
**Textiles and textile products — Smart
(Intelligent) textiles — Definitions,
categorisation, applications and
standardization needs**

*Textiles et produits textiles — Textiles intelligents — Définitions,
catégorisation, applications et besoins de normalisation*

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

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Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Terms like “smart textile” and “intelligent textile” mean different things to different people. However, there is a common agreement that these are textiles or textile products that possess additional intrinsic and functional properties not normally associated with traditional textiles.

Although adjectives such as “smart” or “intelligent” are mainly intended for marketing purposes, more technically correct definitions will not prevent the use of this terminology by textile manufacturers or by the general public. Nor will the unintended inclusion of “non-smart” products make products any less safe or fit for purpose.

The standardization of smart textiles or smart textile products or systems is not straightforward because it involves an overlap between the standardization of the “traditional” textile product, e.g. a fire fighter's jacket, and the standardization of the additional intrinsic functional properties of the “smart product”. This overlap can manifest itself in a number of areas, possibly including:

- Expertise: the knowledge and experience of standardization for the textile properties and for the additional properties (temperature sensing, variable thermal insulation properties) can come from different unrelated standardization groups. To take the above example, there should be input from standardization groups working in the areas of textiles, medical devices and electric or electronic devices.
- Testing: there is a need to test the additional functional properties to specific textile test standards and vice versa. Again, with the same example, the electronic elements should be assessed for their resistance to cleaning and the textile elements need to be tested for electrical safety.
- Unexpected and/or unintended synergies: these might result from the combination of technologies in smart textiles and need be recognized and addressed by standardization, wherever possible. For example, the presence of conductive fibres to incorporate a personal stereo into a smart raincoat might increase the risk of the wearer suffering a lightning-strike in a thunderstorm. This is despite the fact that neither rainwear nor personal stereos, when separate, need to be assessed against this risk.
- Legislation: Certain textile product groups, e.g. protective clothing, geotextiles or textile floor coverings, are in addition subject to specific national and/ or regional legislation. It can be necessary to simultaneously address the requirements of legislation covering more than one product category. For example, a “classic” fire fighter's suit needs comply with the requirements for personal protective equipment, whereas a “smart” fire fighter's suit with built-in electronic and ICT features should also comply with the applicable provisions for electronic equipment and ICT. Conformity assessment will therefore need to follow the conformity assessment schemes for all applicable legal provisions.

The purpose of this document is to identify the considerations that need to be addressed when writing standards for smart textiles or applying existing standards to them. This information can be of use to:

- end-users, in determining whether a product has indeed been fully assessed;
- conformity assessment bodies, as a guide towards assessing products according to the appropriate standards;
- specification writers, as a guide to writing new specific standards for smart textiles;
- manufacturers of smart textiles, to advise them on appropriate product testing and on suitable ways to substantiate product claims;
- market surveillance authorities, to help in the assessment of product claims, product safety and fitness for purpose.

The factual information in this document is available elsewhere in a more comprehensive form and each individual item will inevitably be common knowledge to at least one group of readers. The aim of this document is to guide readers through those areas, with which they are not familiar, and to direct them

towards further, more specialized reading. In accordance with ISO rules, this document is intended to be reviewed regularly to keep it in line with technical and market evolutions.

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Textiles and textile products — Smart (Intelligent) textiles— Definitions, categorisation, applications and standardization needs

1 Scope

This document provides definitions in the field of “smart” textiles and textile products as well as a categorization of different types of smart textiles. It describes briefly the current stage of development of these products and their application potential and gives indications on preferential standardization needs.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1

textile fibre

unit of matter characterised by its flexibility, fineness and high ratio of length to maximum transverse dimension, which render it suitable for textile applications

[SOURCE: Regulation EU 1007/2011, Article 3, 1. (b), (i)]

3.2

textile product

product made of *textile fibres* (3.1), yarns and/ or fabrics and intended to be used, as such or in conjunction with other textile or non-textile elements

3.3

functional textile product

textile product to which a specific function is added by means of material, composition, construction and/or finishing (applying additives, etc.)

3.4

smart textile product

intelligent textile product

interactive textile product

functional textile product (3.3) which interacts reversibly with its environment, or responds or adapts to changes in the environment

Note 1 to entry: The term “smart textile” can refer to either a “smart textile product” or a “smart textile system”. Only the context, in which the term is used, determines which one of the two is intended.

3.5 environment surroundings

circumstances, objects, or conditions, which surround a textile material or textile product or the user of that material or product

3.6 non-textile element

product which is not composed of *textile fibres* (3.1)

Note 1 to entry: Non-textile element(s) can include elements used for garment construction, for example slide fastener(s), press stud(s), button(s), membranes, non-textile patches, prints, coatings, finishes.

Note 2 to entry: Non-textile element(s) can also include elements with functionalities listed in 4.1 and 4.2.

3.7 textile system

assemblage of textile product(s) and non-textile element(s)

3.8 smart textile system

textile-based system which exhibits an intended and exploitable response as a reaction either to changes in its surroundings/environment or to an external signal/input

4 Functional and smart textile products

4.1 Functional textile products

4.1.1 General

Functional textile products can be components of smart textile systems and hence functional textile products, which are relevant for these smart textile systems, are discussed here. This is illustrated by the following examples.

EXAMPLE 1 A textile resistance heater

- Functional textile product: a conductive material forming the basis of a resistance heater in a textile system.
- Smart textile system: a textile resistance heater as (part of) a textile system, connected to an electrical power supply which can only be switched on and off manually or a resistance heater as part of a textile system, connected to an electrical power supply with a regulated power output and equipped with a temperature sensor as to maintain a constant temperature around the heater.

EXAMPLE 2 Optical fibres

- Functional textile product: optical fibres used as part of a textile system
- Smart textile system: optical fibres as (part of) a textile system, connected to a light source which can only be switched on and off manually or optical fibres as part of a textile system, connected to a light source with a regulated power output and equipped with a sensor to adjust the illumination level to the amount of light present due to other light sources in the surroundings of the textile system.

4.1.2 Electrically conductive textile products

Electrically conductive textile product conducts an electrical current or supply an electric field to a device. Electrical conduction is the movement of electrically charged particles through an electrical

conductor, called an electric current. The charge transport can result as a response to an electric field or as a result of a concentration gradient in carrier density, i.e. by diffusion.

NOTE A material is considered to have a "good electrical conductivity" if it has a specific conductivity (resistivity) of $> 10^2 \text{ S/m}$ ($< 10^4 \text{ } \Omega \cdot \text{cm}$). A material is considered to have "ohmic behaviour" if its resistance follows Ohms law, a fundamental law of electricity, stating that the voltage at the terminals of an ideal resistor is proportional to the current in the resistor¹⁾. The materials with the highest specific conductivity are metals. Some polymers and ceramics can also show ohmic behaviour, e.g. intrinsically conductive polymers (e.g. doped polyaniline) or indium tin oxide (ITO).

4.1.3 Thermally conductive textile products

Thermally conductive textile products conduct heat. The transfer of thermal energy in a substance is due to a temperature gradient, i.e. from a region of higher temperature to a region of lower temperature, acting to equalize temperature differences.

Metals have thermal conductivities above approximately $20 \text{ W/(m}\cdot\text{K)}$ and are considered to be very good thermal conductors. Their thermal conductivity increases with their electrical conductivity. There are also non-metallic elements and compounds that are (very) good thermal conductors (e.g. carbon and boron nitride).

Applications in smart textile systems can be as a heat sink, e.g. for cooling electronic components.

4.1.4 Thermally radiative (emissive) textile products

Thermally radiative (emissive) textile products radiate heat, i.e. they emit electromagnetic radiation in the infrared range of 750 nm to $100 \text{ } \mu\text{m}$ from their surface due to their temperature.

Thermal radiation (emission) can be utilized in the form of a resistance heater, where the resistance of a conductor is used to heat the conductor to a sufficiently high temperature to generate heat radiation or as a heat exchanger, e.g. a pipe with hot air or hot water flowing through it.

Applications in smart textile products are as thermal heaters, as described in [4.1.1](#).

4.1.5 Optically conductive textile products

Optically conductive textile products transport (visible) light, i.e. electromagnetic radiation in the range of 400 nm to 750 nm .

Optical fibres from glass or plastic keep the light in their core by total internal reflection, i.e. the fibre acts as a waveguide. Optical fibres are widely used in fibre-optic communications, which permits transmission over longer distances and at higher bandwidths (data rates) than other forms of communications. Fibres are used instead of metal wires because signals travel along them with less loss, and they are also immune to electromagnetic interference.

Fibres are also used for illumination, and are wrapped in bundles so they can be used to carry images, thus allowing viewing in tight spaces. Specially designed fibres are used for a variety of other applications, including sensors and fibre lasers.

4.1.6 Fluorescent textile products

Fluorescence is the molecular absorption of a photon, followed almost instantaneously by the emission of a less energetic photon. As the emitted photon is of lower energy than the absorbed photon, the emitted light will be of longer wavelength than the absorbed light, which allows, for example, to turn UV radiation into visible light.

1) www.electropedia.org IEC ref 131-15-08.

Fluorescence is used in high visibility clothing for safety purposes. Fluorescent textile products are available in a variety of colours from red to blue-violet. A variety of organic and inorganic materials show fluorescence.

4.1.7 Phosphorescent textile products

Phosphorescence is the molecular absorption of a photon, resulting in the formation of an excited state, followed by the emission of a less energetic photon. Since the emitted photon is of lower energy than the absorbed photon, the emitted light will be of longer wavelength. The lifetime of the excited state in phosphorescent materials can be very long, in the order of hours. This means that once activated, phosphorescent materials will continue to emit light for hours without any external power supply. This makes them suitable for emergency lighting in the case of power interruptions or for watches, toys, apparel, giving a "glow in the dark" effect.

Examples of phosphorescent materials are doped (mixed) sulphides (ZnS , $(\text{Cd}, \text{Zn})\text{S}$, $(\text{Ca}, \text{Sr})\text{S}$) or doped (mixed) oxides (SrAl_2O_4) but can also be organic molecules.

4.1.8 Textile products releasing substances

These textile products release substances at a molecular level under the influence of an external stimulus. The substances used for this purpose are pharmaceuticals, cosmetics, fragrances, etc. They are bonded to the textile structure by micro-encapsulation or by surface bonding.

NOTE Some of these textiles are referred to as cosmetotextiles (see CEN/TR 15917^[1]).

The micro-encapsulation technique makes use of small capsules, in which the substance to be released is enclosed. When the shell of these capsules is pierced due to an external stimulus, the substance is released. The different stimuli that can cause piercing of the shell include mechanical force, heat, pH and contact with water.

The surface bonding technique makes use of substances (loosely) bonded to the surface of the textile material and released during the use of this material. The nature of the bonding and the surroundings of the material determines the release rate.

4.2 Smart (intelligent) textile products

4.2.1 General

In this subclause, examples (non-exhaustive) for different smart (intelligent) textile products are described. The described textile products (see 4.2.2 to 4.2.14) can be used on their own or in combination with other (non)smart textile products or used in textile systems. The latter are described in [Clause 5](#).

NOTE Some of the smart functionalities can also be achieved by non-textile elements. Therefore, we will be referring to textile products to clearly make the distinction.

[Table 1](#) provides an overview of the most common stimulus-response pairs and the corresponding effect materials or structures can exhibit.

Table 1 — Overview of most common stimulus-response effects (adapted from the final report of the FP6 project Clevertex^[2])

Stimulus	Response				
	Optical	Mechanical	Chemical	Electrical	Thermal
Optical	Photochromism			Photovoltaic/ photoelectric effect	
Mechanical	Piezochromic	Dilatant, thixotropic, auxetic, controlled release	Controlled release	Piezo- electricity	Friction
Chemical	Chemiluminescence, Solvatochromism, Halochromisms	Shape memory, super-absorbing polymers, sol/hydrogel, controlled release	Controlled release	Chemical gradient causing charge separation – Galvanic cell	Exo/endotherm reactions
Electrical	Electrochromism, Electroluminescence, Electro-optic	Inverse piezo- electricity, electrostriction, electro-osmosis, shape memory	Electrolysis		Joule/coulombic heating Peltier effect
Thermal	Thermochromism, Thermo-opacity	Shape memory, controlled release	Controlled release	Seebeck effect, Pyroelectric	Phase change
Magnetic		Shape memory Magnetorestriction			

4.2.2 Chromic textile products

Chromic material is the general term referring to materials whose absorption, transmission and/or reflection of light changes due to an external stimulus. The result is a different colour impression.

Chromic materials can be classified depending on the external induction stimulus, e.g. light (photochromic), heat (thermochromic), pressure (piezochromic), enzymes (biochromic), electricity (electrochromic). It goes beyond the scope of this report to list all possible chromic effects or to discuss them in detail.

One commercial application of a thermochromic textile product is baby clothing which shows a change in colour when the baby has developed a fever. Other applications envisioned for safety clothing are the use of chromic textile products for indicating exposure to chemicals or radiation.

4.2.3 Phase change textile products

A phase change material (PCM) is a substance which is capable of storing and releasing large amounts of energy in the form of latent heat, at a specified temperature range (range of phase transformation) during which the material changes phase or state (from solid to liquid or from liquid to solid). This energy (heat) is absorbed or released when the material changes from solid to liquid (or the other way around), thus buffering any external temperature change by evoking a phase transition in the material.

Classic PCMs are water, hydrated salt complexes and saturated hydrocarbons (where the length of the chain determines the melting point). Depending on the nature of the phase change, e.g. when formation of a liquid phase is involved, micro-encapsulation can be required. The choice of material or composite depends on the temperature to be buffered.

The most common method today to produce phase change textile products is by coating or impregnating fibres or fabrics with a polymeric binder containing micro-encapsulated PCMs. Alternatively, micro-

encapsulated PCMs can be incorporated into fibres during the fibre spinning or filling of hollow fibres. They can also be laminated as a PCM containing polymeric film onto a textile structure.

Space suits and gloves were the first application of phase change materials (PCM), but nowadays PCMs are also used for consumer products to improve the thermal comfort of active-wear garments and clothing textiles. During a sports activity, the thermal stress is mainly due to the disequilibrium between the heat produced by the human body during an effort, and the heat released into the environment. When PCMs are encapsulated on underwear during the same activity, a larger amount of the human heat will be released to the environment.

4.2.4 Textile products with active ingredients inside the microcapsules

Content of the micro-capsules can react on a stimulus from the environment without being released.

One example is PCM materials (see [4.2.3](#)).

Another example are polyols inside a micro-capsule, which can take up perspiration. There is an endothermal reaction between the polyols and the water, which results in a cooling effect.

NOTE Some of these textiles are referred to as cosmetotextiles (see CEN/TR 15917).

4.2.5 Shape change (shape memory) textile products

These materials change in shape, size or internal structure upon an external stimulus, e.g. temperature, UV light, moisture, magnetic field, pH value. The shape change can have a one-way or a two-way effect.

A one-way material has a preformed structure, which returns in a non-reversible way to its original, not-preformed state after receiving an external stimulus.

A two-way material or composite can be cycled between two different preformed states by receiving opposing external stimuli, e.g. a higher and lower temperature.

Shape memory materials can be:

- polymers with a combination of permanent physical or chemical cross-links, integrated into a mobile matrix, which is able to store mechanical deformation energy until recovery is activated by an external stimulus;
- metal alloys switching between two different crystal structures upon a thermal impulse, e.g. Nitinol, or
- composites of shape-memory-materials and materials providing an elastically restoring force in one unit (e.g. artificial muscles).

Shape memory materials can be implemented in textile systems in the form of yarns, i.e. in the bulk of the textile structure or as a coating on a fabric, e.g. creating a membrane. Applications can be textile systems adjusting their shape, e.g. a garment reducing its length when exposed to heat; or a membrane adjusting its porosity, e.g. to adjust the water vapour transmission rate.

4.2.6 Super-absorbing polymers and gels

Super-absorbing polymers and gels absorb and retain extremely large amounts of liquid relative to their own mass resulting in strong swelling and gel formation. Water absorbing polymers (hydrogels) absorb aqueous solutions through hydrogen bonding with water molecules. The ability to absorb water depends on the presence of ions in the water, being 500 times its weight (30 to 60 times its volume) for distilled or deionised water, but only 50 times its weight for a 0,9 % saline solution.

The total absorbency and swelling capacity are controlled by the type and degree of cross-linking in the polymer. A low-density cross-linked polymer has a higher absorbent capacity and a softer and more cohesive gel is formed. High cross-link density polymers exhibit lower absorption capacity, but the gel strength is firmer, maintaining its shape under low pressure.

Examples of the use of super-absorbing polymers are hygiene products, blockage of water penetration in underground power communication cables, horticultural water retention agents, spill and waste control, artificial snow for motion picture and stage production and filtration.

4.2.7 Auxetic textile products

Auxetic materials or composites harden and laterally expand upon elongation. This phenomenon is caused by the macro-structure or micro-structure of the material and not by its chemical composition. Such materials have a so-called negative Poisson ratio.

Some auxetic textile products contain on a micro-scale both temporary, relatively weak bonds (e.g. hydrogen bonds), which can be broken and restored (slipping from one to the other) under a low shear force and stable bonds which, under a high shear force, counters the full load of the force, resulting in a "stiff" behaviour.

Other auxetic textile products are based on the use of materials with diverging properties, e.g. a textile yarn comprising a thicker, elastic cord entwined with a thinner, stiffer cord. When tensioned, the system changes to the thin, stiff cord being entwined by the thicker, elastic cord and the total diameter increases as compared to the relaxed state.

Auxetic textile products are intended for improved energy absorption and fracture resistance. Examples of auxetic textile applications are blast resistance, window covering, military tents, and hurricane defence. Examples of auxetic foam materials are found in sound and shock absorption, medical engineering, filtration of biological fluids and process engineering.

4.2.8 Dilating and shear-thickening textile products

These materials show an increase in viscosity with increasing shear rate, i.e. they become hard upon impact and remain soft under low force movement.

A dilatant effect occurs when closely packed particles are combined with enough liquid to fill the gaps between them. At low flow velocities, the liquid acts as a lubricant, and the dilatant flows easily. At higher flow velocities, the liquid is unable to fill the gaps created between particles, friction strongly increases, resulting in a sudden increase in viscosity.

Applications in textiles are found in protective clothing against mechanical impact, e.g. body armour, and in traction control. An example is a soft silicone coating on a fabric, which hardens under impact, thus damping the force of the blow.

4.2.9 Piezoelectric textile products

The piezo-electric effect consists of a separation of electrical charges across a material in response to an applied mechanical deformation. This effect can also be inversed, i.e. a mechanical deformation is generated in response to an applied electric field.

Applications of the piezo-electric effect are found in insulating materials having a non-centrosymmetric crystal lattice (e.g. quartz, PZT, PVDF). In order to utilize the charge separation by mechanical deformation or to realize the mechanical deformation by applying an electric field, the piezo-electric material needs to be positioned between two electrodes. For polycrystalline materials to exhibit the piezoelectric or inverse piezoelectric effect, the individual crystallites need to be aligned, which is done by applying a high electric field at elevated temperatures.

Piezoelectric materials can be used to develop textile products for strain or acceleration sensing as well as for energy production utilizing mechanical deformation (e.g. in shoes).

4.2.10 Electroluminescent textile products

This refers to textile products emitting light in response to an electric current passing through them or to a strong electric field being applied to them. In these structures, the electroluminescent

layer are sandwiched between two electrodes, the top one being transparent for transmission of the emitted light.

For the electroluminescent layer most commonly inorganic or organic semiconductors (thin film or powder) are used, together with a dopant (additive) to define the colour, or inorganic materials such as ZnS, doped with Cu, Ag, or Mn.

Electroluminescent textile products can operate at low voltage and low current. They can be used to provide lighted displays on apparel or canvasses for leisure or advertising purposes.

4.2.11 Thermo-electric textile products

These materials generate an electric field when a thermal gradient is applied. The material needs to show a good electrical conductivity but a poor thermal conductivity in the direction of the thermal gradient.

In these structures, the thermo-electric material are sandwiched between textile electrodes and a good heat transfer needs to be ensured at the external surfaces.

Thermo-electric textile products applications are power generation and refrigeration.

4.2.12 Photovoltaic textile products

In photovoltaic (photoelectric) materials, the impact of a photon results in the transition of an electron from the valence band to the conduction band of a semiconductor.

Photovoltaic materials, as used in photovoltaic cells, consist of a top electrode, a p-type semiconductor/n-type semiconductor junction and a bottom electrode. Illumination of a photovoltaic cell results in the generation of charges, i.e. building up of a voltage between the two electrodes. Hence the device can act as a power supply.

Examples of photovoltaic materials are doped Si and dye sensitized oxide semiconductors (TiO_2 , ZnO). Their major application field is in solar cells (absorption of sunlight), as grid independent power supply.

4.2.13 Electrolytic textile products

An electrolyte is a substance containing free ions that behaves as an electrically conductive medium (based on ion conduction). Electrolytes are used as a part of a battery. Placing a metal into an electrolyte results in the deposition of ions on the electrode or dissolution of ions from the electrode into the electrolyte, i.e. the formation of a galvanic half-cell. Two galvanic half cells are combined to form a battery.

Fully textile-based batteries have not been developed yet, but are anticipated as they are much lighter weight and retain textile properties as compared to current battery technology. The latter is usually a major drawback in textile systems requiring an input of electrical energy.

4.2.14 Capacitive textile products

Capacitive textile products have the ability to store electrical charges. A typical capacitor consists of an insulating material placed between two conductive materials (electrodes). When an electrical field is applied to the insulating material, negative and positive charges are separated and stored at the opposite surfaces of the material.

Capacitive textile products can be created by multilayer weaving or embroidering, laminating multilayer structures or printing multi-layers of conductive ink.

5 Smart textile systems

5.1 Categories

5.1.1 General

A smart textile system is basically composed of:

- actuator(s), completed by possible sensor(s);
- information management device.

The information within the smart textile system can be controlled and/or managed by electronic device(s) (such as a processor). Such textile systems are also called “electronic textiles” or “e-textiles”.

NOTE A separate CEN/TR on electronic textiles is under preparation.

A smart textile system can be characterized by two functions: the energy function and the external communication function. External communication can be unidirectional or bidirectional, and implies a possible interaction with human intelligence.

Based on these two functions, depending on whether they are present or not, four different categories can be determined (see [Table 2](#) and [Figure 1](#)).

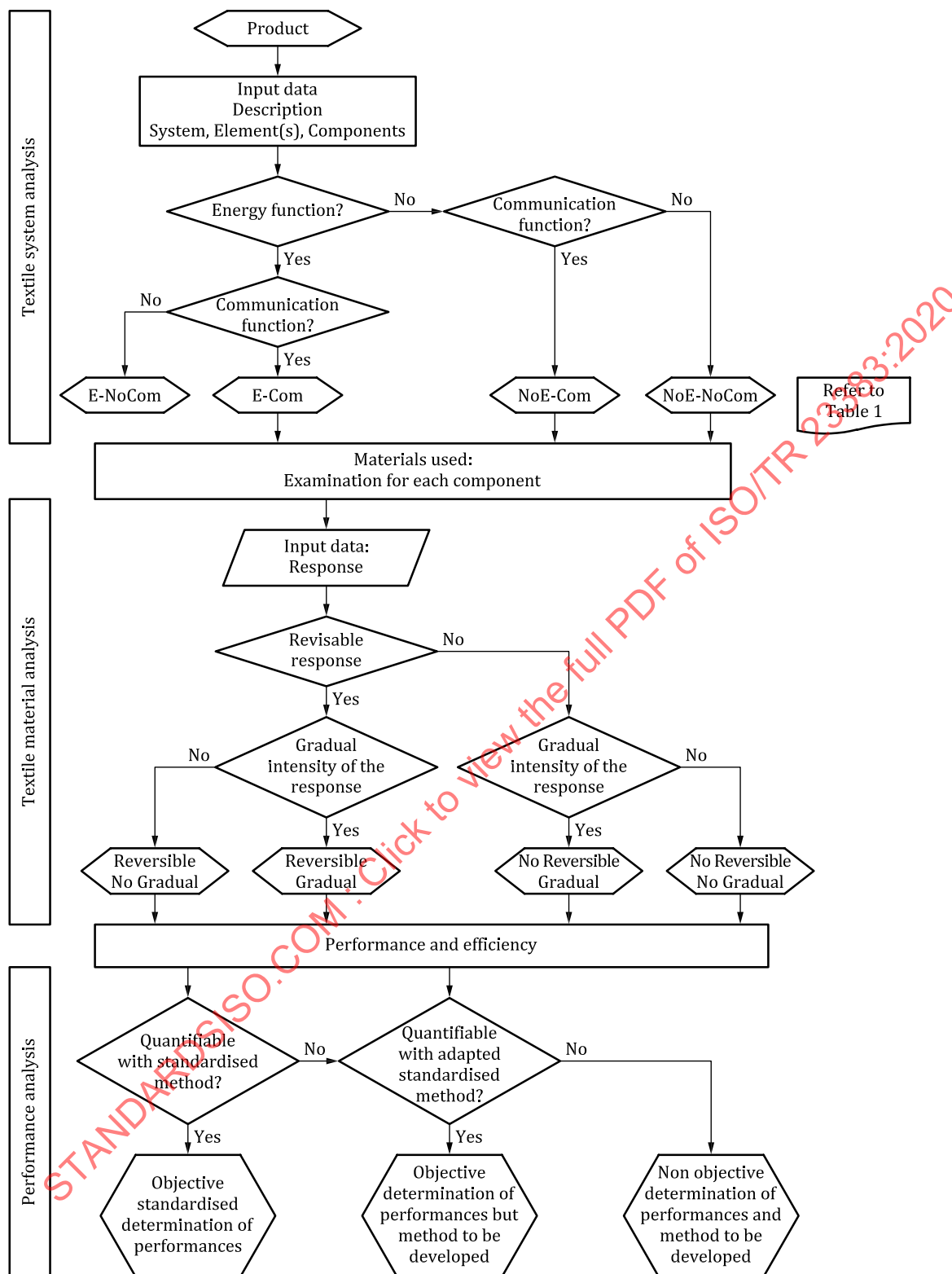


Figure 1 — Flow chart for characterizing a smart textile system, also giving guidelines for later standardization efforts

Table 2 — Categories of smart textile systems

	Without energy function	With energy function
Without communication function	"NoE-NoCom"	"E-NoCom"
With communication function	"NoE-Com"	"E-Com"

Smart textile systems **"with energy function"** are based on the presence of an internal power supply device fed by elements of the system capable of producing and supplying energy to it. Energy sources outside the textile system are usually needed for ensuring the continuity of the energy function.

Smart textile systems **"without energy function"** are not equipped with an internal energy supply device, but can require an external supply of energy, usually in form of the stimulus.

Smart textile systems **"with communication function"** include the presence of mono- or bidirectional means of communication with their environment. The communication can be intended for direct perception by humans, e.g. visual information, sound, odours, etc., or for detection by electronic devices (emission of phonic, electromagnetic, photonic waves) relaying the information towards man.

Smart textile systems **"without communication function"** are characterized by the absence of external communication with their environment/ surroundings. This does not exclude internal communication, e.g. in a self-regulating system.

5.1.2 Systems without energy or communication function (NoE-NoCom)

Examples of this category are:

- Garments equipped with shape memory or phase change material: the thermal energy is externally supplied from the temperature of the environment. A temperature rise or drop will be the stimulus leading to the modification of the material's behaviour.
- A LED Curtain: the energy is supplied by the external electrical power grid. The electric current is the stimulus that leads to the emission of photons (lamp)

In both examples, there is no internal energy supply source or communication with the external environment.

5.1.3 Systems with energy function, but without communication function (E-NoCom)

Examples of this category are:

- A backpack with a battery connected to a photovoltaic device. The battery needs to be replaced when it runs empty, but this replacement is delayed thanks to the photovoltaic device transforming photonic energy (light) into electricity.
- A shoe with a battery connected to an electro-mechanical transducer. The battery needs to be replaced when it runs empty, but this replacement is delayed thanks to the electric energy produced by the electro-mechanical device.

Both examples show systems, which comprise an internal energy source (battery), completed by an external energy source. Neither of them is designed for communication with the external environment.

5.1.4 Systems with communication function but without energy function (noE-Com)

Some (non-exhaustive) examples of this category are:

- Breathing sensor on a hospital patient. The mechanical stimulus (deformation of material) acts on a sensor which transmits an electric signal to the system, leading to the emission of radio waves towards the environment, received by a detector used by a physician.

- A baby pyjama dyed with a thermochromic pigment for indicating a raise in body temperature of the baby (development of a fever). When the temperature of the baby rises above a certain threshold the dye changes colour, giving a visual warning signal to the observer, e.g. a parent.

Both examples do not include an internal energy supply source, although an external source is present. These systems include a means of communication with the external environment.

5.1.5 With energy and communication function (E-Com)

Examples of this category are:

- Sensing and warning system for chemical plant workers. The chemical stimulus (molecule) acts on a sensor, which transmits the chemical information internally to the system. The information is then transmitted towards the outside environment as a change of colour or as a sound, perceived by the human eye or ear.
- Thermal Detector in a fire fighter's jacket. The thermal stimulus (temperature) acts on the thermal sensor which transmits the internal information to the system (electric signal), leading to the emission of a light signal, perceived by the human eye.

Both systems make use of an internal energy supply (battery) and include a means of communication with the external environment.

5.2 Examples of “Smart textile systems” and their functional analysis

5.2.1 Medical application: monitoring of health situation

Medicine is expected to clearly benefit from smart textile technologies. These applications cover a broad and complementary range of explorations (i.e. a diagnosis of heart disease), prevention (i.e. biofeedback) and treatment/healing (i.e. wearable orthoses, drug delivery). Future medical applications can include sensors, that non-invasively measures blood gases (CO, SO₂, CO₂) and vital signs.

Wearable monitoring systems with integrated sensors can be separated into two categories:

- Systems with conventional sensors integrated by textile technologies in a textile-based material
- Systems with textile-based structures used as sensors to measure vital parameters of the human body.

The vital parameters can be separated in electrical, mechanical and other parameters. For monitoring the EMG, ECG, or EEG the electric stimulus acts on the conductive textile by a galvanic skin-contact or by a non-contact capacitive principle, which transmits internal (electric) information to the system leading to the emission of electromagnetic waves (radio waves) towards a detector device used by a physician.

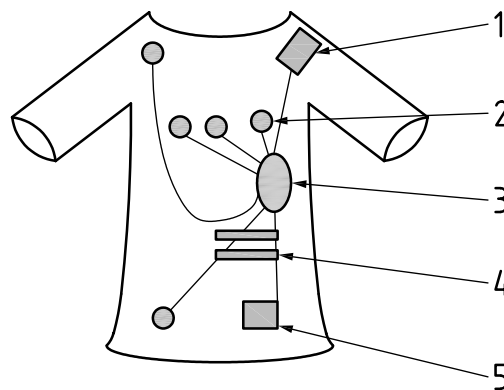
Mechanical signals like breathing rate can be measured by elastic conductive ribbons which change their resistance under strain. The mechanical stimulus (deformation of material) acts on the deformation sensor (elastic conductive ribbon) which transmits internal information (electric) to the system leading to the emission of electromagnetic waves (radio waves) towards the environment, detected by a detector device (used by a physician).

Beside the sensor, the wearable monitoring system contains at least a storage device. Devices for data analysis, data transport and actuator devices for warning or defibrillation functions can complete the monitoring system.

Considering that in this example the system is autonomous, this “Smart textile system” belongs to the “E-Com” category:

- “with energy function” because the concept is based on the presence of an electric battery as power source. The replacement of the battery is necessary when the reserve is depleted.

- “with communication function” because the concept is based on communication with the environment, in the form of emission of an electromagnetic wave suitable for electronic monitoring devices.



Key

- | | | | |
|---|---------------|---|---------------|
| 1 | communication | 4 | actuator |
| 2 | sensors | 5 | energy supply |
| 3 | processors | | |

Figure 2 — Example of a wearable textile system

5.2.2 Occupational safety application: work wear and protective clothing

These systems bring together features such as sensors, connections, transmission systems, power management, etc. The integration of smart textile technologies into work-wear or protective clothing can result in such systems being able to gather, present and transmit information about the wearer and his or her immediate environment.

For example, protective clothing incorporating such textile systems could potentially gather information on:

- wearer position, either globally by GPS or locally by reference to one or more base-stations;
- wearer activity, monitored by accelerometers integrated into various parts of a garment;
- physiological data including the wearer's body temperature, pulse, blood oxygen level and breathing rate (see also 4.2.1, medical monitoring application);
- environmental temperature measured using textile sensors. In the case of fire-fighters' PPE this might include information on the direction of sources of radiant heat relative to the wearer;
- chemical hazards in the environment including monitoring of toxic chemicals and detection of explosive atmospheres;
- electromagnetic hazards in the environment, including monitoring of various forms of electromagnetic radiation;
- the status of the smart system itself. For example, this might include data on the state of charge of an incorporated flexible lithium-ion polymer battery or confirmation that sensors are operating correctly and mutually consistently.

Such information can then either be transmitted to a command/control station, e.g. via a low power consumption “Bluetooth” module integrated with a textile antenna, or be presented to the wearer in the form of audible or visible warning signals or smart textile display devices. The wearer might also interrogate the system via a textile keypad incorporated into the garment. Data can also be stored intermittently.

Considering that this textile system is autonomous with respect to energy, this smart textile system can be categorised “E-Com”:

- with energy function: although some parts of this textile system could be based on sensors not requiring an internal energy input, e.g. chromic sensors, the system as a whole relies on an internal energy supply source.
- with communication function: communication with the wearer and with external observers is an essential feature of the system.

5.2.3 Leisure and fashion application

The emergence of smart textiles leaves its mark on the fashion industry. Adding a dynamic aspect to the ever so static garments is a very challenging issue that attracts many designers. This can include location of the wearer (GPS), listening to music, use of mobile phone and internet, or showing one's mood through changing colours.

An example is an interactive dress with stretchable circuit board technology. The concept of the interactive dress is to translate the pattern of the dynamic body movements into a changing light pattern on the dress. The body movements are detected by an acceleration sensor and processed by a microcontroller, which is used to control the illumination pattern of light emitting diodes (LEDs) that are integrated onto the dress. To show the lightweight character of the system, a very light dress was chosen as a carrier. To create the visual aspect, 32 LEDs are integrated into the dress. To improve the spreading of the light, these LEDs are placed under different layers of transparent and freely draped cotton cambric fabrics. The interconnections between the different components of the system are based on stretchable circuit board (SCB). The base of this technology is an elastic thermoplastic polyurethane substrate material with specially shaped copper conductor lines. The dedicated meander shaped lines allow stretching of the interconnections of up to 300 %.

This “smart textile system” can be categorized as “E-Com”

- “with energy function” because the dress operates autonomously. A small batter, hidden in the belt of the dress, provides energy to the LEDs and the microcontroller require. It allows running the system for about eight hours.
- “with communication function” because the dress establishes a communication function with the environment through the dynamic illuminating pattern. The changing of the lights tells the neighbouring people something about the body movements of the wearer.

5.2.4 Garment based on thermal control by phase change materials (PCM)

The example considered is a garment containing PCM microcapsules. The thermal properties of PCM are linked to their phase change process: During the phase changing processes the temperature of the material remains constant. During melting (heating) the heat is absorbed and stored in the liquid phase. During the solidifying process (cooling) stored energy is again released. Hence, the stimulus is a change in the temperature of the environment (increasing or decreasing). The response is the melting or solidification of the PCM with an absorption or emission of energy (cooling effect or heating effect).

This is a “NoE-NoCom” system:

- without energy function because the concept is based on the absence of an internal energy supply; external energy is required as a stimulus.
- without communication function because the concept doesn't include communication with the environment.

5.2.5 Heated garment, car seats, etc. for comfort or protection

Heating features are present in many applications such as home or automotive textiles. Textile-based heating elements can be found in garments, seats or carpets. Protection of technical installations, e.g.

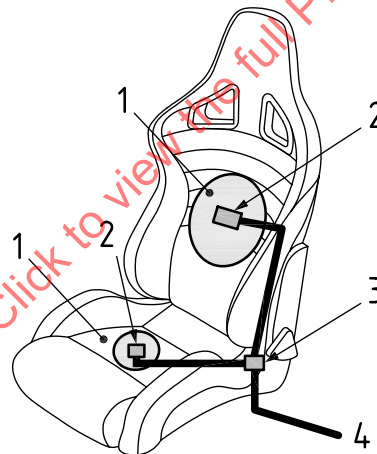
de-icing of water pipes, or improved comfort to a car driver by a heated car seat are only two examples. The combination of conductive fibres and non-conductive fibres can be used to create textile structures with heating capacities.

The combination of these textile heating structures with an electric power supply, a control unit or a temperature sensor creates a smart textile system, which acts as a self-regulating heated unit. The complexity of such systems depends on the application requirements. For example, the system can include several heating zones, which can be individually regulated.

In the case of a heated seat cover with integrated temperature control, the seat cover textile is equipped with two heating elements, one in the seat area and one in the back area of the seat. The power is supplied through a cable connected to the car power network. The power of each heater can be adjusted through an integrated power controller. This controller receives temperature information from two embedded temperature sensors and regulates the temperature of each heating structure individually.

The smart textile system includes sensors, active heating and a power controller to form a self-regulated system, i.e. a “E-NoCom” system. However, the textile in itself is a “noE-noCom” system:

- without energy function because the energy is not provided by the textile itself. The power is supplied by an external power supply through a power cable.
- without communication function because no information is transmitted to or received from the outside. The temperature information is given by the embedded sensors to the embedded controller integrated in the textile.



Key

- | | | | |
|---|------------------|---|------------------|
| 1 | heating elements | 3 | power controller |
| 2 | sensors | 4 | power cable |

Figure 3 — Example of a heated car seat

5.2.6 Irradiation system for medical therapeutics

Treatment and healing applications are of interest due to the desire of patients to have more autonomy when receiving treatment. Smart textile products take advantage of the fact that people wear textiles most of the time and sometimes even 24 h a day. That permits to use a smart textile system for therapies where longer periods of continuous treatment are needed, e.g. skin diseases that need to be treated with light irradiation. Textiles with embedded active light emitting components can be used to perform this task. Such textiles can also be equipped with optical sensor elements to measure the degree of skin healing in order to inform the doctor of the healing status of the skin.

Such a smart textile system for light therapy includes sensors, active light emitting components, a communication unit and an embedded power pack for energy supply to allow for the mobility of the patient. It is an “E-Com” system,

- with energy function because the system includes the power supply in form of an electric battery. Replacement or recharging of the battery is necessary when the reserve is depleted;
- with communication function because collected and processed information from the sensor can be transmitted by a wireless standard to a fixed communication module connected to the web. By this way a link over IP can be established to the medical doctor.

NOTE This smart textile system is a medical device and compliance testing specific to these devices can be necessary.

5.2.7 Geotextiles applications

Smart geotextile systems are used to provide early warning of deformations in soil structures. It consists of a geotextile that incorporates optical glass fibres, linked to special instrumentation equipment and software outside the system. Slight settlements and temperature and strain changes in e.g. embankments and dykes can thus be registered at an early stage. This makes it possible to take any necessary measures and to avoid breaches. The system is built into dyke bodies during the construction of seawalls, roads and railways and the building of retaining walls, tunnels, underground structures and pipelines.

Fibre Bragg gratings (FBG), stimulated Brillouin scattering and Raman scattering are all proven fibre optic technologies that can be built into these systems. These technologies measure strain or temperature changes or both in soil structures. All have in common that an incoming optical signal is changed along the length of the optical fibre, with the changes being determined by the stimulus to be measured at the sensor points in the optical fibre.

This is a “noE-noCom” system

- without energy function since the power input (light source) is external,
- without communication function since the signal processing unit is located outside the smart textile system.

6 Considerations for standardization

6.1 General

Product specifications and test methods for the different textile products and textile systems described in [Clauses 4](#) and [5](#) are very specific since they depend on the intended conditions of use. It is expected that smart textile products and textile systems meet the requirements of similar “non-smart” materials and systems, plus specific requirements linked to their particular properties. Existing specifications and test methods can be used as such or with modifications in some cases, but new specifications and test methods can also be developed (see [Figure 1](#)).

The standardization work related to smart textile products and textile systems will not necessarily be allocated to Technical Committees focusing on textiles and general textile products (ISO TC 38). There are specific technical committees dealing with, for example, textile floor coverings (ISO TC 219), protective clothing (ISO TC 94 SC 13 and SC 14, IEC TC 78), geosynthetics (ISO TC 221) or medical devices (several ISO TCs). These specialized committees address standardization items – both product standards and test standards – related to smart textile products or systems in their specific field of application. The horizontal committee (ISO TC 38) could then address standardization items of a more horizontal nature or in the domain of leisure and fashion clothing, curtains, upholstery fabrics, etc. In many cases, it might not be possible to draft satisfactory standards with textile or clothing expertise only and a multidisciplinary approach will be necessary. This can require cooperation with other

technical committees or even with other standardization bodies, such as IEC or ITU (for electrotechnical and telecommunication, respectively), one example being IEC TC 124.

NOTE Large groups of textiles products are subject to regulations.

Product standards for smart textile products or systems need to consider the following aspects:

- a verification of the claimed performances both as a textile product and as a smart textile products or system;
- the innocuousness of the product in its interaction with the human body and/or with the environment of the product;
- the durability of product properties, in particular with relation to repeated cleansing;
- product information needed for safe use and maintenance of the product;
- environmental aspects

6.2 Verification of claimed performances

It is important that manufacturers of smart textile products or systems are able to substantiate the claims they make for their products. Since claims and the techniques to prove them are constantly evolving, it is not possible to provide compulsory or binding methodologies. State-of-the art techniques, codes of good practice and/or generally accepted and available methods need to be taken into account.

The performance claimed for a smart textile products or system concerns the performance of the product as such and the performance of the features that make the product “smart” or “intelligent”.

For example, a fire fighter's jacket needs to comply in Europe with the harmonized European Standard EN 469. In the case of a “smart” fire fighter's jacket, in addition to complying with EN 469, the performance of the “smart” features, e.g. body temperature or heart rate monitoring, chemical sensing, wearer location, etc. needs to be assessed, under conditions representative for the intended use and using methods that are relevant, repeatable, reproducible and available on the market.

6.3 Innocuousness

It is important that the following principles are respected:

- Smart textile products and systems are be designed and manufactured in a way as to preclude risks and other nuisance factors under foreseeable conditions of use.

NOTE The provisions of the relevant European and national regulations and their supporting standards also apply.

- The constituent materials and parts of smart textile systems, including their decomposition products, do not adversely affect user hygiene or health. Textile products do not contain or release substances known as irritating, allergenic or otherwise hazardous to health. The surface of any part of the system in contact or in potential contact with the user is free of roughness, sharp edges, etc. which could cause excessive irritation or injuries.
- Any impediment caused to movements, postures or sensory perception is minimized and does not endanger the user or other persons.
- Constituent materials and system parts do not create additional risks for the user, other persons or goods, e.g. they do not constitute increased fire risks or a risk of electroshock or explosion in their interaction with the environment.