modulus and strength to weight ration. Generally, those cannot be attained by other engineered materials alone (COYLE et al., 2007). Now the new generation of nanocomposites presents even superior structural proprieties. Moreover, nanofibre reinforced composites may possess some additional merits which cannot be shared by traditional (microfibre) composites. For instance, producing completely transparent nanomaterials (FRENOT; CHRONAKIS, 2003; HUANG et al., 2003; THIYAGARAJAN; SAHU, 2014).

The applications for electrospun nanofibres are as broad as the number of researches conducted in this area. Nanofibres are leaving the before exclusive environment of the laboratory to perform a major part on commercial applications (YOON; LEE, 2011). Other important applications of nanofibres are on biomedical structural elements such as wound dressing (DASTJERDI; MONTAZER, 2010; DASTJERDI; MONTAZER; SHAHSAVAN, 2009, 2010), tissue engineering (HUANG et al., 2003)(NEZARATI; EIFERT; COSGRIFF-HERNANDEZ, 2013), drug delivery (FRENOT; CHRONAKIS, 2003; HUANG et al., 2003), artificial organs (COYLE et al., 2007; FRENOT; CHRONAKIS, 2003) and vascular grafts (FRENOT; CHRONAKIS, 2003). Other functionalities also range from protective shields in speciality fabrics (FRENOT; CHRONAKIS, 2003); filtration (AUSSAWASATHIEN; TEERAWATTANANON; VONGACHARIYA, 2008; GRAFE; GRAHAM, 2003; HUANG et al., 2003); membranes (AUSSAWASATHIEN; TEERAWATTANANON; VONGACHARIYA, 2008), sound absorption materials (LYONS, 2004); functional wallpapers (KIM et al., 2011); nanocatalysis (FORMO et al., 2008) and cosmetics (HUANG et al., 2003).

Clothing

The default form of nanofibres is nonwoven. These fibres can result from the conventional process of electrospinning. This format is useful when applied for filtration, some tissue engineering and wound dressing. However, when addressing tradition fibre and textile industry, the nonwoven will not meet the specifications. Nonwoven materials, like the name says, in not woven or knitted, present low physical characteristics. Only when aligned fibre bundles, or continuous single nanofibres are produced, that nanofibres can be applied and utilized as traditional textiles. Another possibility is to explore this non woven as a laminate coating for regular textiles, which will highly increase physical properties of the layer base.

Most part of nanofibres and nanotechnology in to garments are currently used for protective clothing which major utilization in military. It is expected from the garment "to help maximise survivability, sustainability and combat effectiveness" (HUANG et al., 2003) of the wearer "against extreme conditions like weather, ballistics and nuclear, biological and chemical warfare" (HUANG et al., 2003). Protective clothing and breathing apparatus can be utilized as protection against chemical agents utilized in war, such as sarin, soman, tabun and mustard gas. Usual protective clothing has high weight due to the utilization of charcoal absorbents. It is also very limited in terms of water permeability. So it is desirable a material that can be water proof, breathable, lightweight insoluble to all solvents and reactive with nerve gases and other threatening chemical agents (HUANG et al., 2003). Electrospun nanofibres are a good answer to those requirements, since it presents a great surface area, therefore being capable of neutralizing chemical agents and aerosol with no harm to the air and water vapour permeability becoming the ideal material for protective clothing (SCHREUDER-GIBSON et al., 2002).

As well as protective clothing, outdoor clothing also needs to control the body temperature, to save the wearer from unpleasant conditions (KIM et al., 2011) Electrospun nanofibres can be applied to outdoor clothing by lamination process. This would contour the drawbacks caused by its low physical proprieties. Waterproof breathable fabrics are used for protecting the body from harmful agents, rain, and wind while allowing the skin to breathe through it. It has a vast range of utilizations from outdoor clothing to specialized military and medical use. These types of materials are in high demand, which drives resources to this research area for the purpose of enhance the waterproofness and breathability of the already available fabrics on the market. Electrospun nanofibres present those qualities. It provides extremely thin fibres that look like an ultrathin membrane-like web (YOON; LEE, 2011). It has very small pores which allows body vapour to go through it, but not big enough that a water molecule can cross it.

Those proprieties make this material attractive for many different uses, other than outdoor and protective clothing. This all can be explained by those fibres "combination of high specific surface area, flexibility, light weight and porous structures with the desired level of openness" (YOON; LEE, 2011)Those characteristics make this material ideal for high performance apparel. Kang et al. (2007) researched the feasibility of polyurethane being electrospun directly on fabric for outdoor clothing utilization. Sumin et al. (2010) tested laundering effects on mechanical proprieties, thermal and water transfer proprieties. Both studies concluded that nanofibres are suitable to be laminated on other fabrics and even after repeated laundering the tested proprieties remain intact.

Schreuder-Gibson and Gibson tested the nonwoven electrospun nanofibres mats with their correspondent meltblown nonwoven and concluded that the electrospun mats have pores 4-100 times smaller than the meltblown mat. Because of this difference electrospun mats shown 156 more resistance to air flow. On the other hand, the breathability (moisture vapour diffusion) of the two of them was the same. Another remark of this research was showing that because of the crosslinkage of the fibres in an electrospun nonwoven the liquid transport through the membrane is drastically diminished. This can explain why electrospun nanofibrous mats are declared to be water proof, wind blocking and yet highly breathable (AHN; PARK; CHUNG, 2009).

Conclusions

In the future nanotechnology-based energy sources can be the answer for cooling. Developing highly dense fabric batteries coupled with phase-changing materials could be the solution for cooling down the wearers' body or electronic components in the textile. Nanostructures like photonic crystals that present colour-turning proprieties could be utilized for garments, not only to enhance aesthetically, but also for sensing applications (TSANGARIDES et al., 2014). In the same note, nanotextiles can be functionalized with sensitive materials and analytic dyes in order to serve as diagnosis tool (DAVIES, 2017).

The demand for smart clothing with improved appearance, comfort, functionality and connectivity has been pushing forward nanotechnology-based textiles. Many different nanomaterials can be layered, woven, deposited on the fabrics or constructed as nanotextiles. Already established technologies in textiles include UV protection, antibacterial, water repellence among others. Sensors, health monitoring devices, drug release and textile based batteries are transitioning from rigid integrate and flexible wearable devices. From a designer´s perspective Nanotechnology is how a stagnated technology of textiles can give a leap and definitely catch up with current trends for technology integration in our day to day lives.

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