Chapter 1
Textile Development and Its Influence on Designers

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1.1 Introduction

The need for clothing is influenced by the population of consumers and influenced by the availability of technical textiles and composite structures. The manufacturing footprint of the textile industry is huge due to the increasing demand for consumption. Also, there is a distinct move from mass production to niche products with distinctive properties (e.g., light-emitting textiles, textiles with electromagnetic shielding capabilities, chameleonic textiles). The industry's future depends on its ability to integrate the fields of chemistry, physics, and engineering into the construction of new textile structures. These new inventions should be able to adapt to changes in environmental conditions and specific technical textiles with customizable properties (Militký et al., 2021).

1.2 Trends in Textiles

The specificity of the textile field is that practically the same materials, structures, and technologies are used for diametrically different applications. The textile materials and construction innovations are practically used to construct new textile products with enhanced comfort and functionality. Very popular for new textile products changing their application for future is the concept of smartness. The term "smart" is used for differentiating new materials and structures from traditional materials and structures (Srinivasan & Farland, 2001). Hence, the "smart" textiles are expected to have special properties rather than being logical. Structures that can evaluate the

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state of the environment and respond appropriately are classified as smart. Smart structures are often used for clothing and technical textiles. They can also be used in different branches such as the automotive industry, civil engineering, and architecture. One example is the utilization of smart energy-harvesting textile cladding. These structures respond to the sun's angle and twist to open views or create privacy (Ritter, 2013). Special inflatable, contractible/expandable three layers membrane can be the base for the creation of hangars (see Fig. 1.1). For light effects caused by the sun, it is possible to use translucent PTFE-coated fiberglass fabric (see Fig. 1.2).

Both applications demonstrate the organic joining of smart structures and new design dimensions. One category of so-called passive smart textiles are textile structures that are sensitive to external stimuli (various types of radiation, pH, mechanical magnetic or electric field) and, depending on changes in these stimuli, react reversibly (usually by changing porosity, color (Ramlow et al., 2021), shape, etc.). These stimuli-sensitive materials are generally composed of gel materials that can be resized or altered in shape depending on the stimulus. As a cohesive mass, the gel is made up of liquid particles that are either dispersed or arranged over the entire surface of the gel. In some cases, the gel can be sufficiently elastic and jelly like to conform to the body (gelatin) or firm and rigid (silica gel). Gels comprise swollen polymer networks that have been crosslinked with a suitable liquid. They have the ability to reversibly swell and precipitate (up to 1000 times

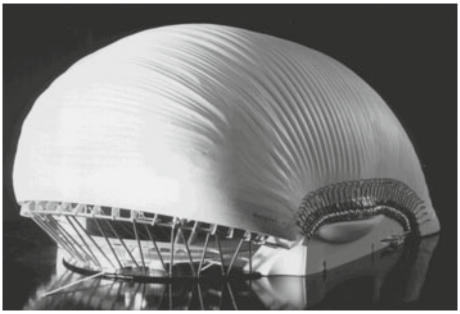


Fig. 1.1 Airship hangar (Ritter, 2013)

Fig. 1.2 New Stockton Marina berth covers (Huntington, 2015)

the volume) due to small changes in ambient conditions (pH, temperature, electric field) (Militký et al., 2021). Gel fibers deform in milliseconds; however, thick chemical compound layers need minutes to hours. They are ready to transmit comparatively high voltages. Examples are gels from: polyvinyl alcohol (PVA), polyacrylic acid (PAA), and polyacrylonitrile (PAN). The 3D network created by crosslinking polymer chains has the ability to swell or collapse while retaining its shape and integrity. This results from a complex interaction between hydrogen cation transfer, ion exchange, redox reactions, phase changes, electrokinetic processes, etc. There exists a special group called hydrogels, with water content ranging from 20 to 100% that form elastic networks with a controllable arrangement. Polymer gels respond to external physical or chemical stimuli through isotropic or anisotropic reversible swelling (Jeong & Gutowska, 2002; Militký et al., 2021). Reversible swelling may be triggered through the change of ionic strength, pH changes (acrylic and alkaline ranges) (polyvinyl alcohol), and temperature changes (polyvinyl methyl ether-based gels). In the case of physical objects, reversible swelling may be triggered due to irradiation in the UV range (PVC containing spyrobenzopyran), electric field (polyelectrolyte gels based on polyacrylic acid and non-ionic polymer gels based on polyvinyl alcohol crosslinked with glutaraldehyde with dimethyl sulfoxide $(CH_3)_2$–SO (solvent)), and magnetic field where gels contain iron. The anisotropic deformation depends on the direction of the triggering radiation. Thus, these gels induce a kind of motion according to the polarity of the electric field and its direction (Militký et al., 2021). An example of such reversible shape change is the polyvinyl alcohol/dimethyl sulfolide system. It demonstrates 7% elongation in the direction of the applied electric field when the field is 350 V/mm at 1 mA. The magnitude of the elongation increases with the square of the magnitude of the electric field without any significant losses due to heating (Militký et al., 2021). Polyurethane elastomers also demonstrate similar property changes. The advanced textiles with multifunctional effects with special properties (e.g., antibacterial activity, ultraviolet protection, electromagnetic shielding, photocatalytic self-cleaning) are not smart but functional because they have no reversible reactions. Both smart and functional textiles are changing textile design style from mainly aesthetic to more user oriented.

Classic and advanced textile structures differ in their manifestation of practical use, economics, productivity, engineering, etc. It is possible to expect a change in the share of production of different types of textiles compared to the current state in favor of technical and home textiles.

For clothing, the aspects of fashion, style, and comfort apply (Militký, 2021). However, it is also necessary to ensure the management of transport processes (water, temperature, air, water vapor), protection against dangerous environmental influences (microorganisms, UV radiation, high temperatures), ecological production, and easy maintenance, including cleaning and ironing and ecological disposal (biodegradability), achieving new effects (cosmetic, self-cleaning effects, healthcare support, etc.) and controlled active identification in conditions of limited visibility. Advanced structures provide multifunctional effects. In technical textiles, aspects like high strength and initial modulus (tension, bending, torsion), low deformation to break, low creep, resistance to environmental influences (UV, humidity, temperature), small abrasion, long-term heat exposure, cyclic stress, exposure to chemicals, low degradation under storage conditions, and slow aging under conditions of use apply (Militký, 2021). It is also important that the textiles have easy degradability, enabling easy disposal. In the case of protective clothing and barrier textiles, the properties ensure the elimination of safety and health risks with sufficient user comfort. The major advantage of textile structures as construction materials is that they could be prepared in any shape with different surface modifications and layers of different structures, with necessary properties incorporated into them. Its easy formability can be adjusted as needed with the application of weak force fields, sufficient flexibility and rigidity, and geometry with easy maintenance, cleaning, and repair.

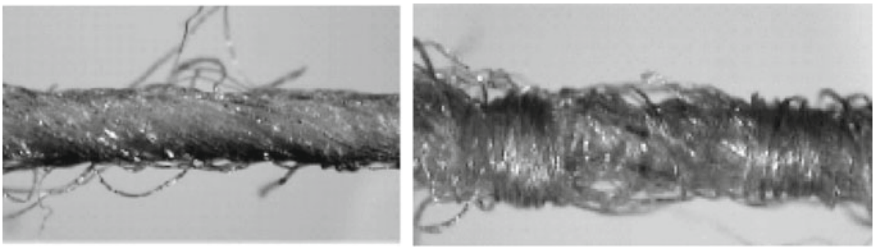
Currently, a number of different fibers are available with properties that predetermine them for technical applications. In addition to traditional natural fibers (especially cotton) and standard synthetic fibers (polyamides, polyesters), special fibers are also used for many applications. These fibers already carry the required mechanical, thermal, electrical, biochemical, and other properties without any special modification. (Wilson, 2011). Fibers in textile structures also have their challenges of brittleness, low elongation, poor adhesion, and abrasion with limited UV or chemical resistance. These fibers were originally developed for the transmission of light (light guides) and information (optical cables). An optical fiber is a dielectric waveguide that usually transmits light or infrared radiation along its axis through a process of complete internal reflection at the interface of two media with different refractive indices. The fiber is composed of a core and surrounded by a sheath. For an optical signal to be transmitted, the refractive index of the core must be higher than that of the sheath.

Textile design is increasing in sophistication with the use of computer-aided approaches. Specialized software enables the construction of textiles and the prediction of their properties. The advanced algorithms also allow visualizing the results of the combination of different properties without full-fledged production. For optimization, or "soft" methods, such as case-based reasoning (CBR), are also beginning to be used to design products with specified properties on an industrial scale.

1.3 Development in the Textile Industry

The textile industry is being driven by factors like eco-friendly production, waste reduction, reduced energy consumption, lesser usage of dangerous chemicals, and easy disposal. It is important to find the right balance between productivity and impact on the environment. The dominant method of yarn production still remains ring spinning (Lawrence, 2003). The ring-spun yarns have a typical surface characterized by protruding fibers, creating hairiness (see Fig. 1.3).

The ring compact spinning system is used to limit hairiness and increase the strength of cotton yarns (Lawrence, 2003), Czech researchers invented the revolutionary rotor spinning (open-ended spinning) (Kašpárek, 1992). The most powerful



(a) Ring yarn 20 tex (cotton) (b) Rotor yarn 20 tex (cotton)

Fig. 1.3 Structure of ring and rotor yarn (Militký, 2021)

yarn production system is adhesive bonding Bobtex (around 700 m/min) (Lawrence, 2003). I Other high performance systems are Dreft friction spinning and Vortex jet spinning systems (Militký, 2021).

In weaving mills, there are three very sophisticated weft insertion systems (Militký, 2021):

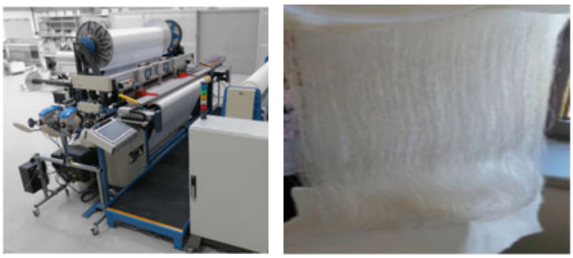
1. shuttle (weft insertion speed is around 1500 m/min),
2. rapier (weft insertion speed is around 1000 m/min), and
3. jet (weft insertion speed for air nozzle condition is around 3500 m/min and for a water jet around 2600 m/min).

The most productive shuttle looms use the water jet weft insertion (Gandhi, 2020). The jet weaving loom DIFA (see Fig. 1.4) is created for the production of 3D-layered fabrics composed of two woven layers (distance between layers 12–50 cm) connected by binding threads (see Fig. 1.4) (Militký, 2021).

The main limitation of textile structures is their thickness (see Fig. 1.5), which depends on their type and has a direct influence on their properties, e.g., thermal resistivity.

Thickness may be adjusted by the use of a vertically laid nonwoven manufactured using STRUTO and ROTIS technologies (Hanuš et al., 2002). Both technologies provide higher insulation and sound absorption. STRUTO is already produced by some companies, and ROTIS (see Fig. 1.6) is still in the pilot plant phase.

Fig. 1.4 **a** Air jet loom DIFA and **b** structure of DIFA fabric (Militký, 2021)



(a) (b)

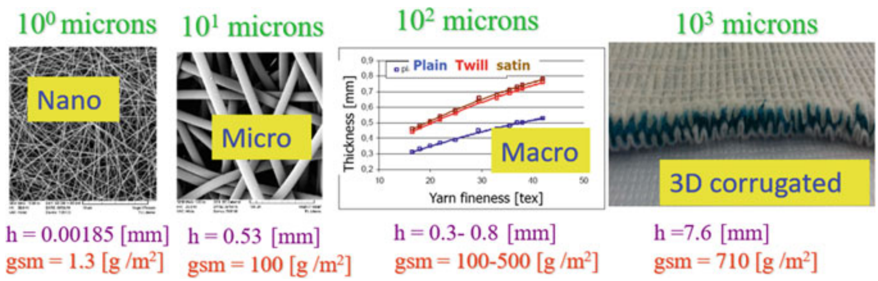


Fig. 1.5 Typical thickness *h* and planar mass *gsm* of different planar textile structures

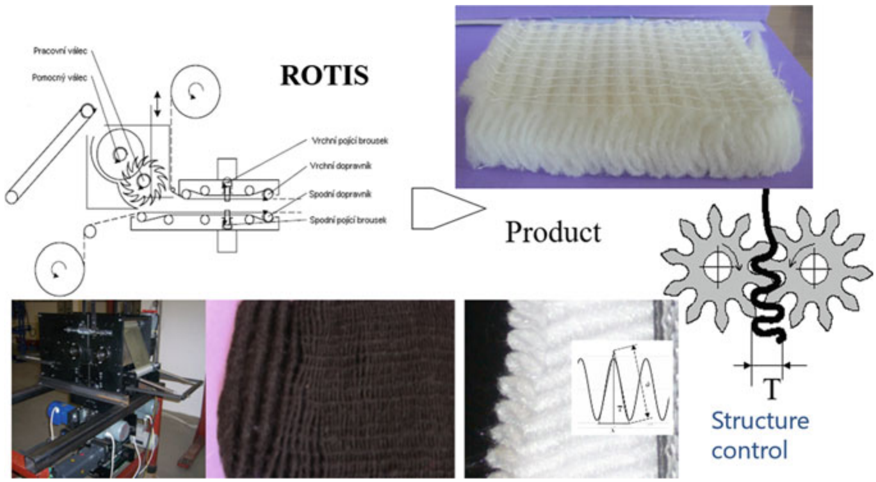


Fig. 1.6 ROTIS technology (partially adapted from ref. Militký, 2021)

Corrugated structures fabricated by ROTIS technology can be used for filtering purposes. Utilization of micro-denier polypropylene allows to prepare layer with high sorption capacity for oils and practically no sorption of water (see Fig. 1.7).

For nanofibrous layer preparation, the technologies of needle electrospinning were published (Mishra & Militký, 2019). Czech researchers are deeply involved in the development of nanofiber webs based on needleless electrospinning (Mishra & Militký, 2019). Some modification of the original NANOSPIDER machinery is shown in Fig. 1.8 (Militký, 2021).

Textile engineering has to overcome the challenges of increased production speed, reduced machine weight, computer-aided manufacturing, and application of mechatronic principles while maintaining production values. This continuous evolution is a prerequisite for high-quality products. Another area of concern is the impact on the environment. The textile industry has to join the bandwagon of reuse and recycling in

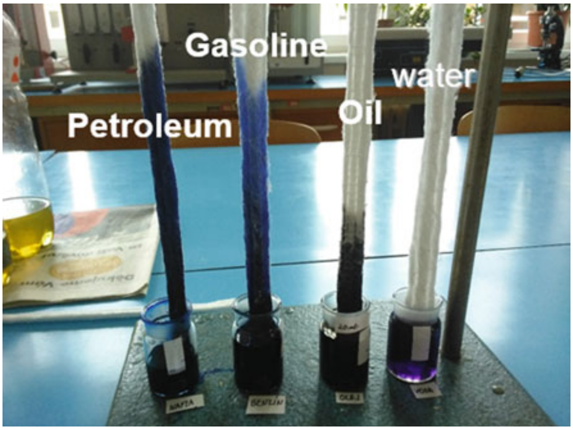


Fig. 1.7 ROTIS filter: removal of oils (O), gasoline (G), and petroleum (P). Zero water absorption

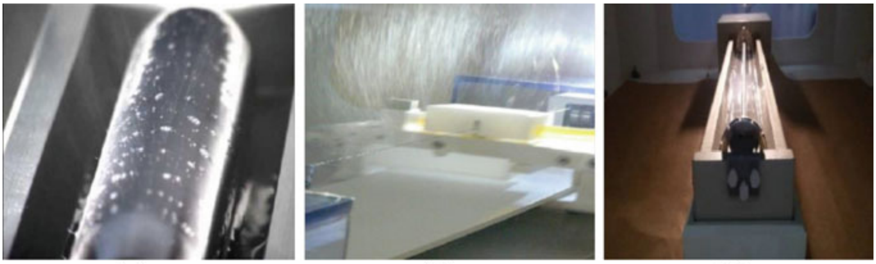


Fig. 1.8 Modification of the NANOSPIDER system with **a** rotating cylindrical electrodes with indentations on the surface, **b** wire electrodes, and **c** rotating wires (Militký, 2021)

the textile life cycle. This has led to the creation of products with high-value addition. A simple way is to convert waste into carbon structures (Fig. 1.9).

Cold (non-equilibrium) plasma is standardly generated at low pressures (in vacuum) using low-power direct current and microwave generators. It has a plasma gas temperature of around 30−100 °C and can be used for all organic materials. Cold plasma is suitable for various types of surface modification, from simple topographic changes to surface grafting, where the surface's chemical composition (and properties) is completely different from the core composition. The energy particles of the plasma break chemical bonds when they collide with the material's surface and cause the formation of free radicals. Due to the composition of the plasma, further reactions then take place. The effect of plasma depends mainly on the composition of the plasma gas. If the plasma gas contains a large proportion of carbon and hydrogen atoms (methane, ethylene, ethanol), plasma polymerization occurs. On the other hand, plasmas containing gas with strong electron affinity (oxygen, air, CF_4, etc.) have a strong etching capacity. Due to the reactivity of excited oxygen atoms, oxygen-containing plasmas are used for many applications. Also, during the usage of inert

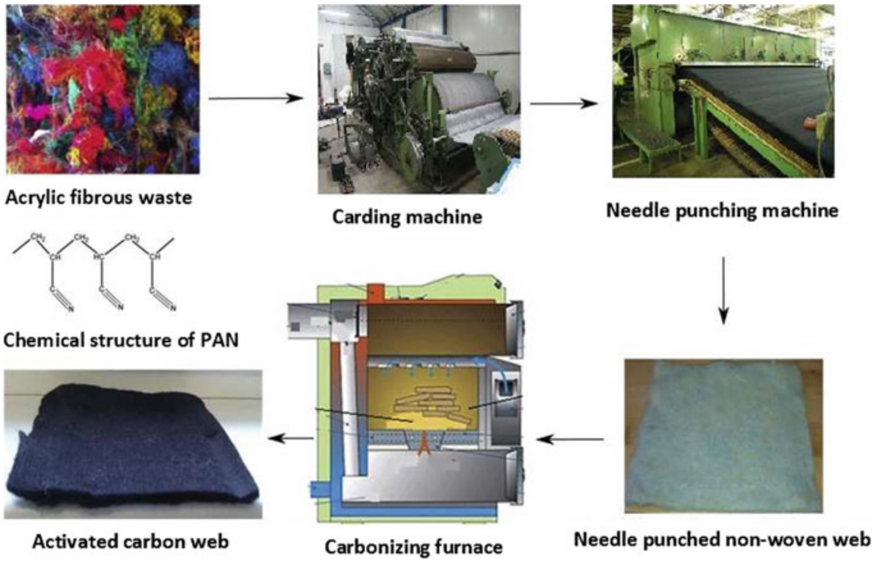


Fig. 1.9 Schematic diagram of carbon web preparation from acrylic fibrous waste (Kašpárek, 1992)

gases (helium, neon, argon, krypton, and xenon), their ionization strength is excessive and sufficient to provoke chemical reactions (ionization energies for helium are 24.5 eV neon 21.6 eV, argon 15.8 eV, Xenon 10 eV, and krypton 14.0 eV). Emissions of individual types of plasma in the UV region are also important for the course of etching. Hydrogen-containing plasma has significant emissions in the region below 160 μm. Nitrogen-containing nitrogen also emits UV radiation in the range from 300 μm upward (type A). For work at normal pressures, a corona discharge is used instead of cold plasma. It is advantageous to use a high-frequency discharge with a frequency in the microwave range (~2.45 GHz) resp. frequency of radio waves (~100 kHz). Plasma penetrates to a depth of about 10 μm. Plasma is used in textiles mainly for cleaning, etching, deposition of layers (metallization), and activation of surfaces resp. implementation of various types of reactions on the surface of textiles. Its use is also advantageous for hydrophilizing surfaces and grafting various materials onto the surface of the textile. Plasma treatment only modifies surface structures in contact with energetic particles (gas radicals). Thus, the particles must have a sufficient free path to strike the fabric's surface from the site of plasma generation. The problem is that the surface of textiles is very complicated and uneven. In a yarn composed of staple fibers, the distances between the fibers are around 1−10 μm. The distances between the yarns are around 0.1−1 mm. The free path of the particles then depends on the distance between the fibers and the density of the plasma gas (collision of the particles leads to recombination of the radicals). The logarithm of the mean free path of gas molecules decreases practically linearly with the logarithm of its pressure. When using conventional cold plasma, the pressure is less than 1 millibar (usually around 0.5 mbar), resulting in a free path greater than 100 μm.

This free path is substantially greater than the distances between the fabric elements. As a result, the plasma gas particles predominantly come into contact with the fiber surface, and the losses due to the recombination of the particles are small. In the area of atmospheric pressure, around 800 millibars, the average free path of gas molecules is around 0.1 μm, which leads to a state where, in the case of larger textiles, radicals do not penetrate to the surface of most fibers. In the article (Poll et al., 2001), $1-100$ millibars were proposed as the optimal pressure range, which corresponds to the range of free lengths from about 100 μm to 0.9 μm. The effect of plasma can also be increased by increasing the processing time. The practical problem is that most devices operate in the range of about 8 millibars, which leads to a mean free length of about 10 μm. To use higher pressures, special electrodes and a gas supply system must be selected (the transport mechanism changes from diffuse to convection). Thus, by controlling the pressure of the plasma gas, it is possible to influence the penetration of the plasma treatment into the structure of the fabric (to fibers that are not directly on the macro-surface of the fabric). Therefore, the results obtained on the films cannot be directly transferred to the field of textile structures. When atmospheric pressure is used, a corona or spark discharge is used to generate the plasma. The plasma stream emerges from the nozzle and impinges on the surface of the fabric. Due to the very short free length of ionized air molecules, there is no significant penetration into the textile structure. There is only a significant disruption of the surface layers of the fibers. Therefore, it is clear that atmospheric plasma equipment cannot simply be used for finishing operations where surface modification of most of the fibers in the textile structure is required. Electromagnetic radiation of a suitable wavelength can also be used to ensure a wide range of reactions (polymerization) on the surface of textiles. UV irradiation is commonly used, resp. γ—beams and, in special cases, also excimer lasers (emitting pulsed radiation of high intensity). However, excimer lasers are more suitable for initiating grafting reactions and surface etching.

An excimer laser (excited dimer) uses either two molecules of noble gas or one molecule of noble gas and a halogen atom to generate coherent radiation in a certain wavelength range, most commonly UV. The energy source of the excimer laser can be a current of a smaller number of electrons at high energy or electrons at a high-current discharge (100,000 A). The gases used in excimer lasers have a short lifetime, so they need to be constantly replenished. Excimer lasers generate nanosecond high-energy pulses that remove electrons from atomic nuclei. This causes cracks in the polymer chains and etching. The excimer laser generally generates less thermal energy than other types of lasers. It allows the creation of very special surface structures (transverse wrinkles) that change the adhesion properties, wetting, and optical properties of the fibers. It can also be easily used to modify fabrics and nonwovens. An overview of changes in surface structure due to UV laser irradiation is given in the works of Knittel and Scholmeyer (1997). Thus, an excimer laser is an intense pulsed source of monochromatic (usually UV) radiation that can be used to irradiate a surface. Ceramics and polymers can absorb the light energy emitted by the excimer source, which generally does not absorb light and IR radiation. In addition, the radiation is supplied with high energy (typically 0.5 J) and short pulses (30–40 ns), which prevents equilibrium within the irradiated material during energy transfer. Due to irradiation, a number of surface modifications occur. In the case of polymers, surface removal of the material occurs (etching). Due to the low wavelength of the radiation, this process can be localized very precisely (dimensions of the order of μm). There are no accompanying thermal effects that distort the localization. Therefore, it is possible to create various structures on the surface with precisely defined dimensions. Surface etching of polymer particles occurs only after exceeding the total density of laser energy (added over the time of action), referred to as the etching threshold ε_0 (J/cm^2). Above this threshold, the amount of substance removed per pulse of constant speed increases up to a saturation value which corresponds to the maximum etching depth per pulse Z_0. As the wavelength increases, a greater depth of penetration (at 193 μm, it is 0.034 μm, and at 351 μm, it is already 4 μm) and a local surface melting occur. This affects the structure (the transverse folds are wider and even "merge".). The increase in the number of pulses, which leads to an increase in the total energy supplied by the laser, also results in a very significant effect. The excimer laser makes it possible to create a whole spectrum of surface structures, which will significantly affect the number of properties of textiles Jeong and Gutowska (2002). For industrial use, the low speed in the processing of full-width textiles is still limiting (the repetition rate of laser pulses is low).

An interesting application of the KrF excimer laser (=248 nm and with a sufficient energy density of 100 mJ/cm^2) consists in irradiating polyamide materials (Quin, 2000). A surface graphitic structure with a thickness of about 1 μm and electrical resistance of about 10^{-2} Ωm is formed. The result is a semiconducting material, the electrical resistance of which decreases abruptly in the region of 359 K (This phenomenon is repeated even during several heating/cooling cycles)—all these unconventional methods of heating resp. activation of reactions will (in addition to machinery) also require the selection of suitable treatment agents, TPP, and other substances supporting resp. and ensuring their operation of laser radiation. The laser can easily be used to create surface patterns due to local degradation of fabrics leading, e.g., to local changes of color (see Fig. 1.10).

A separate problem of textile technologies will be the selection of suitable liquids for ecological and less energy-intensive processes such as:

Fig. 1.10 Using of laser engraving for patterning of fabric

- Dissolution of various substances (surface cleaning, solution formation).
- Mass and heat transport (simple and efficient mixing or blending).
- Creating a reaction environment.
- Enabling mixing of reactants in the required concentration (bath processes).
- Stabilization of transients (foam, paste, emulsion, dispersion, gels).
- Storage of solid particles (dyeing, printing, finishing).
- Reaction energy control in a relatively homogeneous environment without "surface/volume" effects.
- Endothermic reactions—heat is supplied by heating the liquid.
- Exothermic reactions—the liquid acts as a heat sink to allow the reaction to proceed. Excess heat is removed, for example, by boiling or evaporation.

Liquids are used in textiles and will probably continue to be primarily used for the following purposes:

1. Removal: Most pre-treatment operations are based on cleaning the surface of textile materials and removing unwanted substances. Water is used as a standard. The active substances are usually in the form of a solution, dispersion, or in front of a polymer (monomer). Both water and evaporative removable organic solvents are used.
2. Cleaning: Maintenance of textiles by washing (usually water) or dry cleaning (organic solvents—perchloroethylene).
3. Heat transfer: Many technologies combine heat transfer with the application, reaction, etc. Shaping and fixing are special.

The most commonly used liquid remains water. Water is cheap, easily available, and usable in many applications. However, it has some limitations:

- Low solubility of some organic substances.
- Compatibility with some reagents.
- Complicated wastewater treatment.
- Easy mixing with some organic liquids (polar nature).
- High evaporation energy, specific heat, and surface tension. The specific heat of ice at 0 °C is 2093 J g^{-1}, and water vapor at 100 °C (constant pressure) is 1934 J g^{-1}.
- High dielectric constant $\varepsilon_r = 78.4$ (strongly polar liquid).
- The dipole moment is $D = 1.85$ Debye, and the ratio ε_r/D^2 is large.

To reduce water consumption, substitutes need to be considered. The industry should consider solvent-free technology (complex exothermic reaction, mixing problem in non-uniform environment), supercritical liquid (CO_2), ionic liquid, or lactate ester. Materials and techniques are bound to keep changing unless the optimal solution is found in the future.

1.4 New Materials and Design

In most cases, the new materials will have influence on properties, service ability, and the useability of designed products. It is typical for most high functional textiles. In some cases, it is a new function supported by fabric construction, especially by porosity characterizing packing density. Examples are textiles for protection against electromagnetic fields, ultraviolet protection textiles, and conductive textiles. Here the proper design of clothing can support special functions of new materials (see Chap. 2). The design of textile products with illumination effects (examples are side-emitting polymeric optical fibers and LED arrays) needs the right placement of the illumination part and the design of the right placement of another component enabling their functionality. Appropriate lighting and power supply system stable under the conditions of use will need to be supplied with each structure. The resulting complex systems can be designed to be easily attached to various classic textile structures and easily replaceable (see Chap. 5). A separate problem, which occurs especially when using LED sources for the design of illuminating textiles, is the generation of heat, which can be so high as to preclude the use of a textile product for clothing purposes.

Smart textiles require power sources for the embedded electronics to function. It requires batteries to be placed in the garments which might limit certain functions. The energy sources may be batteries, solar or from kinetic energy of the movement (Bedeloglu et al., 2010). The movement of the wearer results in high amplitude and low frequency, up to 67 W with each step. The thermal energy of human body also has potential to be converted to electrical energy. Research showed that at a thermal difference of 5 °C, the power density of electricity is up to 0.14 microW/mm^2 (see Chap. 5) (Militký et al., 2021). It is possible to use solar radiation for creation of photovoltaic solar cells as a source of energy as well (Mather & Wilson, 2017). Bonding solar cells to fabric is less effective in maintaining the performance of solar cells. Better is construction of the cells on fibers that are embedded into fabric or creating cells on the finished fabric (Mather & Wilson, 2017). It is necessary to always keep in mind that design, regardless of the specific requirements generated by the use of functional and smart textiles, may be acceptable from an aesthetic point of view but not from a functional point of view. The information about behavior of standard and advanced textile structures useful for designers is one of main aims of this book.

1.5 Conclusion

The future of textile industry depends on its ability to evolve continuously. The solutions being invented should be able to scale up to industrial scale. New inventions should address the needs of the industry, manufacturer, consumer, and environment. New inventions of materials and new methodologies would help the industry to become more sustainable and responsible. The sustainable textile design will be probably seriously influenced by these changes in materials and technology.

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