SMART TEXTILES BASED ON CONDUCTIVE WOVEN STRUCTURES

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We live in a knowledge-based society, which is facing an increasing impact of science and technology on all aspects of life through products, services and consumer needs. The field of functional textiles is an interdisciplinary field that incorporates science, technology and design, and its future lies in the potential to combine different technologies. Functional textiles will serve to improve the quality of life by increasing the well-being of society and could lead to significant savings for health and budget. The uniqueness and challenge of technical textiles lies in the need to understand and apply the principles of textiles science and engineering to provide the right solutions for the growing and varied demands of their applications in areas such as protective clothing, automotive textiles, geotextiles, agricultural textiles, medical textiles, textiles used for construction, specialized textiles for defense and military applications, etc. Woven fabrics of copper and stainless steel wires, because of their structural order and ability to bend and conform to the most desirable forms, offers a great opportunity to develop a new generation of multifunctional and interactive textiles. The term "Smart Textiles" refers to a wide range of studies and products that extend the functionality and usefulness of common fabrics.

Keywords: smart textiles, functionality, conductivity

INTRODUCTION

Smart textiles are defined as textiles such as fibers and filaments, yarns along with woven, knitted or nonwoven structures that can interact with the environment / user.

The convergence of textiles and electronics (e-textiles) may be relevant to the development of smart materials that are able to perform a wide range of functions, encountered in rigid and inflexible electronic products today (Perumalraj *et al*., 2010).

Active functionality could include power generation or storage, human interface elements, radio frequency (RF) functionality, or assistive technology. All electronic devices require energy, and this is a significant design challenge for smart textiles. Energy generation can be achieved by piezoelectric elements that collect energy from motion or photovoltaic elements. Human interfaces to active systems can be grouped into approximately two categories: input devices and announcement or display devices. Input devices may include capacitive portions that function as buttons or fabrics that are sensitive to shape, which can record movement or bending, pressure, and stretching or compression. Advertising and display devices may include material speakers, electroluminescent wires, or wires that are processed to contain organic light emitting diode (OLED) networks. Fabrics can also include elements that provide bio-feedback or simply vibrate. Fabric-based antennas are a relatively simple application of smart textiles. Simple fabric antennas are only conductive yarns of specific lengths that can be sewn or woven into non-conductive fabrics (Stoppa and Chiolerio, 2014).

Smart textiles will serve as a means of increasing social welfare and could lead to significant savings in the welfare budget. They integrate a high level of intelligence and can be divided into three subgroups:

- Passive smart textiles: only able to feel the environment / user, based on sensors;
- Smart active textiles: detection reactive to environmental stimuli, integrating an actuating function and a detection device;

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- Very intelligent textiles: able to feel, react and adapt their behavior to the given circumstances (Stoppa and Chiolerio, 2014).

Smart textiles are a challenge in many areas, such as the medical, sports and arts, military and aerospace communities.

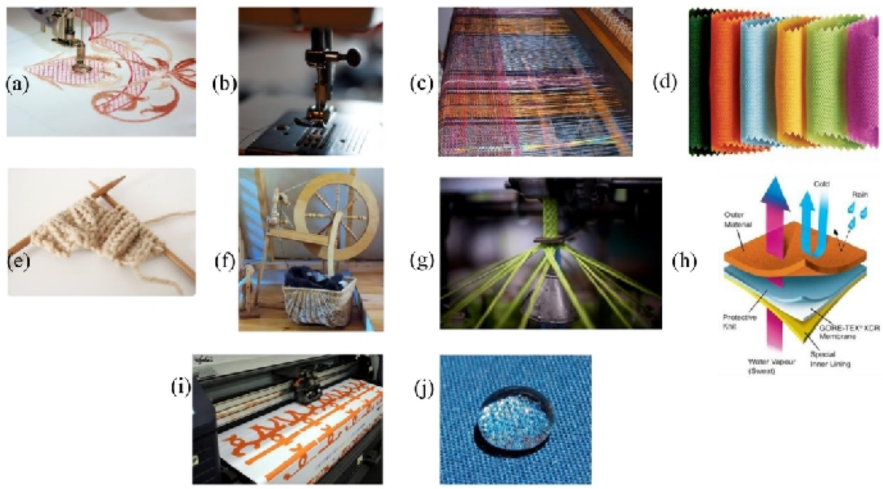

Figure 1. Different types of manufacture and treatment of textiles / fabrics. (a) embroidery; (b) sewing; (c) tissue; (d) nonwovens; (e) knitting; (f) spinning; (g) bread; (h) coating / rolling; (i) printing and (j) chemical treatment (Stoppa and Chiolerio, 2014)

Countless combinations of these source materials result in a whole range of textiles, but sometimes commercial production is represented by garments containing conventional conductors, miniaturized electronic components and special connectors.

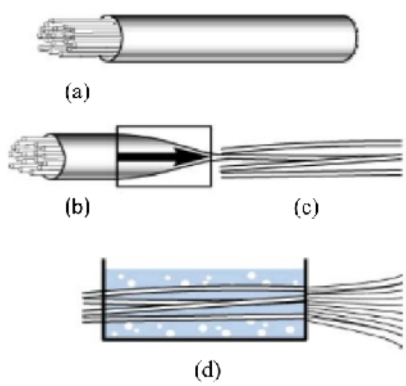

Figure. 2. (a) Metal coated wire combined in an iron tube; (b) Several reductions in tube diameter; (c) Pipe fitting; (d) Leaching, fiber making (Stoppa and Chiolerio, 2014)

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The firing die, used to pull the fiber, consists of a steel frame with a ceramic, carbide or diamond core. The initial diameter of the wire varies depending on the material. For copper, for example, it is usually 8 mm, while for iron it is 5 mm. After drawing, the wire is annealed at temperatures between 600 and 900°C. Subsequently, they are extinguished. The fine metal wire is then wound on a rotating wire drawing cylinder (Stoppa and Chiolerio, 2014).

Table 1. Electrical properties of metal monofilament fibers

Element	Electrical properties				
	Conductivity [S·m/mm^2]	Resistivity [Ω·mm^2/m]	Heat resistance coefficient [10^{-6} K^{-1}]		
			Min	Typ	Max
Cu	58.5	0.0171	3900	3930	4000
Cu/Ag	58.5	0.0171	3900	4100	4300
Ag 99%	62.5	0.0160	3800	3950	4100
Ms * 70	16.0	0.0625	1400	1500	1600
Ms/Ag	16.0	0.0625	1400	1500	1600
AgCu	57.5	0.0174	3800	3950	4100
Bronze	7.5	0.1333	600	650	700
Steel 304	1.4	0.7300	-	1020	-
Steel 316L	1.3	0.7500	-	1020	-

CONDUCTIVITY OF TEXTILES

There is a growing interest in conductive textiles in the scientific and industrial community. Textile structures that have conductivity or serve an electronic or computational function are called electrotextiles (Šafářová and Grégr, 2010).

Due to the attributes of textiles (softness and flexibility), electrical properties are increasingly required in technical applications to perform functions such as heating, shielding from electromagnetic interference, transporting electrical data or signal detection. With the growing interest in smart textiles, the demand for highly conductive textiles has also increased.

In general, textile structures are electrically inactive and can be transformed into electrically active materials by various methods (Aileni *et al*., 2017).

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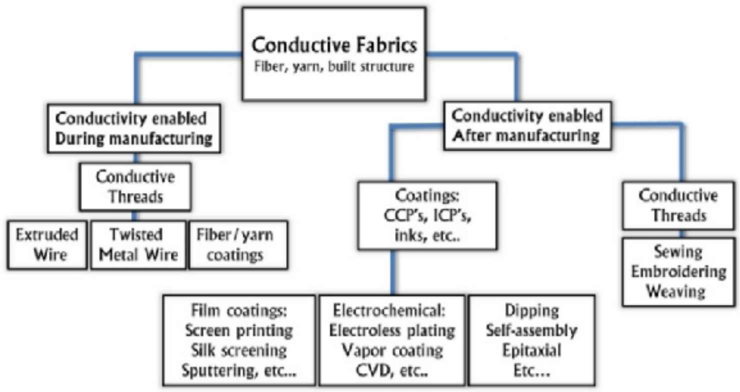

Figure 3. Techniques for introducing electrical conductivity into textiles (Castano and Flatau, 2014)

Thus, conductivity can be introduced at different levels in a textile material (Kirstein, 2013):

- at the level of fibers, yarns or fabrics;
- during production;
- or applied as post-treatments.

The electrical conductivity of flat textiles results from the electrical conductivity of their components, fibers and yarns. It is obvious that the electrical conductivity depends on the structure of the textile material (Tokarska, 2019).

Production of a network of conductive yarns in a textile structure can be obtained through textile manufacturing techniques (weaving, knitting) and fabric manufacturing techniques (sewing, embroidery). Fabrics are used as electrically conductive anisotropic substrates with conductive yarns in the direction of the weft or warp or as electrically conductive isotropic substrates with woven conductors in the direction of the warp and weft (Aileni *et al*., 2017).

The choice of conductive yarns for a smart textile application is the basis of some essential requirements that must be taken into account for the development of the application (Raji *et al*., 2017):

- necessary conductivity level,
- durability of the conductive component,
- yarn content,
- method used in manufacturing,
- degree of fit for the wearer and comfort.

There are several methods for making electric wires:

- the easiest way is to incorporate filaments / metal fibers into yarns;
- another approach is the production of all-metal wires, such as stainless steel wires;
- the use of wet spinning or spinning processes with intrinsically conductive polymers or conventional polymers with conductive additives such as carbon nanotubes or carbon black particles;

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- electrospinning is another useful process for obtaining electroconductive fibers / wires, either by using conductive polymers or by using electroconductive additives homogeneously dispersed in polymer matrices, thus obtaining micro- and nano-composite materials with good mechanical and electrical properties;
- coating non-conductive yarns/ fibers with electro-conductive materials such as metallic powder, carbon black, carbon nanotubes (CNT) or intrinsically conductive polymers (Latifi *et al.*, 2010).

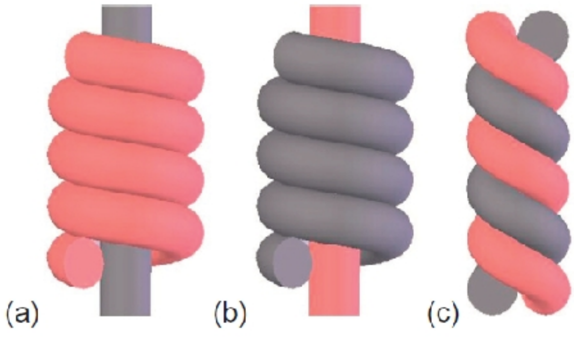

Figure 4. Three typical structures for polymer-metal hybrid yarns: (a) metal-core yarns, (b) metal-threaded polymeric yarn cores, and (c) polymer-metal braided yarns. (Polymeric fibers are displayed in red, while metallic fibers are displayed in gray) (Dias, 2015)

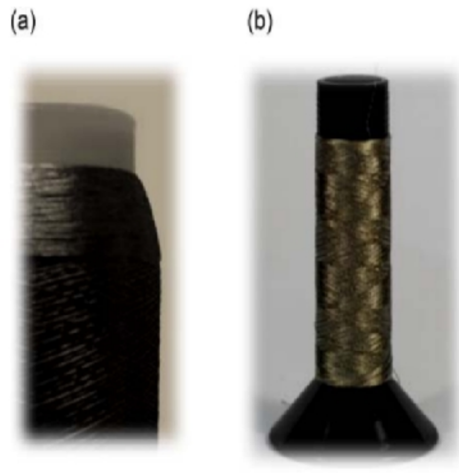

Figure 5. Electrically conductive wires of: a) stainless steel (Bekaert); b) silver coated nylon (Statex) (Koncar, 2019)

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CONCLUSIONS

Fabric testing plays a crucial role in evaluating product quality, ensuring compliance with regulations, and evaluating the performance of textiles.

The critical factors that control the properties of the fabric are the properties of the yarns, the thickness of the fabrics and their design. The handling of these elements and the way they interact produce fabrics with different physical and mechanical properties.

For the realization of advanced textile materials, the research methodology includes innovative techniques for functionalizing the materials by:

- High-tech yarn processing, with functionalizations at nano and micro level through classic, flexible, ecological technologies;
- Incorporation of passive and / or active interactive elements in textile structures;
- Eco-technologies such as electrospinning or 3D printing;
- Closing the value chain through eco-innovative waste processing technologies.

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