Textile Strategy for Innovative Higher Education

e-book

Edited by Rimvydas Milašius

Co-editors:

Daiva Mikučionienė
Aileni Maria Raluca
Sofia Papakonstantinou
Desiree Scalia

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CHAPTER 1

Advanced textile materials

Edited by:

Daiva Mikučionienė
&
Rimvydas Milašius

1.1. High Performance Fibres

Audronė Ragaišienė, Kaunas University of Technology, Lithuania

All fibres can be divided into two groups: organic fibres and inorganic fibres. Until the last century, well known organic natural fibres, such as cotton, wool, flax, silk, etc, were used not only as clothing, upholstery, carpets and/or other fabrics, but also as technical or industrial textiles. In the first half of the 20th century manufactured synthetic fibres (acetate (AC), polyester (PES), nylon (PA), rayon (CV), polyacrylonitrile (PAN) and others) had superior technical properties that met the needs of mentioned period.

Inorganic fibres, as carbon, glass, metal, ceramic and asbestos**,** have special properties as well, that are common to the technical/industrial textiles. Often these fibres are used for reinforcing the composites. For example, the most important mechanical and physical properties exhibited by carbon fibres are elastic modulus, tensile strength and the electrical and thermal conductivity. Such properties allow to use carbon fibres in composites of the aircraft and space shuttles, automotive, sports and recreational equipment, marine and other areas. Glass fibres are used in insulations and filtration**s** materials, also as reinforcement or optical fibres. Glass fibre is heavy in weight, rather strong, but not resistant to bending and abrasion. Metal fibres are used not only for decoration of textile, but also for metal filters, abrasion materials, as well as in transport cords. The metal core can be wrapped with textile yarns or composite could be done in opposite versa. Asbestos fibres in their nature are resistant to the fire. But this fibre is dangerous to human health. Most common fibres used in constructions of aerospace or aircraft shuttles are ceramic fibres.

Despite all the advantages of the fibres discussed, the needs for high-performance composite materials in the mid 1960s led to the intensive development of strong, high-temperature and heat resistant fibres. Aramids, aromatic polyester, Ultra-High Molecular Weight Polyethylene (UHMwPE), and other fibres, have mentioned properties. DuPont company (USA) first commercialised two aramid fibres. One of those fibre, belongs to the para-aramid group, is named as Kevlar®. The second fibre, named as Nomex®, belongs to the meta-aramid group. Teijin company (Japan) commercialised para-aramid, named as Twaron®, meta-aramid, named as Teijinconex®, Teijinconex® neo and aromatic copolyamide fibre, named as Technora®. A number of commercial UHMwPE fibres are available, which include Spectra® (Allied Signal, USA), Dyneema® (DSM, The Netherlands), and Tokilon® (Mitsui Toatsu, Japan). Vectran® (created by company Celanese, since 2005 acquired by Kuraray™ group) and Zylon® (polyparaphenylene benzobisoxazole) fibres also belong to the high performance fibres. Vectran® is aromatic polyester spun from a liquid crystal polymer (LCP) in a melt extrusion process. This process orients the molecules along the fibre axis, resulting in a high tenacity fibre. First produced in 1990, Vectran® is the only commercially available melt spun LCP fibre in the world.

It is known, that polymers can be spun using melt, wet or dry spinning technologies and techniques. To achieve the required para-aramid properties (an excellent energy-absorption-to-weight ratio, as well as excellent strength and durability), is used dry-jet wet spinning process. Heat treatment under tension in fibre preparation allows achieving an extension less than 5% at temperature above 500^0C, also increasing the fibre modulus and the crystalline orientation, which always is of the radial order. Aramids are prepared by the generic reaction between an amine group and a carboxylic acid halide group. Molecular weight of para-aramid fibre must be high, as well as, molecular orientation - no less than 12^0. It led to achieve a high tenacity of such fibres. Mera-aramids are based on a wholly aromatic polyamide. These fibres mostly are made using wet spinning technology. Technora® fibre, which is eight times stronger than steel, is copolyamide synthesized via the copolymerization of several aromatic and diacid chemical materials.

Aramid fibres have unique properties comparing with the other fibres. Aramids, as the final product, can be: multifilament yarns; staple, including short staple, yarns; nonwovens; paper; spunlaced fabrics; powder; and pulp. A low stiffness and high elongation of these fibres give it textile-like characteristics which allow processing on conventional textile equipment. Yarns from aramid fibre can be easily woven on fabric weaving looms. So, their technical material preparation is easier then preparation from inorganic fibres (glass, carbon, metal or ceramic). Yarns from para-aramids fibre are very strong: their tensile strength is 2-3 times higher than that of high-strength polyester and polyamide yarns and 5 times higher than that of steel (on weight basis). Most important properties of meta-aramids (Nomex, Conex and others) are excellent resistance to heat, flame and chemicals. In Figure 1.1.1 and Table 1.1.1 are presented typical stress-strain curves of different organic and inorganic fibres and different properties of such fibres, respectively.

There are several modifications of Kevlar fibres, i.e. Kevlar 29 (as benchmark of Kevlar's; standard modulus (70 GPa)), Kevlar 49 (high modulus (135 GPa)), Kevlar 149 (ultra-high modulus (143 GPa)), Kevlar 68 (intermediate modulus (99 GPa)), Kevlar 119 (High Elongation (4.4%)), Kevlar 129 (High Strength (3.4 GPa)), as well as Twaron fibres, i.e. Twaron 1000 (standard modulus (66 GPa)), Twaron 1055/6(high modulus (125 GPa)), Twaron 2000 (High Strength (3.8 GPa)). These modifications are made using different technological parameters in production of para-aramid fibres.

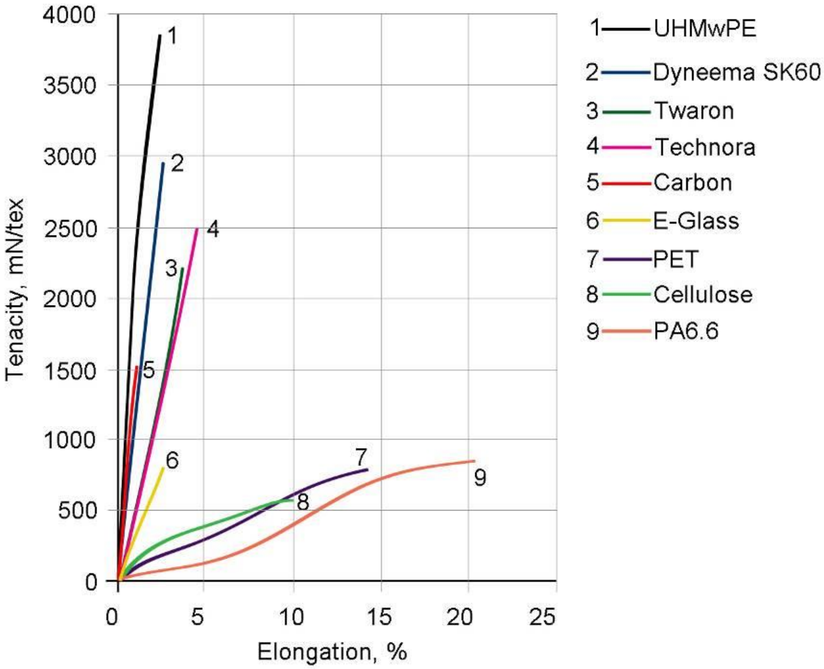

Figure 1.1.1. Typical stress-strain curves of different fibres.

Meta-aramids also are produced of a few modifications, as well as, composites of para- and meta-aramids. For example, Nomex 430 (a high crystalinity filament yarn with higher strength and chemical resistance than staple spun yarns); Nomex 450 (a natural staple fibre); Nomex 455 (a patented blend of NOMEX® and KEVLAR® fibres, when converted to fabric is known commercially as NOMEX® III); NOMEX®IIIA is blend with a proprietary static dissipative fibre P-140; Type N102 (texturized filament yarn); and others. Composition of spunlaced fabrics may be 100% NOMEX®, 100% KEVLAR® or blends of the two (DuPont). These fabrics are durable, soft, conformable, saturable and lightweight – a unique combination of these properties.

In general, all para-aramids are used as high strength fibres and meta-aramids – as fibres resistant to the heat, flame and chemicals, despite the fact, that LOI of all of them is higher than 20. Aramids also have drawbacks. For example, low resistance to light of all aramid fibres is the most important of them. The strength of such fibres decreases after exposing them to sunlight and colour changes because of ultra-violet radiation. The second one drawback of aramids is a relatively bad colouring.

Table 1.1.1. The properties of fibres

Index / Fibre	Density g/m^3	Tenacity N/tex	Modulus GPa	Elonga-tion, %	Mois-ture, wt%	Decom-position melt, ^{0}C	LOI
Kevlar®	1.44	2.0-2.2	57-127	2-4	-	560	31-32
Twaron®	1.44	1.65-2.5	60-120	2.2-4.4	3.2-5	500	29[2] - 37[3]
Technora®	1.39	2.2	55-104	4.4-4.6	1.9	500	25[2]
Nomex®	1.46	0.5	0.8	31	3.5	371	29-32
Conex®	1.38	0.45-0.5	-		5-5.5	400	29-32
UHMwPE	O.97	2.3-4.0	52-132	3-4	< 0.1	150	<20
Carbon (PAN based)	1.78	2.0-3.9[1]	230-540	0.7-2.0[1]	0	3700	-
E-Glass	2.55	0.6-1.2	72	1.8-3.2	0.1	825	-
PBI	1.43	0.24	5.1	27	15	450	>41
PET	1.38	0.6-0.8	-	10-15	0.4	255	15-20
PA 6.6	1.14	0.75	-	18-25	4-6	260	20-21

[1] - in a matrix structure
[2] – fabric measurement
[3] - filament yarn measurement

Vectran® is thermotropic; it is melt-spun and it melts at high temperatures. Therefore, it is very different from aramids and UHMwPE fibres. UHMwPE are the lightest fibres with a density of only 0.97 g/m^3, which is lower than the density of water. They are particularly resistant to moisture, alkali, and UV environments, as well as chemically inert. They also display good abrasion resistance, bending and creep fatigue, compression and radiolucency. The main drawbacks are poor creep resistance and poor matrix compatibility.

Depending on modification and properties, high performance fibres, including their composite, are used in the following application areas: Protective material, Thermal Protective Apparel, Marine and aerospace construction, Civil engineering, Ground transportation, Engineering plastics, Sporting goods. Different kinds of protective materials from high performance fibres can be used for ballistic, cut-through or high temperature protection. It is known, that protective materials need to absorb kinetic energy in the shortest possible time. So, high tenacity, high energy-absorption rate, and high modulus of elasticity of para-aramids allow the rapid dispersion of deformation waves, making them an ideal protective material. Ballistic protection materials include helmets, plates and armour vests, laminates that provide effective protection against a wide range of ballistic hazards, including bullets, grenades and even certain mines. protection products, such as military and police Aramids, Vectran® and Honeywell Spectra® fibers and ballistic composite materials – Spectra Shield®, Gold Shield® and Gold Flex® can be used for hard-ballistic vehicles, cash transporters, as well as bulletproof cars, helicopters, planes and boats. Materials for cut-through protection are such: work wear and shoes for high risk jobs in the timber, meat or glass industries, safety gloves, socks, protective suits, wear for high risk sports and others. Also these materials have an effective resistance to molten metal splash with low-temperature metals, such as lead, zinc, or pot metal. Almost all kinds of high performance fibres can be used for such protection materials.

Probably the most advantage of all aramids is the possibility to use them in thermal or high temperature protective apparel: apparel fabrics to protect against flash fire and electric arc exposure; garments for firefighters or race car drivers; insulation in fire resistant thermal protective apparel. DuPont commercialised NOMEX OMEGA® which is a total turnout system for firefighters. Components include an outer shell of DuPont™ Z200™ firer, a moisture barrier, and a thermal liner of DuPont materials. The system is designed to minimize heat stress and maximize thermal performance and comfort. Firefighters' clothing, for instance consists of a FR inner layer composed of a moisture barrier, thermal barriers and lining, while the outer shell provides flame resistance, thermal resistance and mechanical resistance. Suitable fibres for such garments include aramids and polybenzimidazole (PBI). NASA is developing the next generation of suit technologies that will enable deep space exploration by incorporating advances such as regenerable carbon dioxide removal and water evaporation systems.

Due to a much higher specific strength of high performance fibres comparing with steel in air and, especially, in sea water, they can be used in building, aircraft and platforms constructions, ship buildings, mechanical cables, mooring ropes. High performance fibres are widely applied in the production of different tyres for trucks and aircrafts, motorcycles or bicycles, even for high speed tyres. Also they are used as filtration materials, including filtration fabrics in hot gas, friction materials and gaskets.

High performance fibres, that have higher elongation and lower modulus, are used as rubberised goods, such as, conveyor or transmission belts, hoses for automotive, hydraulic hoses and others. Some uses for the aramid paper products include insulation in electric motors and transformers, wire wrapping, and honeycombed strength members in many aircraft. Moreover, high performance fibres are used for making transportation textiles such as aircraft carpets, sewing threads, fishing lines, zipper tapes, medical grades and the number of applications is growing all the time.

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1.2. Overview on the technical applications of textile materials

Ariadna Detrell, AEI Tèxtils, Spain

From a broadly point of view, technical textiles can be defined as *all textile products that cannot be fitted within the traditional sectors of clothing or furnishing*, or better yet: *all textile products in which functionality is as much or more important than aesthetics*.

Figure 1.2.1 shows the technical textiles' value chain, which alike the regular textiles production begins with natural fibres or the production of fibres by extrusion. Next, it follows (if applicable) spinning and yarn transformation in order to produce the fabric with yarns or directly from fibres; or the elaboration of plaited structures, webs, tapes or other types of laminar or even tridimensional textile structures that can be finished in order to give them new functional properties for specific applications.

The resulting products can be finished or assembled for their final use, or go through a stage of semi-finished products, such as pre-impregnated materials or adhesive materials or those used for the manufacture of composites.

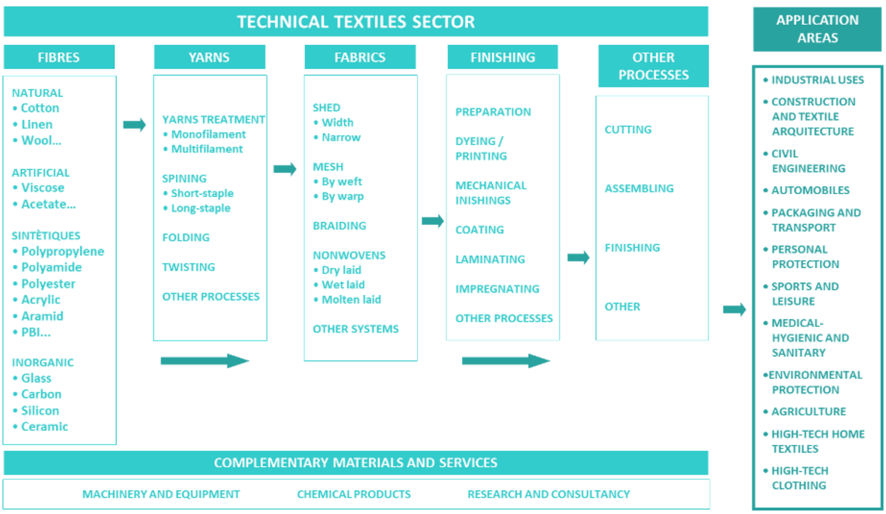

Figure 1.2.1 Technical textiles value chain (Source: AEI TÈXTILS)

Therefore, all natural, artificial or synthetic textile fibres can be used in the field of technical textiles. However, the arrival of new fibre families with high mechanical, thermal and chemical resistance, among others, is one of the factors that has essentially contributed to the structure of the current sector of technical textiles:

being able to satisfy needs that some decades ago would have never been related to textile materials.

The most usual classification of technical textiles is the one defined by the trade fair Techtextil, from Messe Frankfurt, first celebrated in 1986, and which is being used since 1997: Agrotech, Buildtech, Clothtech, Geotech, Hometech, Indutech, Medtech, Mobiltech, Oekotech, Packtech, Protech and Sportech.

Next, a description of each application area is provided.

Agriculture and fishing

Textile materials in this area are used to facilitate and improve the conditions of agricultural holdings, in gardening and for fishing. They help to enhance the efficiency and productivity of the sectors they cover. Products can be classified in 2 main groups:

- Textiles for agriculture crops, horticulture and gardening: soil covering, protection of crops (from hailstones, sun, birds, insects, wind), irrigation and drainage systems, silos, liquid and water storage systems, temporary constructions, ropes for agriculture, greenhouses and meshes.
- Textiles for fishing: nets, cords, ropes for fishing, marine farming and fish farms.

Raw materials used are mostly polyolefin and polyester yarns and vegetal fibres. Most common structures are woven and knitted fabrics, nonwovens, nets and cord.

Building and textile architecture

Textile materials used in this sector are resistant to deformation and extension under tension to wind, water and to degradation.

Main product groups/functions are: Soil and subsoil stabilization, textile reinforcement for concrete, reinforcing meshes, textile materials for formworks, structures for facades, insulation (heat, cold, noise, electromagnetic waves), fillers, insulating screens, walls and ceilings, draught excluder, waterproof fabrics for plane covers, materials for interior facing, safety nets, textile architecture and temporary constructions (awnings and canopies, marquees pavilions and coverings, inflatable constructions, tensed structures, covers for ponds and water tanks).

These products, according to their final application, can have several structures, such as fibres, woven fabrics with or without coating, nonwovens and nets. Raw materials include: polyester or polyolefin fibres; polyester polypropylene, fibre yarns; PVC, acrylic or PTFE resins.

Industrial uses
It includes all textile materials that have a specific role in industrial processes such as:

- Transportation of materials between processes.
- Transportation of materials through machines and by energy transmission
- Separation and purification of industrial products.
- Cleaning of gases and wastewater.
- Dirt and oil absorbency.
- Use as a substrate for coated products and composite materials.

Examples of final products in which textile materials are used: cables covering, filters, paper felts, reinforcement of wood, plastic and paper products, industrial cleaning products, etc.

As there are many kinds of products, the range of raw materials used is very wide and most of textile structures are used.

Civil engineering
Textile materials for civil engineering (also called geotextiles) are used on or below ground level to provide the following functions:

- Separation of subsoil layers in roads, airports and railroads.
- Reinforcement: soil consolidation, subsoil reinforcement, slopes protection and riverbanks protection.
- Drainage systems in roads and tunnels.
- Waterproofing in reservoirs, tanks, swimming pools, tunnels or dumps

There are geotextiles that perform several functions simultaneously. In most applications, a geotextile performs a primary function seconded by other functions.

For the manufacturing of geotextiles, most used raw materials are polyester or polypropylene yarns and PVC resins. Textile structures cover mainly knitted or woven fabrics with or without coatings and both needlepunched and spunbonded nonwovens.

Automobile and public transportation
This application area includes all the companies involved in the manufacture of textile components for ground, naval and air transportation. Products classification can be done in four main groups:

- Materials for automobiles: fabrics for tyres, tubes and ventilation hoses, nets and grids, filters, conveyor belts, safety belts, upholstery, carpets and coverings, insulating materials, air-bags, textile materials for moulded pieces, battery separators and protective car covers.

- Fireproof textile materials for interior design in public ground transport (bus, rail, etc.).
- Fireproof textile materials for interior design in air and maritime transport.
- Textile materials for the aerospace industry.

Raw materials used for automobile textile materials are mainly polyester, polypropylene, viscose or glass fibres; polyester and polypropylene yarns. Most common structures are: nonwovens, knitted and woven fabrics, narrow fabrics, flocked fabrics and tufting.

For public transportation main raw material used are: polyester, polypropylene; wool, carbon or aramid fibres and yarns. Most common structures are: nonwovens, knitted and woven fabrics, composites and tufting.

Packaging and transportation
It includes products with a textile component which are used to cover, contain or hold goods. Their final aim is to protect, handle or present them.

Products can be divided in the following groups: tarpaulins for trucks, materials for shipment protection, textiles for packaging, conveyor belts, big bags and containers, slings and lashing systems and plaited cables for packaging and transport.

Most used materials to manufacture bags, slings and ropes are: yarns made of polyester, polyolefin and vegetal fibres. The most common structures are: woven and knitted fabrics, narrow fabrics, ropes and cables.

For tarpaulins, the raw materials are: polyester, cotton/polyester or acrylic yarns and PVC resins. The usual structure of these products is a coated woven fabric.

Personal protection
It includes textile materials which have the following functions:

- Protect workers against dangerous elements, materials or processes that may occur during their working hours.
- Protect the products, the workplace or the environment.
- Protect people from other people in security/defence situations.

Products with these functionalities can be classified as follows:

- Textiles for safety wear (PPEs) against: cold, chemical agents, electrical shocks, heat and flames, mechanical actions, nuclear danger, electromagnetic-radiation, X-rays, dust, falls and sharping elements.

- Emergency and rescue equipment: life preserves, life jackets and survival equipment, hoses and rescue equipment, fire hoses.
- Protection in extreme sports.
- Reflective textiles.
- Protection of clean rooms.
- Textiles for security forces: nets and camouflage materials, sand bags, NBC protection equipment, tents, bulletproof vests and anti-fragmentation curtains and fabrics and materials non-detectable by IR.
- Security gloves.
- Security footwear.
- Workwear and uniforms.

Most common fibres used are: cotton, wool, polyester, aramid, PBI, PBO, etc. to manufacture woven fabrics with or without coating, knitted fabrics and nonwovens.

Sports and leisure

This area covers the equipment and facilities for sports practice and the enjoyment of leisure time. Products can be classified in eight main groups:

- Textiles for sportswear, leisure wear and footwear.
- Textiles for sports material: racket strings, gloves, kneepads, balls, nets.
- Textiles for watersports: sails, inflatable boats, airbeds and other leisure products, life jackets, ropes and cables, composites for light boats' hulls, diving equipment.
- Textiles for air sports: hang glider, balloons and parachutes, high-resistant ropes, composites for aeronautics.
- Textiles for extreme sports: Skating and fencing apparel.
- Textiles for mountain sports: tents, backpacks, sleeping bags, etc., fabrics for skiwear, ropes for climbing and bungee jumping, protection against extreme weather conditions.
- Textiles for sports facilities: coverings for pools and courts, artificial turf.
- Textiles for garden, beach and camping furniture

Main raw materials used, depending on the final product, are: yarns from cotton and cotton blends, polyester, wool, aramid, carbon, etc. to form woven or knitted fabrics with or without coating or laminate, nets, ropes and composites.

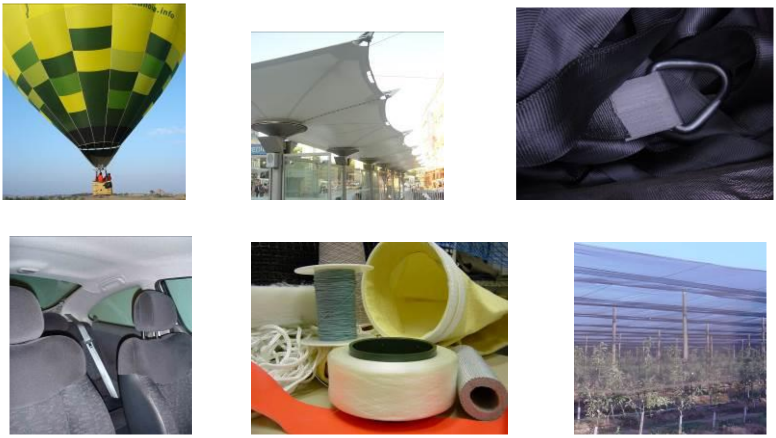

Figure 1.2.2. Different applications of technical textiles (Source: AEI TÈXTILS)

Medical-hygienic-sanitary uses

The area includes all the textile materials used in medical, sanitary and personal care applications, both in consumer markets and in medical markets. They include a well-defined range of products with considerable variations in terms of product benefits and added value. They can be classified in 3 main groups:

- Materials for hospitals: hospital equipment and clothing.
- Sanitary-hygienic products: surgical tapes, gauzes, absorbent cotton, conventional and elastic bandaging, incontinence dressing, feminine hygiene products, diapers, dialysis and filtration material, immobilization material, disposable garments, surgical masks, cleaning and cosmetic wipes.
- Surgery and orthopaedics: prosthesis for locomotive apparatus, girdles, compression stockings, orthopaedic protective gear (ankle, knee supports, etc.), suture threads, implantation tubes in circulatory apparatus.

Main raw materials used in this sector are: absorbent cotton; cotton, polyester, polyamide and elastomeric yarns, etc. Final products may have the following textile structure: woven fabrics with or without coating, knitted fabrics, nonwovens and braids.

Environmental protection

It includes products with textile components used to protect the environment. Five kind of protection are considered:

- Atmospheric protection: Gas/solid separation
- Water protection: Systems for solid/liquid separation, storage systems for residues and dumps
- Soil protection: river banks and coastal, dune stabilization

- Vegetation protection: protection against forest fires, reforestation
- Textiles for erosion control
- Sound insulation: open-air sound barriers, interior sound insulation

Both synthetic and natural fibres and yarns are used. Nonwovens, woven and knitted fabrics are the most common structures.

High-tech home textiles and high-tech clothing

In the areas of high-tech clothing and home textiles, that are border line with both traditional sectors, textile products are considered "differentiated" by some innovative technological characteristic at the present time and that, possibly in the future, when it is consolidated as usual, they will no longer be considered as a technical textile.

For high-tech home textiles, some examples are wall coverings, curtains or carpets that are located in public places, where fireproof is a requirement by EU Directives.

As high-tech clothing; footwear components, interlinings, e-textiles, etc. can be considered.

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1.3. General trends of innovation in the technical textiles' sector

Ariadna Detrell, AEI Tèxtils, Spain

The Strategic Innovation and Research Agenda, developed by the European Technology Platform Fibres Textiles Clothing, in 2016, singled out four strategic innovation themes as particularly impactful for the further development of the European textile and clothing industry:

I. Smart, high-performance materials
II. Advanced digitised manufacturing, value chains and business models
III. Circular economy and resource efficiency
IV. High-value added solutions for attractive growth markets

These themes also concern the technical textiles sector, however, being more specific and directly related to product functionalities, the common trends of innovation in technical textiles can be stated as:

- The dynamism, at the level of product development, to respond to new market-pull demand or to replace other materials in analogous functions.
- The multiplicity of possibilities for the selection of materials, structures, products manufacturing and their adaptation to very diverse uses.
- A slow but continuous progress of substitution of conventional raw materials for new materials of high cost and performance and, especially, by the application of the technological innovations of the general textile sector to articles of technical use (microfibers, new breathable finishes, grafting techniques of monomers, etc.)

From the perspective of innovation, the continued development of new fibers or improved fibers, the new combinations or processing of existing materials, the continuous creation of new styles and designs or the increasing application of textile materials in industrial uses and in the services, have been the main engines of the textile industry in the last decades. Those have proven to be the cornerstone of European companies for improving their competitiveness in the global market.

The innovation cycle of technical textile products differs from the conventional textiles' one. Main fact is that the first one follows a strategy based on the offer (market push), while for the conventional textiles (fashion and home textiles), it is based on the adaptation to the demand (market pull).

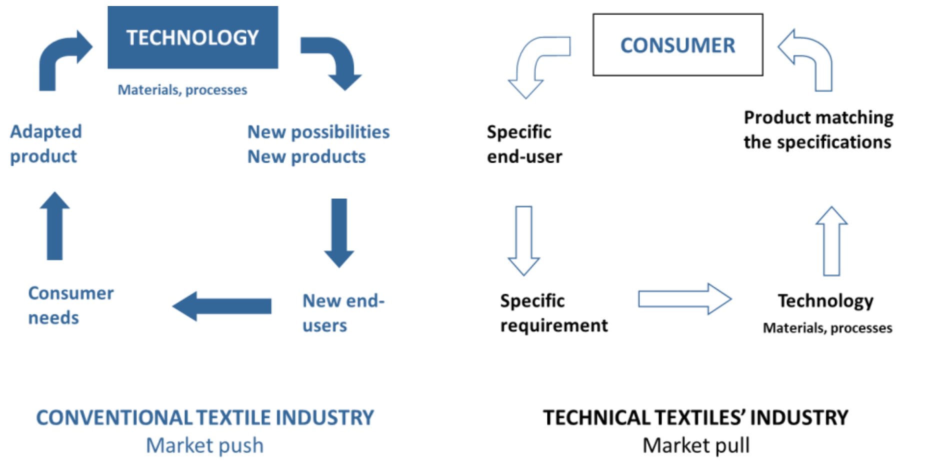

Figure 1.3.1 Innovation cycle for technical textiles vs conventional textiles (Source: AEI TÈXTILS)

Technology used in technical textiles' production is mostly alike to the regular textile manufacturing processes in terms of equipment (except for certain products). The main difference remains in the level of requirements and the quality of the final product demanded.

From a technological point of view, figure 1.3.2 presents the life cycle stages of materials and manufacturing systems.

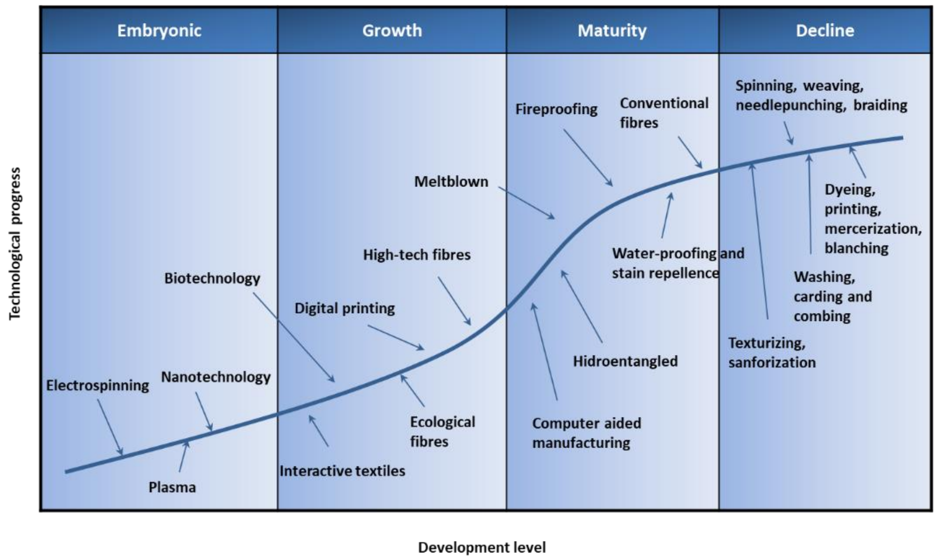

Figure 1.3.2 Evolution of textile technologies (Source: Tecnitex Ingenieros)

The figures shows that the so-called high tech fibers are already in the maturity phase (aramides, polyketetones, PBI, etc.) while others (PBO) are in growth, along with the ecological ones, derived from the increasing collective sensitivity towards the issues of conservation of energy and ecology.

Table 1.3.1 Main research lines in materials, structures and treatments

Technological area	Main lines of research
Materials /Fibres	• Deployment and exploitation of technical capacity from current fibers. • Development of adaptable fibers, capable to regulate their functionality according to the surrounding environment. • Production of super-mimetic fibers, with a deployment functionalities alike living beings.
Structures	• More resistant composites, including lightweight and improved manufacturing processes • Creation of 3D structures using high technological value yarns, new manufacturing processes for new applications • Seamless products
Functionalization treatments (embryonic technologies)	
Plasma	• Anti-aging of wool. • Treatment prior to dyeing (improvement of dye absorption). • Plasma induced grafts (creation of surface active centers that bind covalently to chemical compounds applied later to confer different properties (antimicrobial, hydrophilic / hydrophobic, etc.)).
Nanotechnology	• Sol-gel nano-finishing • Thermo-chromic and photo-chromic microcapsules resistant to high temperature • High durability PCMs • Microencapsulation of bug repellent and natural antimicrobial products, reducing toxic biocides • Drug microencapsulation in medical textiles • Halogenated-free fire retardant microcapsules • Kinetic control of microcapsule release of active compound • Formulations of micro- and nano-capsules finishing with improved fastness • New methods of application, including surface modification • Determination of nanomaterials' health and environmental impact
Electrospinning	• Scale-up to large volumes • Precision and reproducibility during the whole manufacturing process • Safety and environmental aspects

Technologies such as the manufacture of yarns or of woven and knitted fabrics are already in the aging phase, whereas electrospinning, derived from nanotechnology, is still in the embryonic phase.

Nanotechnology is driving a revolution in material science as for example with fibre forming polymers. This would allow the textile sector to offer innovative products with new types of functional fibres ready to cover a large variety of needs.

Regarding the finishing processes, dyeing will keep its important and traditional role, although this will be slightly affected by innovation due to environmental aspects. There is a trend of generalization of coating and laminating systems reaching maturity and awaiting the impact of developments in electro-spinning; the use of biotechnology with finishing based on the application of enzymes; the solution to the current problem of adding microcapsules or the consolidation of nanofinishing. On the other hand, the still growing technologies of surface finishing through plasma technology or digital printing can quickly reach a stadium of maturity without becoming real substitutes to the current technologies but rather occupying a complementary role due to technological and economic reasons.

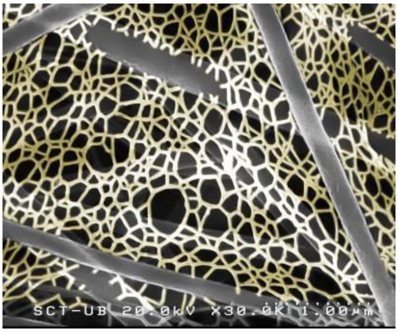

Figure 1.3.3 Nanofiber web (Source: LEITAT)

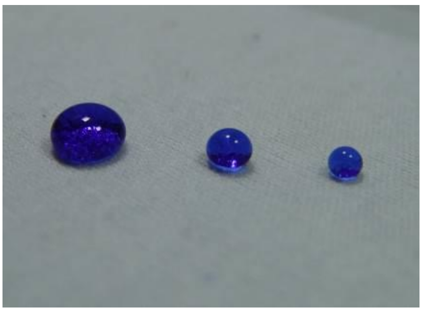

Figure 1.3.4 Hydrophobic cotton fabric (Source: LEITAT)

Textile technology is an enabling technology for numerous fields and can make important contributions to new solutions for effective and affordable health care, highly functional sportswear and goods and smart personal protection. All these are rapidly growing markets and targeted by the European societal challenges of active ageing and safety and security. CONTEXT Cost Action proposers defined the following main technological challenges for textile materials in the healthcare and medical, automotive and aeronautic, sports, personal protection and building and living sectors.

Table 1.3.2 Technological challenges for textile materials

Sector	Key challenges
Healthcare and medical	• development of controlled drug release fibre and textile structures for therapeutics of different skin conditions • development of garments and home textile products with fully integrated bio-monitoring, active systems to improve life quality and ICT systems enabling remote monitoring of patients and assisted living services for "better ageing concepts" • development of fibre and textile structures with enhanced thermal/breathability electro-active properties with integration of new surface functionalities for improving barrier (antiviral and antibacterial) properties
Automotive and aeronautics	• integration of fully integrated and printed electro active and interactive sensors and actuators that enable the development of ubiquitous sensing and interactive surfaces, while also integrating fully embedded (or printed and/or fibre and yarn integrated) haptic feedback systems via both lighting integration and mechanical stimuli responses • integration of fully customizable self- lighting materials based on active fibres and yarns, and integration or programmable textile matrixes for interactive sensing
Sports	• development of light weight performance garments having new textile surface coatings enhancing thermal management (insulation), controlled drug release for muscle care, and also proving optimized comfort, low pill, low shrink and fast drying • integration of low power/autonomous bio-monitoring and/or integrated ICT and loT communication systems for training monitoring and performance assistance and integration concepts of training analytics, always connected and data sharing for garment/textile structures "peripherals"
Personal protection	• the integration of geo tracking and personal GPS systems (Global Positioning Systems), physiological and biometric monitoring, embedded and integrated communications and energy harvesting, with all data monitoring systems sharing data in real-time • integration of cooling/heating systems into garments
Building and living	• development of new functional textile materials using nano- materials and industrial waste, eco-friendly technologies (like ultrasonic deposition, bi/tri-component fibres, UV curing coatings), considering multilayer approaches • focus on high thermal performance (applying eco-efficient heating and cooling systems, together with low thermal conductivity and diffusivity coatings and additives, infrared reflective and phase change materials), in order to achieve Net Zero Energy Buildings (NZEB) • textile functionalization with smart and efficient systems like sensorization, communication systems and actuators, considering printing electronics approaches, in order to maximize comfort, well-being • develop interoperability between connected devices

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1.4. Innovative textile materials: a selection of contemporary material solutions to offer a new perception of the textile product

Micol Costi, Claudia Reder, Veronica Sarbach, Christian Tubito, Material ConneXion Italia, Italy

Introduction

Textile products are present in a very waste offer of applications, varying from being the main material a product is made of, such as a garment or furniture upholstery, or used only as a minor component of a complex product, thus acting e.g. as filter, screen, protective material, packaging, decorative element, etc. Textile materials may be distinguished in four main categories based on the production method (woven, knitted, braided and non-woven) and conceived differently based on the application field. Thanks to an intrinsic adaptability, textiles are not limited to the Textile & Clothing industry but are applied in almost every industrial sector ranging from furniture and interior decoration, durable and non-durable consumer goods, to very technical applications as in audio equipment or as components in industrial production machinery. Figures 1.4.1 to 1.4.4 show some examples of textiles in non-clothing applications.

Fig. 1.4.1 Woven textile: LogiTech's FabricSkin Keyboard Folio

Fig. 1.4.2 Nonwoven textile: Puma's Clever Little Bag

Fig. 1.4.3 Knitted textile: Ikea PS 2017 Armchair

Fig. 1.4.4 Braided textile: TEF's Tubular Sleeves

Focusing on the T&C sector, three key areas of intervention can be identified where operators can interfere to apply textile materials in an innovative way:

1. Upgrading the textile product through functionalisation
2. Including innovation in the construction of the textile material
3. Employing unusual materials in textile applications

These three aspects are shortly outlined in the following paragraphs, providing a general overview on contemporary textile materials.

Fabric Upgrading: Functional Finishes for added value and improved performance

Wellbeing, healthy and sporty lifestyle is perceived as a general and persisting trend in the T&C sector. Furthermore, aging of population increases the need for properties such as easy-care, easy-wear, anti-odour, non-dusty and textiles embedding 'caring' substances. Thus, easy care is a must for textiles addressing the contemporary T&C sector. According to an independent market research conducted for Novozymes, developer and manufacturer of industrial enzymes: fuzz and pilling are an issue for 71% of consumers and 85% would buy more from brands with a neat surface. Producers should therefore focus more and more on bringing together functionality and fashion. Adjusting fibres properties in order to provide a functional and easy handleable final product is not only a specific request of the T&C sector; innovation in textile finishing and functionalisation enables great performances in technical applications. Nevertheless, the following product cases focus on the T&C sector.

Multifunctionality

Consumers are tending towards increasingly high expectations for the clothing they wear, not only when working out. Because shorts and shirts have to be able to do more and more, manufacturers are applying different processes to offer materials with a new kind of functionality. For example, multifunctional materials that quickly absorb moisture, offer additional features like UV protection or help with regeneration (muscles) through compression. Several specialty coatings are developed to offer high performance fabrics that incorporates microencapsulated active ingredients such as caffeine, retinol, fatty acids, aloe and vitamin E or microencapsulated pet allergens reducing probiotics. For instance, a knit fabric coated with a natural silk protein solution for underwear applications improves, over time, the wearer's skin moisture level. Or a mineral-based and bio-ceramic coating on sportswear enhances easier muscle recovery after exertion and improves blood circulation.

Fig. 1.4.5 Revolutional™ Slim – Nanomineral slimming fabric

Fig. 1.4.6 Nanobionic – Biofunctional textiles

Tradition & high-tech

Traditional materials such as wool and leather are found in niche collections of high-end (functional) apparel. They are engineered to match the expectations of their active wearers who demand functional features combined with classical looks. Comfort and functionality may be those of athleisure items but with sartorial elegance. Say Loden, a fine felted wool and traditional material used throughout history in outerwear jackets and uniforms can be found today in urban jackets which are coated with a Teflon finish to make the material water but also dirt-repellent. Applying high-tech treatments on traditional materials enables producers to enhance performance of their products gaining new market potentials: e.g. water and stain repellent finish for textiles which mimics the natural protection of ducks and other water fowl does not affect the breathability or hand of the fabric, has outstanding wash resistance, and the functionality can be reactivated in the dryer. Other processes offer selective application of reactive chemistry, such as photo-, thermo- or hydrochromatic treatments, to create a novel visual effect that allows for environmentally activated looks and branding. Whereas, Graphene-enhanced textiles are under development striving to perform functions like absorbing heat and releasing warmth over time, conducting electricity, repelling bacteria, and dissipating the body's excess humidity.

Fig. 1.4.7 Ecorepel - Biomimetic liquid and dirt repellent finish

Fig. 1.4.8 Hydrochromatic treatment for textiles

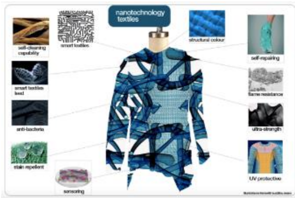

Fig. 1.4.9 Characteristics of nanotechnology enabled textiles

Fabric innovation: new solutions in fabric construction

Material development is looking on smart materials where textiles are the undiscussed protagonist thanks to its versatility to be integrated in any product surrounding the human environment. Advanced manufacturing technologies permit to completely reconsider construction of the textile product incorporating performance and requirements from its conception and responding to tomorrow's market needs striving for complex and difficult shapes, high or low lot sizes, individual and custom designed products, all with minimum waste. New manufacturing and processing in the textile sector applying research on Nano-level will provide disruptive technologies for smart textile materials.

Interactive materials

The principles of smart interiors and domotic homes spread out to soft surfaces and textiles. Development for wearable textile devices from the medical sector are being transferred also into smart sportswear. Wireless charging for mobile devices integrated seamlessly into furniture for the mass market like Ikea's wireless charging collection. Today on and off functions can be integrated into soft flexible devices and nonwovens are used as flexible support for conductive layer. Examples are textile push buttons, soft potentiometers and conductive wallpaper used as security layer or as a plug for LED's becoming an illuminating device.

Fig. 1.4.10 Project Jacquard: joint effort of Levi's and Google to create the first mass-produced article of connected clothing

Fig. 1.4.11 Radius Backpack applying energy harvesting textilestrap

Smart materials, in a broader sense, are also those structures and materials able to change their mechanical properties (stiffness vs resiliency) when submitted to certain forces or when in use, e.g. fabrics that can stretch in vertical, horizontal, and diagonal directions, offering excellent elongation recovery to maintain shape. Applied to sports apparel, the garments using this kind of material distort less, keeping the original shape and silhouettes creating a better, more comfortable fit.

Fig. 1.4.12 Nike Motion Adapt Bra: interior of the bra features adaptive material that stretches at rest to form to your body and locks out when it senses impact

Fig. 1.4.13 Quinny Yezz Air: elasticity of the knitted mesh makes the seat ultra-comfortable as it supports all pressure points evenly

Integrated Protection

New manufacturing technologies paired with high performance finishes and treatments enable to create textile materials, exploiting intrinsic characteristic such us adaptivity, lightness and breathability combined with features for protection.

For instance, 3D knitted protective gear offers, thanks to its innovative layer construction perfect shock and impact-absorbing properties while durable and breathable. Current research explores auxetic textiles as smart materials to meet the high demand in the fields of technical textile. These materials show a special character of getting wider when stretched and thinner when compressed, offering very high load bearing and fracture resistance with high energy absorbency properties. Auxetic materials are now been produced as composites, fabrics, foams where monofilament auxetic fibres will be available commercially in near future. These materials have wide range of applications in fields like medical, soil reinforcement, aerospace, defence, automobile and many more.

Fig. 1.4.14 Ceraspace: abrasion protection fabric technology

Fig. 1.4.15 Kobleder: 3D knitted spacer textiles for protection gear

Fig. 1.4.16 Auxetic textile structure

Product Innovation: unusual materials and processing for textile applications
Today innovation means sustainability: societal and environmental negative backlashes arisen in the past decades are driving the textile & clothing sector, one of the most polluting industrial sectors, to search for more sustainable raw material supplies and have already developed a waste range of alternatives exploiting unusual feedstock such as citrus wastes, Kelp and spider DNA. Moreover, foreseen shortage of T&C's traditional material feedstock (mainly virgin cotton and crude oil), urge the investigation of alternative materials for textile applications. Needs of the industry and avant-garde manufacturing technologies under development are both fostering the 'contamination' of the T&C sector with foreign, innovative materials and processes.

'Contaminated' textile materials
Combination of non-textile materials with fibres and filaments to create fabric-like products are largely appearing on the market to be exploited in textile and clothing applications. These hybrid materials lead the way to the creation of new aesthetics and sensorial experiences that can hardly be connected to one specific material language.

Fig. 1.4.17 Studio Andreea Mandrescu explores different materials for garment textiles

Fig. 1.4.18 b.Cork: Tencel®/cotton knit fabric with post-industrial cork waste

Innovative processing

Currently different technologies are developed to combine different manufacturing processes and involving unusual materials to produce textile products and garments. Research translating processing technologies from other sector into textile production is mainly done by textile and material designers, pushing the boundaries of traditional material development. For instance, selective inlay printing on textiles enable structural modifications of fabrics by applying three-dimensional patterns.

Fig. 1.4.19 Wooden-Textiles: deconstructing wood in geometrical patterns to create flexible, fabric-like products

Fig. 1.4.20 GRDXKN®: Selective inlay printing on textiles to reinforce and enable 3d structures

3D printing is revolutionising manufacturing processes of all industries enhanced by digitalisation and enabling technologies provided through the Internet of Things. First attempts to apply 3D printing for textiles use state-of-art approach where material is deposited in single layers that fuse together to create a 3D printed textile, refashion the concept of textiles made of fibres or filaments.

Fig. 1.4.21 Ludi Naturae: combining 3D-printed plastics, textiles, laser-cut, leathers

Fig. 1.4.22 Silvia Heisel makes 3D printed textiles using fused deposition modelling (FDM)

Fig. 1.4.23 BMW's concept car GINA uses Lycra stretched over an aluminium frame

Fig. 1.4.24 Splinterworks produces Baths-basins in carbon fibre

Fig. 1.4.25 Textiles as the perfect substrate for flexible OLED displays

Conclusions

Recent developments in research and innovation of textile materials broaden application spectra of textile products to a never experienced level, providing textile solutions for any given industrial sector. Individuation of new, economically and environmentally sustainable raw material feedstock, functionalisation of textile products through specialty finishes, along with rapid and customised manufacturing processes enabled through digitalisation will contribute to maintain textile materials' versatility thus confirm to be one of the most used base materials also in future applications. Through interdisciplinary collaboration of material scientist, researchers and designers in material development, fostered by applying a design driven material innovation (DDMI) approach, disruptive innovations can be achieved.

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1.5. Textile Structures with 3D Architecture

Luminita Ciobanu and Mariana Ursache, "Gheorghe Asachi" Technical University of Iasi, Romania

Introduction

All textile materials are three dimensional objects, but many times they are referred to as 1D, 2D or 3D textiles. This classification is based on what directions are significant for their specific geometry. Fibres and yarns are considered 1D materials because their length is defining their geometry. Textile fabrics (woven, knitted, non-woven, braided) are called 2D textiles because they defined along 2 axes - length and width (the fabric thickness is intrinsic to a specific geometry).

Three-dimensional (3D) textile materials are materials with fully integrated continuous fibre assemblies, having multi-axial in-plane and out-of-plane fibre orientation. In other words, the fabric structure is built along all three axes.

All types of technologies can be used to produce such materials, most common being weaving, knitting and braiding.

Even if composite reinforcement is the most known application for three dimensional textiles, they are also used in clothing, medicine, civil engineering, protective equipment, automotive, sport equipment, as well as decorative and architectural textiles.

The advantages of 3D textiles refer to:

- the complexity of the shapes that can be obtained without any assembly, eliminating the cutting and assembly operations and the waste.
- the strict control of the material behaviour along all 3 axes through fabric architecture and yarn characteristics. This means the material strength is controlled in all directions from its design stage.
- In the case of composites, there is no risks of delamination (when layers of 2D materials are used in composite reinforcement, delamination is a significant problem)
- the possibility of developing hybrid structures that combine textile fibres with other materials with specific properties (like ceramics, plastics, etc.)

3D knitted fabrics

Due to their high extensibility and formability, knitted fabrics are well suited for the design of 3D structures. A general classification of 3D knitted fabrics based on their geometry is presented in Figure 1.5.1.

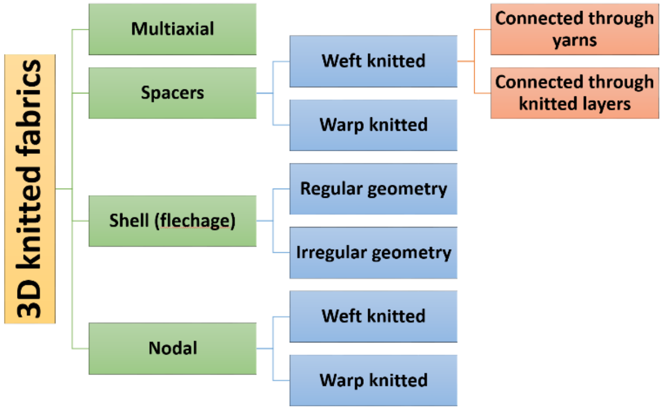

Figure 1.5.1. Classification of 3D knitted fabrics

Multiaxial fabrics are warp knitted structures characterised by the presence of layers of laid-in yarns at certain preset angles: 0° (weft yarns), 90° (warp yarns) and ±α°. The independent layers of yarns are fed into the knitting area and assembled using pillar or tricot stitches, as illustrated in Figure 1.5.2.

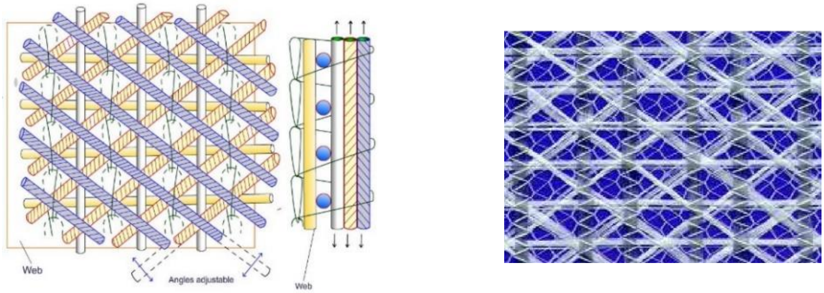

Figure 1.5.2. Multiaxial warp knitted fabric – fabric structure and fabric aspect [6]

Spacer fabrics are formed from two independent knitted layers that connected through yarns or other knitted layers. They can be obtained using warp knitting technology (double bar raschel machines) or weft knitting technology (flat knitting is better suited for spacer fabrics with very complex geometry). Warp knitted spacer fabrics are produced with yarn connection and present the advantages of controlled (and possible variable) thickness, increased stability, possibility of producing open and closed structures and a high recovery from compression (with special monofilament yarns).

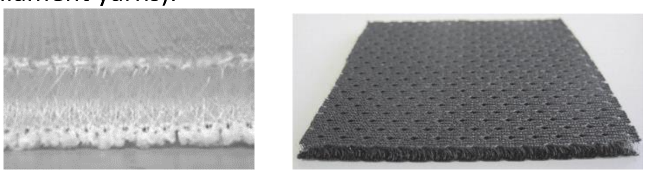

Fig 1.5.3. Spacer warp knitted fabrics – external layers with closed structure (left) and open structures (right) [4]

Weft knitted spacer fabrics (also known as sandwich fabrics) have a similar geometry – two independent layers connected through yarns. Flat knitting technology allows to produce such fabrics where the independent layers are connected through knitted layers, as illustrated in Figure 1.5.4. The complexity of the 3D shape is controlled by varying the number of connecting layers, their position between the external layers, as well as their shape.

Figure 1.5.4. Spacer (sandwich) fabric connected through knitted layer (U shape cross section)

Knitted shell structures are 2D structures that are forced into a 3D geometry due to the presence of fashioning lines (a technique also known as fléchage). These lines are created when the knitting is successively carried out on less and less needles; at a certain point, these needles restart working (in general in the reverse order they stopped working). This way, an area is created in the fabric with a lower number of stitches and the area with more stitches is forced into a spatial geometry (see Figure 1.5.5).

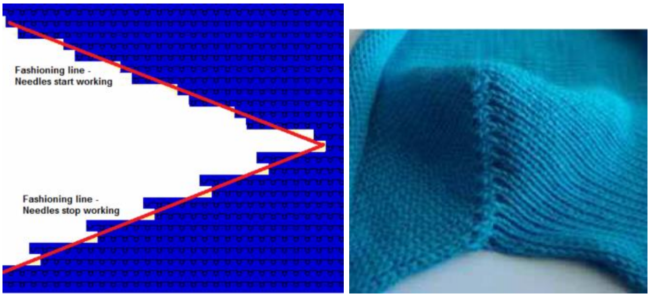

Figure 1.5.5. Principle of creating fashioning lines and shell weft knitted structures

It is possible to relate the 2D evolute of the 3D shape (regular and irregular) to the 2D fabric surface so that complex shapes can be obtained.

Nodal knitted fabrics have a tubular structure with different intersections and positions of the tubes, as illustrated in Figure 1.5.6. Nodal structures can also be produced using double bar warp knitting machines.

Figure 1.5.6. Weft knitted nodal structures – examples [15]

3D woven fabrics

Three dimensional woven structures can be obtained using looms designed to weave 2D structures and looms specialising in 3D weaves.

There are several classifications of 3D woven fabrics, but the simplest one groups these materials into: 3D solid, 3D hollow, 3D shell and 3D nodal.

3D solid woven fabrics have a rectangular cross section in which there are more layers (weft and warp yarns), connected together by binder yarns (warp yarns, in general).

A **multilayer fabric** consists of several layers woven above each other, bound together by yarns in the third dimension or by interlocking. Based on the position of these binder yarns, the interlocking can be angle interlock and ortho interlock. The position of these yarns is defined in Figures 1.5.7 and 1.5.8.

Based on how many layers are bind together, the interlocking can be done by connecting some layers (layer-to-layer) or by connecting all layers (through-thickness).

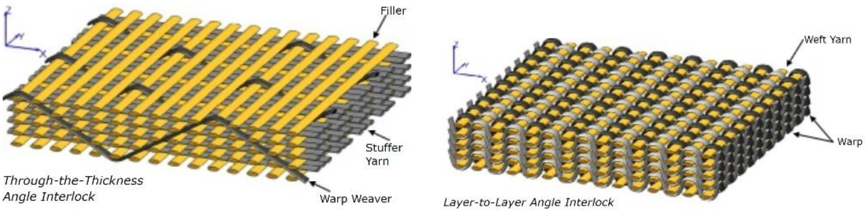

Figure 1.5.7. Angle interlock weave (through-thickness and layer-to-layer) [5]

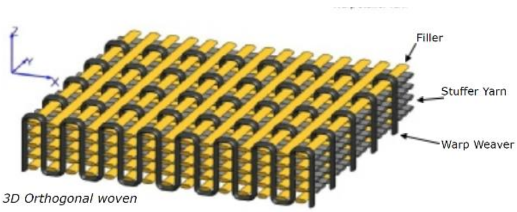

Figure 1.5.8. Ortho interlock (through-thickness) [5]

The 3D woven structures can have a rectangular cross section, as presented above or they can have a **profiled cross section**, exemplified in Figure 1.5.9.

Figure 1.5.9. Profiled 3D woven fabrics – examples [9]

3D hollow woven fabrics are tubular structures with hollow spaces customized in shape and dimension. The surfaces can be profiled or flat, each with several different connection possibilities: oblique, horizontal and/or vertical connections, exemplified in Figure 1.5.10.

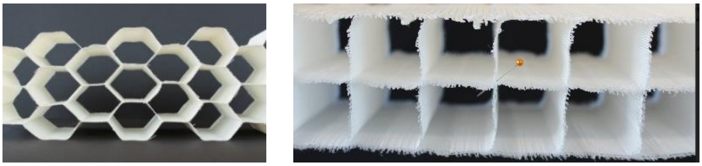

Figure 1.5.10. 3D hollow woven structures (examples) [8]

Nodal woven fabrics are tubular structures with intersections at different angles, as illustrated in Figure 1.5.11.

Figure 1.5.11. Examples of 3D nodal woven structures [7]

Shell fabrics are characterized by the fact that the fabric sheet is forced into a 3D position following the weaving process. Shell fabrics have either a spherical or a box-like geometry and are produced with only one layer or multiple layers.

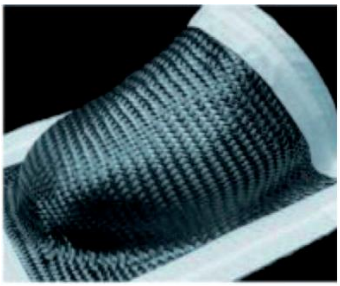

Figure 1.5.12. Example of a dome shaped shell woven fabric [14]

3D braided fabrics

A braid is a linear fibrous assembly composed of two major sets of interlacing yarns, both of which lie on the bias relative to the longitudinal axis of the structure, as suggested in Figure 1.5.13. Braided fabrics can be flat or tubular (Figure 1.5.14).

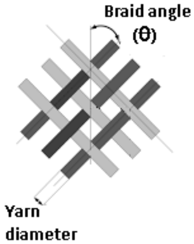

Figure 1.5.13. Position of the two yarn systems in a braided structure [13]

Figure 1.5.14. Aspect of a tubular braided fabric [10]

3D braided structures were developed especially for technical applications. There are different braiding processes that are produce 3D braided fabrics. Using maypole braiding (specific for 2D braids) warp yarns can be introduced in the structures, resulting **triaxial braids**, illustrated in Figure 1.5.15. Mandrels of different shapes can be used to create shaped triaxial braids (Figure 1.5.16).

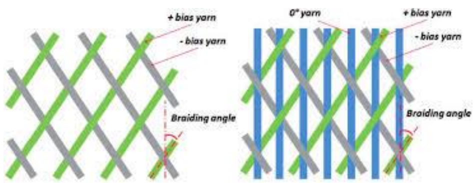

Figure 1.5.15. Triaxial braided structure [3]

Figure 1.5.16. Triaxial braided structures with shaped geometry [12]

Other representative 3D braiding methods are rotary braiding and 4-step (cartesian). In **3D rotary braiding** the horn gears are arranged to form specific geometries and the braider carriers can move freely and arbitrarily over a base plate, forming the braided shape – rectangular, L-shaped, U-shaped, etc. Figure 1.5.17 exemplifies such a solid braided structures with square cross section.

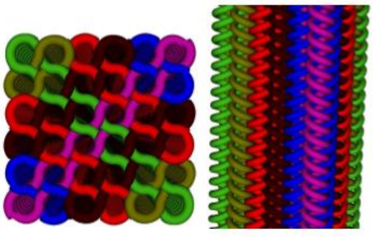

Figure 1.5.17. Solid 3D braiding with square cross section [10]

The basic **Cartesian braiding process** involves four distinct Cartesian motions of groups of yarns termed rows and columns (Figure 1.5.18). For a given step, alternate rows (or columns) are shifted a prescribed distance relative to each other. The next step involves the alternate shifting of the columns (or rows) a prescribed distance. The third and fourth steps are simply the reverse shifting sequence of the first and second steps, respectively.

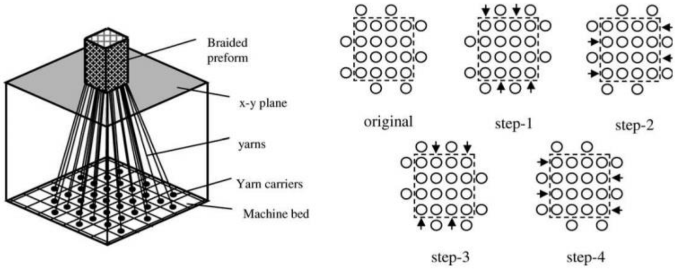

Figure 1.5.18. Schematics of the 4-step braiding process [13]

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1.6. Orthopaedic knitted materials

Daiva Mikučionienė and Laima Muralienė, Kaunas University of Technology, Lithuania

One of the most important field of functional textiles is medical textile, the importance of which is caused by its relation to human health. Medical textile products may be classified into four main sectors: implantable materials, non-implantable materials, extracorporeal devices, and hygiene and healthcare products. According to the classification, a variety of medical and preventive supports and compression garments are assigned to the non-implantable medical textile group. Many different functional textile products for limbs supporting or compression therapy are usually ascribed as medical textile or textile for sportswear. The use of compression textile products for medical purposes has increased significantly since 1970. Originally, these products were used to exert pressure along the human body for the treatment of scars resulting from burns, and treatment of post-surgical condition. Today, the uses of compression products have expanded to applications for venous and lymphatic systems, bone and muscle injury healing, muscle control, etc. The area of medical textile and textile for sports is very extensive. In the most common case these groups of textile are absolutely incommensurable. Medical textile embraces products from first aid blankets to high technology products like man-made vessels or surgical meshes. In turn, textile for sportswear has a common concept that is associated only with apparel and accessories for sports activities and its equipment. However, both of these giant groups have a close connection. In some cases, compression products and various kinds of supports can hardly be attributed to one or another group.

There are a number of well-known commercial brands such as Sigvaris (Switzerland), Orliman (Spain), Otto Bock (Germany), Bauerfriend (Germany) and others in the world market of orthopaedic supports. The main attention is given to compression properties of these products, however, aesthetic, comfort and end-use properties are not less important for consumers. The analysis of textile for medical or sportswear application indicated that there are plenty different classifications of these groups. Firstly, medical and preventive supports or compression garments may be classified by the position on the human' body.

Classification according to the position on the body is essential for primary identification. However, most important is classification of medical textile or textile for sportswear according to the purpose of a special function. Compression garments generate compression to a particular body part. Compression may be defined as the force applied in the opposite direction of the tensile force. Recent medical compression garments are individually designed and manufactured for a particular part of the body: medical compression stockings for vascular diseases, compression bodysuits, face masks, medical orthopaedic supports, prevention compression supports, compression garments for sportswear, etc. All of these products have the same explicit purpose of compression, however the variety of this function applications are wide.

Compression garments are beneficial for the recovery of several markers of exercise-induced muscle damage, accelerate recovery of muscle function, and may also assist athletic following exercise, but the findings are often isolated or inconclusive. However, it is proved that some kind of compression sportswear may affect muscle performance or prevent from injuries. It is found that swelling, power, and strength are improved during recovery with compression garments, and the efficiency of compression garments is affected by garment construction, fabric properties, garment fit and positioning on the body. All these factors play a significant role on the predictive pressure value generated by the compression garment and may undermine its functionality.

In Europe, compression garments are classified into four groups according to the compression intensity. Stockings performing the lowest compression values are used for prevention or marginal ailments, while higher compression values are applied for patients complaining of major diseases. The differences between compression group's valuations in different countries are presented in Table 1.6.1. The highest compression is applied to the ankle and calf and, rising to the top of the product, compression is decreasing gradually: ankle – 100%, calf – 70%, above the knee – 50%, thigh –40%.

Table 1.6.1 Compression class standards

Standard	Compression class			
	I	II	III	IV
	Generated compression, mmHg			
Britain BS	14 – 17	18 – 24	25 – 36	>36
Germany RAL-GZ-387/1:2008	15 – 21	23 – 32	34 – 46	≥49
French AS-QUAL	10 – 15	15 – 20	20 – 36	>36
Europe UNI ENV 12179	15 – 21	23 – 32	34 – 36	>49
USA	15 – 20	20 – 30	30 – 40	>40

There are different technologies for manufacturing of compression stockings that determine the compression class of the product. Compression stockings produced on a flat knitting machine can reach higher compression class (3–4 classes) than that knitted on a circular knitting machine (1–3 classes). However, circular knitting is able to propose seamless products. The most basic conditions expected during the basic socks use are abrasion resistance, elasticity, physiological properties. To achieve these requirements, specific fibres are used or treatment is applied. Polyamide yarns are most popular for compression stockings because of high elongation and abrasion resistance, dimensional stability, possibility to make a highly transparent knitted structure. Polyester microfibers may also be used for compression stockings as they are strong, flexible, elastic, soft, have good capillarity which is a very important comfort property.

Similar to compression stockings, knitted orthopaedic compression supports can be divided by purpose: prevention, rehabilitation or postoperative support. The main difference between these groups is the intensity of compression generated by the support. Preventive compression support may assist as sportswear, as well as textile for medical application. Nevertheless, medical supports may be applied for the same body part, though not for compression therapy purposes. Conventionally, all these products have various distinct applications, from medical to consumer market.

The construction of functional compression supports consists of crucial elements for particular functions that are substantial for patient health or healing process. In this regard, the group of functional post-operative supports may be characterized as most difficult and contains most considerable elements. Orthopaedic supports are usually produced from soft materials with an elastic structure; knitted materials are common and easily used for this purpose. Elastic knitted orthopaedic supports are available in many forms, may contain extra elements for different functional purposes and may be indicated for various diseases.

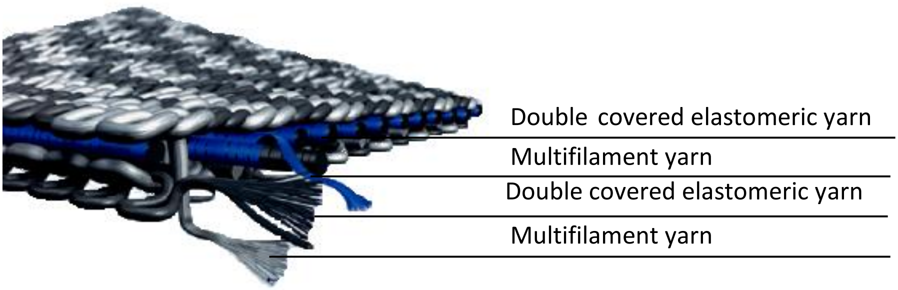

Figure 1.6.1 Construction of the typical compression knit
[http://www.bauerfeindkorea.com/pdf/bro_knie_gb.pdf]

Knitted compression fabrics are made by knitting at least two types of yarns – ground yarn and elastomeric inlay-yarn – together. Ground yarn ensures stiffness and thickness. To generate compression and to achieve better performance of compression support, extra inlay-yarns are inserted into the construction of a knit as inlaid, floated or plated yarns.

Higher level of compression is mainly achieved by increasing the thickness of the elastic core of the inlay-yarn, although adjustments may also be made to the ground yarn. The weft inlay-yarns can be inserted in every single course or in certain courses according to a pattern. The level of compression is partially defined by inlay-yarn properties which are directly related to the modulus of elastic core yarn and the covering parameters. Regardless of the selected raw material of covering yarns, the tensile force of elastomeric inlay-yarn exponential increases by increasing elongation. In the area of low elongations (50% for elastomeric yarns), properties of inlay-yarn's covering yarns do not have significant influence on compression properties, whereas only elastomeric core yarn is affected by the tensile strength. It means that covering yarns may be chosen, depending on comfort, hygienic, aesthetic, etc. requirements. The inlay-yarn insertion density has a valuable influence on the generated compression. This influence has an exponential character. Up to 25% higher compression values were estimated in knits with the inlay-yarns inserted in every single course in comparison with the knits with twice lower inlay-yarn insertion density but with the same total amount of the inlay-yarns.

Orthopaedic supports may be knitted as seamless products, sewn from knitted or other materials (e.g. neoprene) material. Seamless products are usually designed for mass production, are of a few sizes and are used for prevention purposes. Sewn products may be produced by cut out suitable blanks from planar material. The main disadvantage of this is difficulty to achieve an exact anatomical fit of the bandages and a large number of connecting points, such as seams, are created. The latter connecting points partially alter the properties of the material used, and this poses in particular the risk of pressure points or chafing points of the skin. The most advantageous method is shaped knitting on both of circular and flat knitting machines. Compression supports made on flat knitting machines are more beneficial because of the anatomical shape, which guarantees a perfect fitting; supporting and compressing effect due to the stretch construction; stabilization due to integrated viscous-elastic profiles or pads; support and massage effects which improve blood circulation and absorption of haematomas and oedemas.

It is important to notice that a different geometry of knitted structure generates different mechanical properties that are strongly related to the fabric structure, yarn properties and fabric direction. Compression of the support depends on the support area, shape and characteristics of knitting, such as knitting pattern, density, etc. The ways how textile material deforms under applied stresses play an important role in its processing and end-use. Many studies have been published on the deformability of knitted fabrics. Alternating compression in the length of the product can be achieved by changing the knitting density, knitting pattern and / or tension of a laid-in elastomeric yarn.

Knitted orthopaedic supports are often designed with additional details for different purposes. Orthopaedic supports often have added silicone or other parts for functional application and may also comprise other components, such as straps, fasteners, including a disengage-able two-part fastener system for engaging the support with the body. All the rigid elements inserted into the support can change the elasticity of the entire product. In the area of low extensions, there is a strong linear dependence between the rigid element relative area and the compression generated by the knitted orthopaedic support – compression linearly increases by increasing the area of the rigid element. Rigid elements may be classified into three main groups, which are used for: a) medical purposes (elements create the function that is relevant to the patient health and healing process); b) wearing comfort (straps, silicon strips, fasteners, etc.; may affect compression not only according to its relative area, but also due to the different force the consumer uses); c) branding (labels, tags and logos). Additional elements for medical purposes are crucial, cannot be eliminated, and the relative area of these elements cannot be reduced significantly. Implication of additional elements used for wearing comfort can be questioned and their relative area may be changed. At least the inferred group is the branding type elements and the case of this type relevance is overt. Additional rigid elements can significantly affect the compression generated by the support or can even change the compression class of the product. It was established that the rigid element, that occupies ~ 8% of the total area of a support, enhances the tensile force as well as compression up to 15% even at low elongation (10%). This influence depends on the level of elongations in which the orthopaedic support is used. The compression, generated by the support with 25% relative area covered by a rigid element, increases up to ~ 17% at 10% fixed elongation and up to ~ 24% at 20% fixed elongation. However, if the area covered by a rigid element is up to 3% and such a support is used in the area of low deformations (up to 10%), it is not necessary to assess the influence of the relative rigid area on compression of the knitted support.

The effectiveness of compression therapy depends not only on the compression generated. Psychological and physiological barriers of wearing compression products have been researched by various scientists. It is well known that the fabric composition and yarns properties have influence on comfort properties such as thermal conductivity, water vapour permeability and air permeability. It is proved that thermal properties are hardly affected by the capillary structure of fibres and yarn surface geometry. Also, the air in a knitted fabric structure plays a prevalent role in the heat transfer. Lack of comfort during wearing compression garments negatively affects the performance and people are not encouraged to do more activity.

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1.7. Textile reinforced composites

Luminita Ciobanu and Mariana Ursache, "Gheorghe Asachi" Technical University of Iasi, Romania

Introduction

Generally, a composite material is made of distinct materials, that together act in a different way than when considered separately. There are a lot of examples of composite materials, both natural and synthetic, from the human body, to buildings, airplanes and so on.

A composite is a combination of two or more chemically different materials, with an interface between them. One material is called **matrix** and is defined as the continuous phase. The other element is called **reinforcement** and is added to the matrix in order to improve the properties. The reinforcement represents the discontinuous phase, distributed evenly and controlled in the matrix.

There are several options for reinforcement and matrix, the most common being illustrated in Figure 1.7.1.

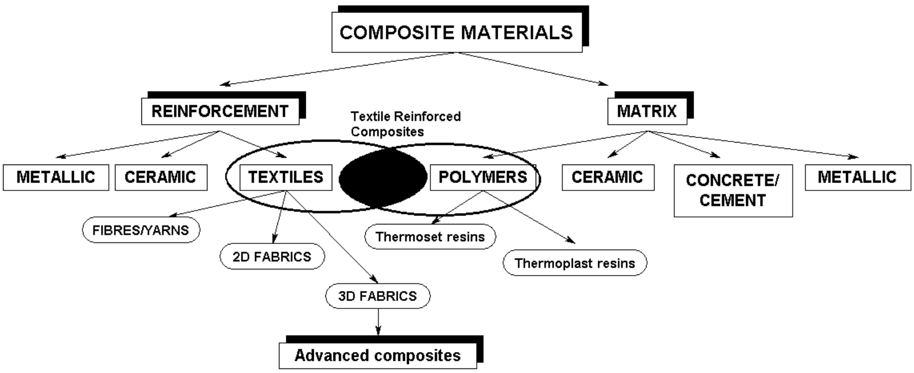

Figure 1.7 1. Structure of composite materials

The development of **textile reinforced composites** (TRCs) with resin matrix (also known as polymer composites) is based on the desire to produce improved materials, with tailored properties. The textile material gives the ensemble strength, while the resin ensures the composite unity and transmits the strains. The advantages of the textile reinforced composites are:

- controlled anisotropy of the textiles which means that their structure materials can be designed so that the fibres are placed on preferential directions, according to the maximum strain;

- the use of textile reinforcements allows to obtain a better weight/strength ratio compared with the classic materials, such as steel;
- textile materials maintain their integrity and behaviour under extreme conditions – for example, they do not corrode in an outdoor environment, nor vary their dimensions when there are significant temperature variations, nor are they sensible to electro-magnetic fields;
- TRCs present an improved fatigue life.

The aeronautic industry was the first that used TRCs for airplanes. Currently, there is a high diversity of TRCs applications, with high economic impact. Composite materials can be found in all fields of technical textiles. Industrial applications of the composites include tanks, storage structures, pipes, hoses, etc. The automotive industry uses TRCs for car frames and other machine parts (e.g. manifold, wheels), while in aeronautics the composites developed from 1st level applications to 2nd level that refers to strength elements in an airplane structure and the current trend is building one using exclusively composites. Another field of great interest for textile reinforced composites is wind energy management – these materials are well suited for wind mills. The TRCs are also used to produce sport equipment – tennis rackets, bicycles and motorcycles, etc.

Another interesting application of textile reinforced composites is in buildings, where these materials (called Textile Reinforced Concrete) are used to reinforce walls and other structures (cement/concrete matrix), increasing their strength, reducing their thickness and subsequently production costs.

Raw material for composites

Textile reinforcement

Two main criteria can be used to characterise the textile reinforcements: the material's structure/geometry and the technological process.

A classification of the type of textile reinforcement that can be used for composite manufacturing is presented in Figure 1.7.2. The reinforcement is divided according to the significant dimensions of their geometry: 1D (fibres and yarns), 2D (textile flat materials) and 3D (materials with three-dimensional architecture, to be developed in another chapter of this unit).

When considering the manufacturing technology, all textile processes can be used to produce reinforcement for composite materials, but the specifics of each type of process and the resultant material geometry lead to differences in possibilities and behaviour. The main processes employed in the production of textile reinforcements are: weaving, braiding, knitting and non-woven technologies. Embroidery is also used, though at a smaller scale.

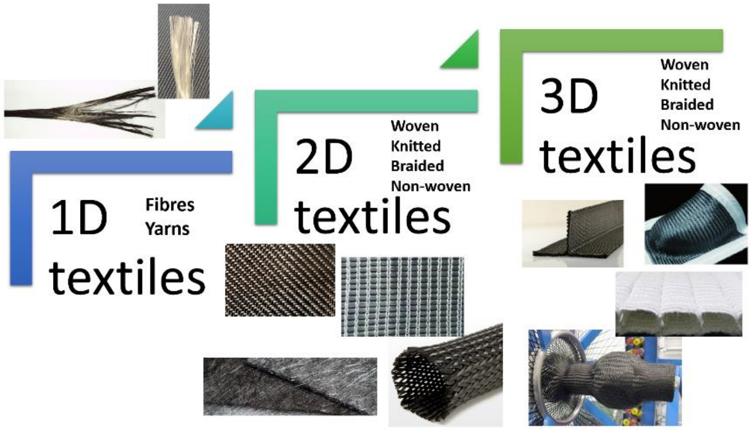

Figure 1.7.2. General classification of the textile reinforcement

There are production processes, such as filament winding and pultrusion, which process filaments together with the resin. Most used reinforcements are woven fabrics (2D and 3D) and nonwovens (fibre mats), due to their good mechanical behaviour correlated with high volume fraction. Warp knitted structures (multiaxial and spacers) are well suited for composite reinforcement. Weft knitted fabrics need laid-in yarns to improve mechanical properties; their high formability recommends them for complex 3D preforms.

The selection of a certain process is based on the architectural possibilities (3D structure), the material characteristics and behaviour (dimensional stability, mechanic strength, drape and formability, etc.) and its suitability with regard to the composite processing and its application.

High Performance Fibres (HPF)

Textile reinforcements are produced using high performance fibres, like glass, carbon/graphite, Kevlar, PES HM and HT, ceramic fibres, boron, etc. Basalt fibres are another type of HPF used in concrete structures for civil engineering.

These yarns have superior mechanical behaviour that can meet the specific demands of composite applications, as illustrated in Table 1.7.1.

Glass fibres (yarns, rovings) are the most common high performance fibres used to reinforce composite materials. They are characterised by hardness, resistance to chemical agents, stability and inertness, low weight and have certain issues related to processability due to their brittle nature.

Table 1.7.1. Main characteristics of some high performance fibres used for composite manufacturing

	Fibre	Relative density [g/cm^3]	Young's Modulus [GPa]	Tensile strength [GPa]
1	Carbon (PAN)	2.0	400	2.0-2.5
2	Boron	2.6	400	3.4
3	E-glass	2.5	70	1.5-2.0
4	S-glass	2.6	84	4.6
5	Kevlar 29	1.44	60	2.7
6	Kevlar 49	1.45	60	2.7

There are more types of glass fibres depending on their chemical composition: E-glass, with good strength and high electrical resistivity, most common in composite materials; S-glass, with high tensile strength, most common in military applications; and AR-glass, characterised by resistance to alkali (used with concrete matrix).

Resins used for matrix

The matrix is giving the composite material its unity and ensures load transfer within it. There are two types of resins that are used as matrix – thermosetting (once cured, the resin will not revert to viscous state) and thermoplastic (the resins can be melted and extracted from the composite material after curing). Table 2 presents the most common types of resins used for the production of composites and their main domains of application. Epoxy and polyester thermoset resins are widely spread due to their accessible costs and good characteristics.

Table 1.7.2. Most common resins for composite materials

<table>
<tr><th>Type</th><th>Matrix</th><th>Applications</th></tr>
<tr><td rowspan="5">1. Thermosetting resins</td><td>Epoxy</td><td>Aerospace industry, aviation, sport equipment, automotive industry</td></tr>
<tr><td>Polyester and vinyl ester</td><td>Automotive industry, naval industry, chemical installations, electric installations, user goods</td></tr>
<tr><td>Polyurethanes and polyuria</td><td>Car components</td></tr>
<tr><td>Phenols</td><td>Aerospace industry, automotive industry</td></tr>
<tr><td>Bismalemide, polyimide, etc.</td><td>Aerospace industry, for high temperatures applications</td></tr>
<tr><td rowspan="2">2. Thermoplastic resins</td><td>Nylon 6, nylon 6,6, polyesters (PET and PBT), etc.</td><td>Composites reinforced with short fibres</td></tr>
<tr><td>Polyetherketone (PEEK), polyphenilen sulphide, polyamide imide, polyether imide, etc.</td><td>Composites reinforced with short fibres and filaments for applications at relatively high temperatures</td></tr>
</table>

Volume fraction

Fibre volume fraction (FVF) represents the ratio between the fibre volume and the entire volume of a composite material. Its importance comes from its direct influence on the strength of the composite material.

The fibre volume fraction is calculated based on the following equation:

$$FVF = \frac{V_f}{V_c} = \frac{W_f/\rho_f}{W_f/\rho_f + W_m/\rho_m} = \frac{W_f/\rho_f}{W_f/\rho_f + (1-W_f)/\rho_m}$$

Where:
W_f = weight of the fibres included in the composite (g)
W_m= weight of the resin included in the composite (g)
ρ_f = fibre density (g/cm^3)
ρ_m = matrix (resin) density (g/cm^3)

The optimum value for the FVF that ensures the quality of the composite material and its mechanical strength varies in the range of 50 to 70% of the total volume. Lower FVF will result in poor quality composites, while higher FVF also affects their level of performance, as the resin fails to penetrate the reinforcement completely. Fibre volume fraction is used in composite design to calculate/estimate the mechanical behaviour.

Production of composites

In general, the composite materials are produced by introducing the matrix (resin) into the reinforcement system (textile material), followed by a curing reaction, when the two components are bonded so that they form the composite material. At the beginning of the process, the reinforcement material is placed into/on a mould that gives the final shape of the product followed by the introduction of the resin. Based on the type of mould, there are two types of process for composites manufacturing:

- **open-mould processes**, where the placement of the reinforcement on the mould is one-sided. Commonly used such processes include filament winding and pultrusion;
- **closed-mould processes**, where the both sides of the reinforcement are in contact with the mould. Most used processes are: resin transfer moulding (RTM), vacuum assisted resin transfer moulding (VARTM).

Thermoforming using hybrid fibres/resin structures is one of the most interesting manufacturing processes (closed-mould), as it eliminates the separate stage of introduction of resin in the reinforcement. The hybrid structures are heated (NIR radiation) and then subjected to pressure to achieve a pre-set form in a press.

Automated Fibre Placement is another example of a process based on hybrid structures (bands of fibres with resin). It allows the construction of the reinforcement layers by controlling the placement of the bands through a robotic arm. The band is heated before placement the layer is consolidated by applying pressure (a pressure roll).

Tailored Fibre Placement is using the embroidery technique to place and fix the fibres (roving) on a hybrid textile support that will bring the resin into the process.

Sustainability of textile reinforced composites

Sustainability is an issue that is starting to gain importance and will influence significantly the development of future composites. The main problem of textile reinforced composites is their disposal. Composites are disposed of through mechanical and chemical processes, as well as incineration, all of them with great added costs. If not processed (recycled), composites end-up in landfills, creating serious environmental problems.

Thermoset composites are particularly difficult to process, as the resin cannot be recuperated. A small percentage of thermoset composites are processed mechanically (powder fillers) or incinerated. Thermoplastic composites are disposed of through thermal processes - incineration, separating resin from reinforcement and pyrolysis/gasification.

The solution to sustainability is the development of green composites that use sustainable components that can be easily disposed without affecting the environment. Currently, the most mentioned solution for sustainable textile reinforcement is the use of natural fibre (like flax, hemp, jute, etc.). Still, one must consider the application and its requirements, as natural fibres do not reach the mechanical properties of HPF.

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Video tutorials (on Youtube)

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2. https://www.youtube.com/watch?v=kF82pnsK9eE (3D woven RTM composites)
3. https://www.youtube.com/watch?v=kaoq8Mc4xxw (An Inside Look at BMW's Carbon Fiber Manufacturing Process)
4. https://www.youtube.com/watch?v=HuoO99oFQYQ (New BMW 7 Series Composite Production)
5. https://www.youtube.com/watch?v=tZhH2B-EI1I (NASA 360 - Composite Materials)
6. https://www.youtube.com/watch?v=haYuTANzzS8&list=PL3B2C07E01F72869B (Composites Materials)
7. https://www.youtube.com/watch?v=NZwvRRoR1xw (Advanced Composites Inc: Excellence in Filament Winding)
8. https://www.youtube.com/watch?v=sxWtzlitq1A (How it works: Pultrusion)
9. https://www.youtube.com/watch?v=J6roJsBcPQQ (Composites Tutorial - VARTM Materials, Supplies, and Process)
10. https://www.youtube.com/watch?v=ycdDyEKrseE (A Fundamental Shift in Composites Manufacturing)

1.8. e-Textile materials

Evangelos Louris, University of West Attica, Greece

Introduction

Recent years have seen an intensification of the research on the new interdisciplinary field of electronic textiles (e-Textiles or Textronics) and a rapidly growing market interest for innovative products that combine textiles with electronic applications. This chapter provides an overview of the materials used in e-textile applications, presenting some typical examples and highlighting major issues and problems associated with e-textile implementations. After completion of this topic the trainee will be in the position to: give basic definitions and use basic terms related to e-textiles, name the basic categories of different materials that are used in e-textiles, know which material categories can be used for a particular e-textile application, and describe advantages, disadvantages and processing problems related to specific materials.

Electrically conductive materials

Electrically conductive materials are the basis for any e-Textile implementation. Conductive materials for e-Textiles can be divided into the following categories:

- Metal fibers
- Fibers coated with metals, metal oxides or metal salts
- Conductive polymer composites (CPCs)
- Inherently conductive polymers (ICPs)
- Conductive inks

Metal fibers are thin monofilaments which are produced with conventional wire drawing process. They can blended with other textile fibers to form conductive yarns or used directly in weaving and knitting processes. Metal fibers from copper (Cu), aluminum (Al), silver (Ag 99%), silver-plated copper (Cu/Ag), copper-clad aluminum (CCA), stainless Steel and Bronze are commercially available.

The second very common category concerns coating of conventional textile fibers with metals, metal oxides or metal salts. The coating can be realized on fibers, yarns or directly on fabrics by using methods like dip coating, ionic plating, electroless plating, vacuum metallization, cathode sputtering and chemical vapor deposition (CVD).

The category of conductive polymer composites (CPCs) concerns man-made organic fibers, in which conductive particles like silver, nickel, stainless steel, aluminum, graphite, carbon black and carbon nano-tubes (CNTs) have been dispersed into their polymer matrix during their preparation. Dispersion is realized by a mechanical blending process in the polymer melt. Higher concentration of conductive particles results better conductivity, but more brittle fibers.

The interest for inherently conductive polymers (ICP) is growing continuously, since they are more compatible with conventional textile fibers in both terms of properties and processability. Typical ICPs are: polyacetylene (PA), polypyrrole (Ppy), polythiophene (PT), polyaniline (PANI), poly(perinaphtalene) (Pna), and poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT-PSS). The contactivity of the ICPs is obtained by the presence of doping agents, which provide more or less electrons in their conjugated chain. This offers the possibility to regulate the conductivity of ICPs by changing the amount of the doping agent. This is of paramount importance because in this way we can prepare organic semi-conductive materials that are critical for the fabrication of fully organic electronic devices, such transistors or capacitors.

Conductive Inks is another class of materials that can be used in the production if e-Textiles. Usually, conductive inks contain metallic fillers such as Ag, Cu, and Au nanoparticles (NPs) incorporated into a polymeric carrier, but they may also contain organic conductive materials. Conductive inks can be applied on fabric surfaces, by a traditional textile printing method like screen printing, roll printing and roll coating transfer or by a more modern ink-jet printing method. Traditional methods of printing are low-cost and more productive, since they can apply thick patterned layers of paste-like materials over large areas. Printing is normally followed by a drying process at high temperatures which depend upon the type of the textile substrate. Inkjet printing is suitable for low-viscosity soluble materials, while high-viscosity materials create nozzle clogging problems.

Optical fibers

A Plastic Optical Fiber or Polymer Optical Fiber (POF) consist typically of a transparent dielectric core fiber covered by an also transparent dielectric clad material with different refractive index. The light inside the core is reflected internally and is transmitted over long distances without losses. Typical POFs are made of a poly(methyl methacrylate) (PMMA) core and a fluoropolymer as cladding material. POF are immune to electromagnetic fields, therefore are ideal for transferring data signals. Although not very flexible, they can be integrated successfully into textile structures, mostly by weaving. Apart of data transmission, they can be used for illumination and display effects, optical sensing, mechanical sensing, chemical sensing, bio-sensing and photo-therapeutic applications. By utilizing fibre optic sensing technologies, such as “Fibre Bragg Gratings“ and “Brillouin and Raman“, it is possible to detect the position in which occurs a change in the light transmission, like for example due to a fiber bending or a temperature change [6]. By removing the cladding at selected locations along the fiber, through mechanical (abrasion), chemical (solvent) or thermal (plasma, laser) treatment, it is possible to create escape ways for the light, thus achieving illumination or even screen display effects (Figure 1.8.1).

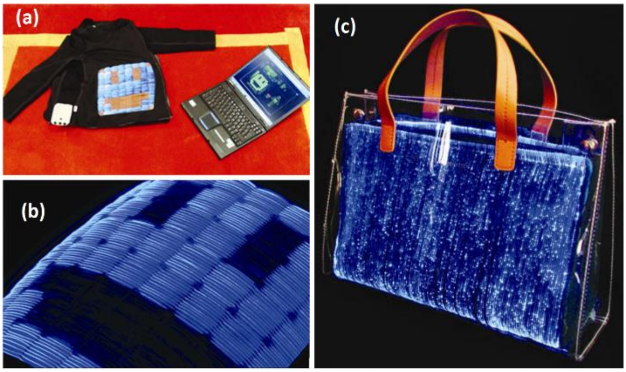

Figure 1.8.1 (a) France Telecom prototype of communicative flexible display based on POFs,(b) Independend pixels formed by POFs,(c) Illuminated bag from Luminex [9]

Light-emitting diodes

A typical Light-emitting diode (LED) consist of two electrodes, the anode and the cathode, and between them a layer of electroluminescent material. When electric current passes through the LED it causes the electroluminescent material to emit light. During the last years, the conventional LEDs are replaced by Organic LEDs (OLEDs). In OLEDs the rigid crystalline layers of the traditional LEDs have been replaced with thin layers of organic materials, which are more flexible, lighter, cheaper and require much less energy to emit light. Water can damage OLEDs, but protection can be achieved by their encapsulation in thin film waterproof coating. Today, the manufacturing industry of thin OLED displays on polymer films is well established. However, the transfer of this technology from the polymer films to the textile substrates remains a challenge. The current textile research follows two directions, either the development of electroluminescent displays directly on textile substrates (figure 1.8.2a) in a similar way as in polymer films, or the development of a multilayered OLED-fiber which then will be integrated into the fabric structure (figure 1.8.2b). OLEDs are widely used in many e-textile applications, but mostly as ready-made components attached in the textile structure by mechanical bonding, embroidering, glue, welding and ultrasonic soldering. Apart of the aesthetic and display capabilities, OLEDs integrated in e-textiles can be utilized for medical applications in the area of phototherapy or photodynamic therapy (PDT).

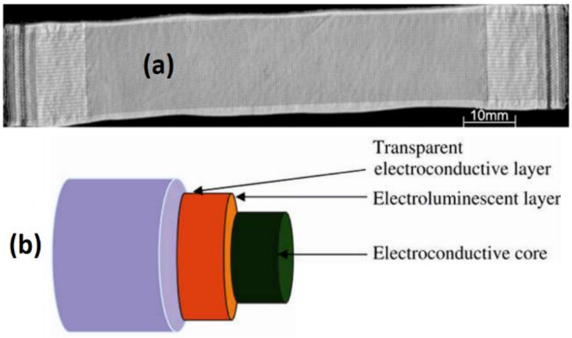

Figure 1.8.2 (a) Woven electro-luminescent display structure,
(b) Structure of OLED multilayer fibre [9]

Energy harvesting materials

The term energy harvesting refers to the collection of energy from the surrounding environment in order to transform it and re-use it as electric power for various applications. For this purpose, various renewable energy sources can be utilized, including sunlight, heat, wind, waves, vibrations and body movements. Regarding energy harvesting applications in e-textiles, the materials with the greatest interest are Piezoelectric (PE), Triboelectric and Photovoltaic (PV).

Research in the field of e-textiles for energy harvesting is at an early stage, while the so far implementations exhibit low harvesting performances. However, further developments in e-textile materials, combined with the continuously decreasing energy consumption of the modern electronic devices, can lead to some effective solutions in the near future.

Piezoelectric materials

Piezoelectric materials can generate electrical charge as a result of applied mechanical stress due to external forces. In this way the kinetic energy of the wind or the human body can be converted into electrical current. Piezoelectric materials can be divided into natural and man-made materials, while the man-made can be further sub-divided into three categories: crystal-based, ceramic-based and polymer-based piezoelectric materials. The polymer-based piezoelectric materials are the most appropriate for e-textile applications. Ceramic-based materials can produce fibers with better piezoelectric performance, but are rigid and non-compatible with the requirements of e-textiles. Examples of polymer-based piezoelectric materials are, poly(vinylidene fluoride)(PVDF), poly(vinylidene fluoride-co-trifluoroethylene) P(VDF-TrFE), polyimide, odd-numbered polyamides and cellular polypropylene.

Triboelectric materials

The triboelectric effect refers to the generation of electrical charges when two dissimilar materials come into contact and are pressed against each other or slide against each other, thus developing friction forces. The charge quantity that is generated depends upon the materials that come in contact. Various textile structures can be engineered as triboelectric generators (TGE), aiming to the maximum interaction between the triboelectric materials and hence the maximum performance of the generator. An example of a textile-based triboelectric generator is presented in figure 3.4. Textile triboelectric generators can give high output voltages. The triboelectric generator of figure 1.8.3 gives maximum output voltages of 28.13 V, 119.1 V and 11.2 V in stretching, pressing and rubbing motions, respectively.

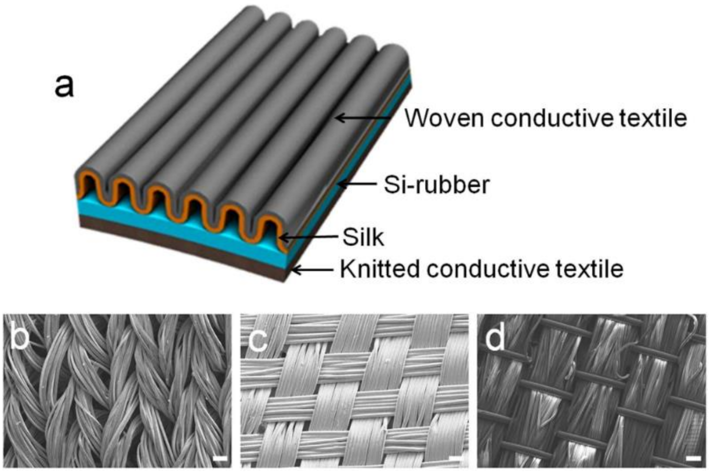

Figure 1.8.3. Corrugated textile-based TEG structure and morphology. (a) Schematic illustration of the CTTEG, SEM images of the (b) woven conductive textile, (c) knitted conductive textile and (d) silk [13]

Photovoltaics

Materials known as Photovoltaic (PV) cells can absorb photons with sufficient energy, as happens under the direct sunlight, and convert this energy to electrical current. A simple commercial form of PV fabrics that are available today, are conventional solar cells fabricated on a plastic substrate and then attached to a fabric surface usually by sewing. Research for making the fabric to operate by itself as photovoltaic, suggests the fabrication of PV fibres which can then be woven in a PV fabric structure. An example of this approach concerns the development of PV layers around a flexible polypropylene (PP) core fiber as presented in figure 1.8.4. So far the performance of PV fabrics is much lower than this of conventional solar cells, but future developments may increase the energy harvesting performance of PV fabrics.

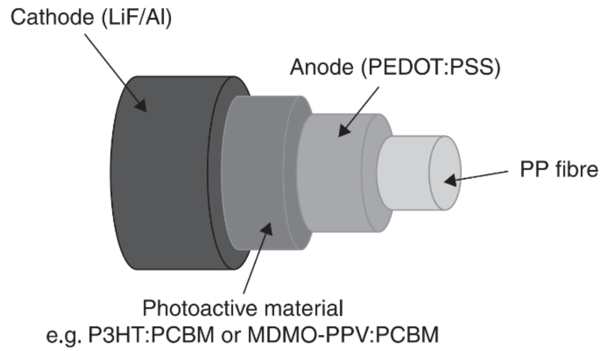

Figure 1.8.4. Schematic view of a coaxial photovoltaic fibre (Bedeloglu, 2010) [11,12]

Energy Storing - Textile capacitors

A capacitor, which is commonly known as battery, is a passive electrical component that can store energy in the electric field between a pair of conductors. The interest for lightweight and flexible batteries is increasing continuously, thus the research in textile capacitors becomes more intensive. An interesting example is the fabrication of a printed battery on a fabric surface, which realized by a German research team in the Fraunhofer Institute in Berlin. The battery is fabricated by screen printing a thick layer of a silver-oxide based paste and then by applying a thin sealing layer. The final result is a 120 μm thick AgO-ZN battery, printed on a textile substrate. This method allows high speed production of flexible textile batteries at low cost and can be applied in many different fabric substrates.

Summary

Developments in e-textiles can be considered as being in an early stage. Traditional materials for electronics are not suitable for e-Textile applications, thus a new generation of materials compatible with the textile properties and processing should be invented. In the new materials era, conductive polymers and hybrid organic-inorganic materials seems to be the leaders. Apart of the developments in the materials, we should keep in mind that manufacturing methods are also very critical for the transition from laboratory prototypes to industrial scale production of e-Textiles.

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CHAPTER 2

Advanced manufacturing methods

Edited by:

Aileni Maria Raluca
&
Rimvydas Milašius

2.1. Electrospinning

Rimvydas Milašius, Kaunas University of Technology, Lithuania

Electrospinning is a process when due to electrostatic forces fine polymeric fibres are forming. Formation of electrospun fibres is possible as well as from polymer solution as well as from polymer melt. Usually are forming fibres in the range from 20 nanometres till 2 microns. A fibres which average diameter is in the range till 500 nm in textile literature are named as nanofibres while thicker fibres are named in various styles – microfibres, submicrofibres, nano-microfibres as well as nanofibres although the last variant is using in not correct way. It is necessary to note that according to the description of nanomaterials, fine fibres can be named as nanofibres only in that case if more than 50 % of all fibres have diameter less than 100 nm. So, some mismatch arise in the description of what kind of fibres we can named as nanofibres. In the majority of textile literature, the following understanding is used – fibres which diameter are closer to 1 nanometer (till 500 nanometres) are named as nanofibre and fibres with diameter closer to 1 micrometer (above 500 nanometres) are named as microfibre or submicrofibre. The typical view of the electrospun web is presented in Figure 2.1.1., the example is manufactured from poly(vinyl alcohol) water solution and in this case nanofibres are created from poly(vinyl alcohol).

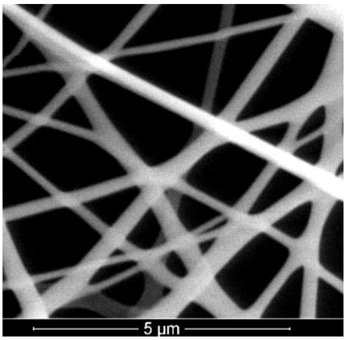

Figure 2.1.1 Typical view of electrospun web

It is necessary to note, that in majority cases the diameter of created nanofibres are distributed in very high level and distribution of diameters in the web usually is not close to Gaussian normal distribution. This phenomenon creates some difficulties for nanofibrous web structure estimation as it is not enough to show the average value of nanofibres diameter but also is needed to show the exact distribution of nanofibres diameters. The typical distribution of nanofibres diameter is presented in Figure 2.1.2 (the presented example is of poly(vinyl alcohol) nanofibres).

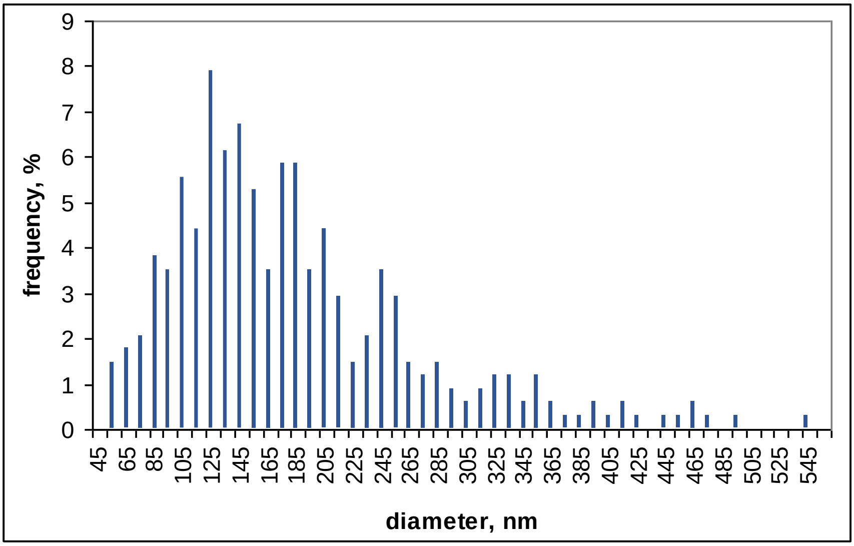

Figure 2.1.2. Typical distribution of electrospun nanofibres diameter

The electrospinning process is known for over 100 years, since 1900 when first electrospinning equipment was patent by J. F. Cooley. Since that time investigations in electrospinning become interesting for various researchers. However, the roots of the electrospinning process are going to Renaissance ages. The first scientist who noted the specific shape of a water droplet influenced by electrostatic forces created by electric amber was English scientist William Gilbert (sometimes known as Gilberd) which is regarded by various researchers as "father of electricity and magnetism". Later behavior of a droplet in the electrostatic field has been noted by famous physicist Robert Hook who mostly is known due to its describing of "Hook's law" that the force need to extend a spring linearly depend on the value of extension. Later also few researchers analyzed the behavior of the droplet in the electrostatic field and most significant works at the end of the 19th century made a famous British physicist John William Strutt, better known as Lord Rayleigh. He explained the droplet shape phenomenon in the electrostatic field, and theoretically and empirically described the required charge for droplet deformation. He builds the main scientific basis for the electrospinning process and equipment development.

As was noted above, the first equipment was patented by Cooley in 1900 and his next one in 1902, and very soon, after few months in the same 1902, W. J. Morton also patented his own apparatus for electrospinning. Very significant work was done by Czech-American scientist J. Zeleny which in 1914 published his first work. The model, developed by Zeleny, with some improvements is used till now. Once more important works in this early period of electrospinning process development were made by A. Formhals which since 1934 to 1944 patented few works for textile yarns electrospinning. In 1936 C. J. Norton patented first equipment for electrospinning from the polymer melt. In 1939 two Russian scientists N. D. Rozenblum and I. V. Petryanov – Sokolov developed electrospinning process for fibrous nonwoven filters manufacturing, also known as Petryanov's filter or Petryanov's fabric. This material was manufactured in former USSR and now is manufacturing in Estonia. Very significant work in electrospinning process development evolution was made by G. Taylor who in 1964 mathematically modeled the shape of the droplet in the electrostatic field. This form of the droplet at the time of electrospinning has been named as Taylor coin and such describing is used till now. The typical scheme of electrospinning is presented in Figure 2.1.3.

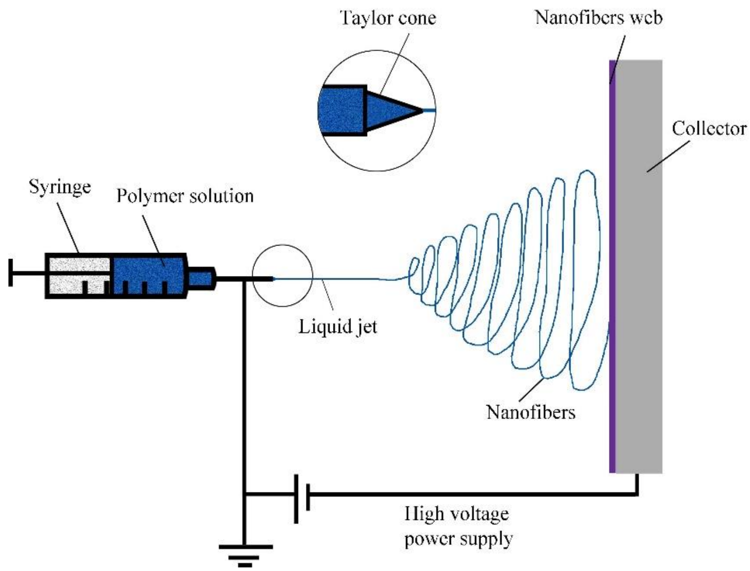

Figure 2.1.3. Typical scheme of electrospinning

Despite of a lot of very interesting theoretical works and patented equipment the electrospinning process till the end of the 20th century still was not well known for the majority of textile researchers. The interest in electrospinning rose since 1990's and in each year more and more papers were published in most important scientific journals cited in the data basis Clarivate Analytics Web of Science. The number of papers in last two decades till 2016 rose in each year, howevere in in 2017 decreased more than in 20 %. The progress in number of papers is presented in Figure 2.1.4.

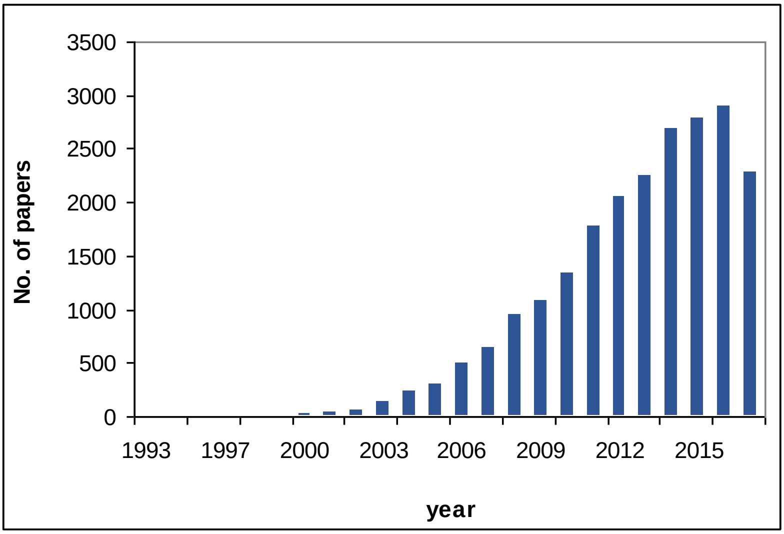

Figure 2.1.4. The progress year by year in number of papers cited in data basis Clarivate Analytics Web of Science

Published works are focused on various problems - on the usage for electrospinning of various polymers and their blends, on concentration of polymer solution, influence of distance between electrodes, used voltage and supporting material on which nanofibrous web is collected, on investigations of usage of materials covered by electrospun fibres for various applications, especially in medicine and health care and etc. Majority of papers are published in not textile journals – in physic, applied chemistry, medicine and others. It shows a very high importance of electrospining and electrospun nano or micro fibres for various kinds of advanced materials and their applications.

The importance of the electrospinning process significantly raised when the importance of nanomaterials was understood and the importance of textile-based nanofibrous materials becomes very interesting for various fields of physic and especially in electronics. These materials also are very important for medicine usage as the structure of the electrospun nanofibrous web is very similar to the structure of human tissue. Also, a structure of electrospun nanoweb can have so small pores that such material becomes waterproof but also is breathable. Yet more, the nanofibrous web can be used as a barrier material for wounds protection against infections as pores could be also smaller than bacteria, viruses or red cells of the blood. Electrospun nanofibrous materials are used for implants in surgical medicine, for regeneration of some parts of human organs and tissues, for bandages and plasters, for high accuracy filters, for electronic devices and micro solar batteries. They are especially important in the development of smart textile.

The fields of electrospun nanofibrous application are very wide and do not closed – various kinds of new materials or garments include in their structure some kind of electrospun nanofibres which gives for garment some new specific property. The importance of electrospun nanofibres grows due to their very low mass and very high surface. As the mass of such material is very low, very expensive materials can be used for manufacturing and functional properties creation.

The main disadvantage of electrospinning is very low productivity of all known equipment and due to that in a high level increase the cost of such material. Anyway, this technology is very important for advanced materials and garments development and manufacturing.

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2.2. Textile functionalization by plasma technology

Surdu Lilioara, Radulescu Ion Razvan, Aileni Raluca Maria, INCDTP, Romania

The perspective of the plasma technology in textile industry

The textile industry is being transformed by technical developments throughout the manufacturing chain from fiber to finished product. Casual wear, leisurewear and sports active wear has grown in importance in recent years and has put further demands for innovation on the fiber and finishing sector. The competitive advantage key in the 21st century is the development of textile products with increasing level of functionality. There are three basic appeals of functional textiles, namely: comfort, health and safety [1-3]. Textile materials have intrinsic properties that make them very valuable, flexible, lightweight, strong, large surface to volume ratio, good touch, softness etc. Because of this, they are excellent for imparting additional functionalities like hydrophobic, oleophobic or antibacterial. Traditional wet methods for applying these finishes require the use of large amounts of chemicals, water and energy. Plasma is a dry processing technique and provides a solution to reduce the use of all three mentioned resources.

Plasma technology is one of the fastest developing branches of science, which is replacing numerous conventional wet-chemical methods in laboratories and industries, with a huge impact in renewable energy, environmental protection, biomedical applications, nanotechnology, microelectronics, and other fields. Plasma, the complex mixture of ions, radicals, electrons, and excited molecules has replaced conventional methods to develop various nanostructured materials with complex morphology and advanced properties such as the production of vertically aligned CNTs, which is difficult to achieve with other synthetic methods.

Today working plasma plants are available at atmospheric pressure as well as in line systems for roll-to-roll manufacturing plants. Literature reviews stated that by treating wool fibers in plasma environment of it was found that shrink resistance is reduced and dye ability is improved.

On cotton, the plasma treatment with HMDSO lead to a surface with lotus effects, which means highly, improved clean ability, whereas the penetration behavior of water was not influenced. On synthetic fibers the hydrophilic / hydrophobic character could be changed in any direction and also coatings were possible to improve the resistance against hydrolysis.

The conventional wet treatments applied in textile processing for fiber surface modification and others are associated with many constraints. These treatments mainly concern with energy, cost and environmental issues. Application of Plasma technology at low temperature in textile processing can prove to be the best alternative for these issues. Unlike conventional wet processes, which penetrate deeply into fibers, plasma only reacts with the fabric surface that will not affect the internal structure of the fibers. Plasma technology modify the chemical structure as well as the surface properties of textile materials, deposit chemical materials (plasma polymerization) to add up functionality, or remove substances (plasma etching) from the textile materials for better applicability. The functional properties of the fabric can be modified by nano scale etching of surface by plasma gas particles. In textile processing, this technology can be explored in various areas like pretreatment, dyeing and finishing through different methodologies. Plasma technology is applicable to most of textile materials for surface treatment and is beneficial over the conventional process, since it do not alter the inherent properties of the textile materials, it is dry textile treatment processing without any expenses on effluent treatment, it is a green process and it is simple process. This technology can generate more novel products to satisfy customer's need and requirement.

Plasma technology offers an attractive way to add new functionalities to textiles, due to the major chemical and physical transformations, that are brought:
- Changes in the chemical properties of the surface layers
- Changes into the structure of the surface layer
- Changes in the physical properties of the surface layers.

Textile materials subjected to plasma environment, will acquire new functional characteristics as water and anti-soiling properties, hydrophobicity, conductivity, biocompatibility, as well as new or improved mechanical and optical properties. All these achievements will offer high benefit to traditional textiles. The advantages of the plasma treatment are of economic and qualitative nature, as well as environmental one.

Plasma treatment applications in the field of textile materials

Plasma treatment can be performed on natural fibers as well as on synthetic fibers, to achieve the effects such as wool degreasing, shrink proofing, change of fiber wettability (hydrophilic, hydrophobic properties), increase in dyestuff affinity, anti-felt finishing for wool or sterilization.

Plasma treatment can improve the functionality of textile materials, such as:

- Wettability: there are a lot of investigations on plasma treatment of textiles for changing their wettability properties, for examples, polyester, polypropylene, wool that plasma treatment can improve the ability of these fibers to retain moisture or water droplets on their surface.

- Hydrophobic finishing: the treatment of cellulosic fibers, wool, silk, PET, with identified plasma gas such as HMDSO, fluorocarbons, leads to a smooth surface with increased contact angle of water.
- Adhesion: plasma technology can increase adhesion of chemical coating and enhance dye affinity of textile materials.
- Product quality: Felting is an essential issue of wool garment due to the fiber scales. Conventional anti-felting gives negative effects on hand feel and environmental issues. Oxygen plasma gives anti-felting effect on wool fiber without incurring traditional issues.
- Functionality: different kinds of plasma gases provide special functionality to textile materials such as UV-protection, anti-bacteria, medical function, bleaching, flame retardant etc. As far as textile is concerns these technology have been shown to enhance dyeing rates of polymers, to improve colorfastness and wash resistance of fabrics. Research has shown that improvements in toughness, tenacity, and shrink resistance can be achieved by subjecting various thermoplastic fibres to a plasma atmosphere. Unlike wet processes, which penetrate deep into the fibres, plasma produces no more than a surface reaction, the properties it gives the material being limited to a surface layer, who can be applied to both natural and synthetic fibers as well as to non-woven fabrics, without having any adverse effect on their internal structures.

Application of plasma treatment in textile processing

Different type of plasma treatment applications in the field of textile, plasma treatment can be thermal and non-thermal plasmas. Non-thermal plasmas are those in which the thermodynamic equilibrium is not reached even on a local scale between the electrons and the higher mass particles (neutral atoms all molecules, ions and neutral molecules fragments). Thermal plasmas are characterized by equilibrium, or a near equality, between the three components of the plasma: electrons, ions and neutrals. Non-thermal plasma is also known as cold plasma, are particularly suited for textile surface modification and processing because most textile materials are heat sensitive polymers. Cold plasmas may be divided into atmospheric pressure plasma and vacuum or low pressure plasmas.

Nowadays, plasma technology for the surface preparation and modification has gained increasing attention from scientists due to some of its special characteristics such as dry technology and ecofriendly, low energy and chemicals consumption. Moreover, plasma technology is easy to use and it is applicable to fibers, yarns and fabrics on the same equipment by changing a positioning device.

The principle of the plasma treatment consists in having the textile material be exposed to a very reactive environment that contains ions, electrons, photons, UV radiations, neutral molecules, free radicals and atoms. The plasma treatment results depend on the treating conditions: the plasma generator, the plasma frequency, the plasma chamber, the primary or secondary plasma, the vacuum, the composition of the plasma gases, the treating time, the plasma power, and also, the differences of material and the presentation form of the textile materials.

The general reactions owing to the plasma treatment are pickling, cleaning, actuating or coating, material surface oxidizing, chemical group generating and surface fringing, material hydrophilic or hydrophobic rendering. The wool fibers that are treated in a plasma environment exhibit a non-felting phenomenon that is due to an increase of the fiber/fiber rubbing coefficient. There is an enormous potential in the plasma treatment for fabrics (figure 2.2.1). Plasma treatment has proved to be successful in the shrink-resist treatment of wool with a simultaneously positive effect on the dyeing and printing. Wool science is continuing to grow, leading to innovations.

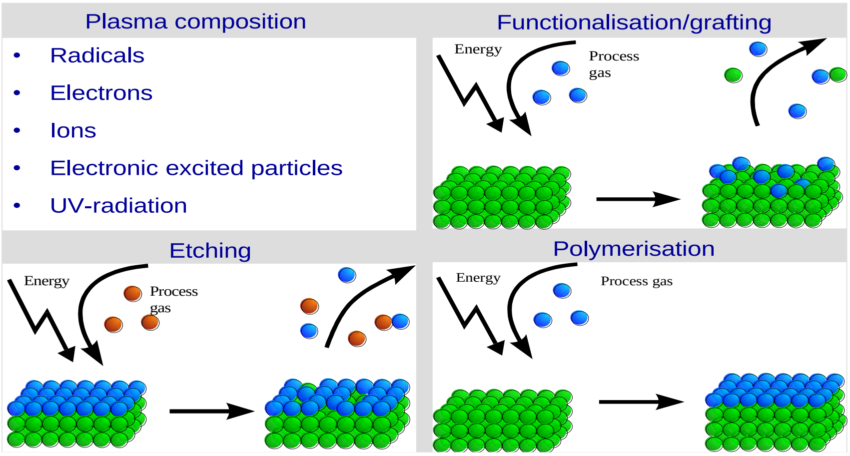

Figure 2.2.1 . Plasma treatment applications for fabrics

The morphology of wool is highly complex, not only in the fiber but also on the surface as well. It is in fact the surface morphology to play an important role in the wool processing. Traditional wool textile finishing operations are carried out in wet processes. Unwanted effects such as shrinkage, felting and barrier of diffusion are most probably due to the presence of wool scales on the fiber surface. In the past, the modification of wool surface morphology was conducted either by chemical degradation (oxidative treatment using chlorination) or by deposition of polymers. However, in both processes, a large amount of chemicals generated from incomplete reactions polluted the wastewater. The oxidation is also required to reduce the water-repellence of wool to obtain good dye-ability. Dyeing represents one of the most expensive processes in terms of energy and water consumption, as well as high chemical agents that are discharged in wastewater or released in the atmosphere. Moreover, the high temperature of these processes can weaken the fiber structure and consequently the mechanical properties.

The main advantages brought by plasma treatment consist in improving the diffusion of the dye into the fibres at lower temperature compared to traditional methods, which will lead to a reduction in water, energy and dye consumption. With regard to the effect on the wool fiber surface, the hydrophobic lipid layer on the surface is oxidized and partially removed when subjected to plasma. As the surface is oxidized, the hydrophobic character is changed to become increasingly hydrophilic. Plasma technology applied to textiles is a dry, environmentally- and worker-friendly method to achieve surface alteration without modifying the bulk properties of different materials. In particular, atmospheric non-thermal plasmas are suited because most textile materials are heat sensitive polymers and applicable in a continuous process. In the last years, plasma technology has become a very active, high growth research field, assuming great importance among all available material surface modifications in textile industry.

Plasma technology can be used for ablation and deposition processes. While ablation enables a complete cleaning of textiles from manufacturing residuals, deposition can be controlled in the nanometer range to achieve new functionalities. The textile properties remain unaffected with both treatments and they are dry and eco-friendly processes. Compared with current standard finishing processes, plasmas have the crucial advantage of reducing the usage of chemicals, water and energy. Moreover, they offer the possibility to obtain typical textile finishes without changing the key textile properties.

Working in the field of textile chemistry is challenging due to the high use of energy and water, and the large diversity and number of chemicals. Although plasma chemistry opens up new opportunities, it has many disadvantages as well.

Conclusion

Plasma technology can be applied to various areas of textile processing vis-à-vis, pretreatment, coloration and finishing. Plasma technology can be used to remove PVA sizing material from cotton fibers, to impart anti-felting property to wool, to enhance dye ability of natural as well as synthetic fibre textiles. Special functional textiles can be produces with the help of this technology. Thus, despite this being costly technology initially, it offers greater production rate, less production cost, better products and most importantly, finishes on fabrics that are either difficult to obtain by other technology or not obtained at all. Above all these, plasma technology gives the freedom from environmental problems that traditional technologies pose.

Plasma technology offers advantages such as environment friendly technology, dry and clean process, little or no water consumption and minimal waste generation. Research in this field has shown tremendous prospects of this technology as eco-friendly and efficient way for surface modification of textile and polymer materials. Functional finishing of polyester and cotton fabrics was achieved by deposition of hydrophobic coating through plasma polymerization.
The plasma treatment and grafting of the textile materials with water repellent monomers can be an alternative to classical treatments that are more expensive and have a negative impact on the environment.

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2.3. E-Textile manufacturing

Aileni Raluca Maria INCDTP, Romania

E-textile- overview

E-textiles (electronic textiles or smart textiles) are textile with embedded electronics parts (actuators, batteries, sensors or small computers). The e-textile defines a product at the common frontier between textile and electronics (figure 2.3.1). The e-textile goal is to obtain a flexible and comfortable product for wearer, with a function such as sensing, actuating, electrical power generating, that is useful in areas such medical, military/defense, protective, sport space and security.

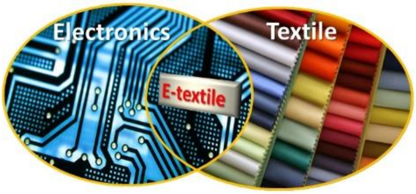


Figure 2.3.1 E-textile ➔ textiles – electronics barrier

An electronic textile is a fabric that can conduct electricity because is made by using metallic yarns, fibers, coating with micro/nanoparticles or by conductive polymers. Electronic textiles (e-textiles) are fabrics that have electronics and interconnections woven into them. An electronic textile refers to a textile surface that incorporates capabilities for sensing (biomedical signals or environmental parameters), communication (wireless), power transmission, and interconnection technology that allow sensors or things such as signal processing devices to use together within a fabric through IoT (Internet of things). E-textiles usually contain conductive yarns that are either spun or twisted and contain conductive material (silver, copper or stainless steel) to enable electrical conductivity.

The technologies for e-textile must allow:

➔Mass production of the flexible e-textile

➔Cheap manufacturing

➔Manufacturing of the product with required comfort and wearability parameters (thermal conductivity, electrical conductivity, permeability, strength, washing resistance)

E-textiles are product based on textile parts and electronics. There are two groups of e-textile products:

• E-textiles with classical electronic devices such as conductors, integrated circuits, LEDs, and conventional batteries embedded into garments.

• E-textiles with electronics integrated directly into the textile substrates such as passive electronics (conductors and resistors) or active components (transistors, diodes, and solar cells).

E-textiles – advanced manufacturing methods

The major requirement for manufacturing methods used for e-textile is to generate a fabric with electro-conductive properties in order to obtain electrical conductors or semiconductors components of the circuits, sensors, actuators, EM or EMI shields manufacturing. The most important technologies used for obtain e-textile (textile with embedded electronics or textile surface with electro-conductive properties) are:

- ➢ **Classical technologies** based on integration of the conductive yarns into textile through new development in embroidery, weaving and knitting technologies (figure 2.3.2).
- ➢ **Advanced technologies** – **textile fabric become silicon wafers**:

Printing technologies such 3D printing and 4D printing have great perspectives to revolutionize the manufacture of e-textiles.

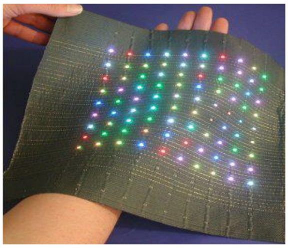
• **3D printing** conductive technology involves additive manufacturing and can be used to fabricate conductive components (circuitry, sensors, EMI and RF shields) directly onto fabric, using different processes:

➔FDM process (figure 2.3.3), that involve a layer-by-layer extrusion of heated filament materials;

➔LDM process for the fabrication of conductive 3D nanocomposite (figure 2.3.4) based microstructures

➔ SC3DP process for the fabrication of the conductive CNT/PLA nanocomposites (figure 2.3.5) used for EMI shielding applications.

a. Embroidery machine STICTRONIC adding conductive yarns to the fabric [9]



b. Light-emitting fabric with LEDs: conductive yarns interwoven with polyester yarns [10]

b. Light-emitting fabric with LEDs: conductive yarns interwoven with polyester yarns [10]

Figure 2.3.2. Classical technologies – new developments

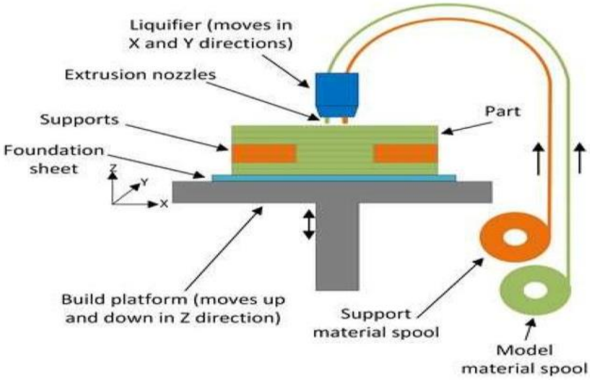


Figure 2.3.3. Fused-deposition modeling (FDM) process [12]

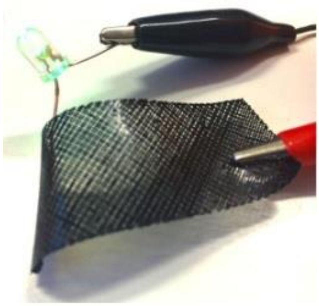


Figure 2.3.4. 3D printed MWCNT-based nanocomposite woven structure used as conductive element in a simple electrical circuit [11]

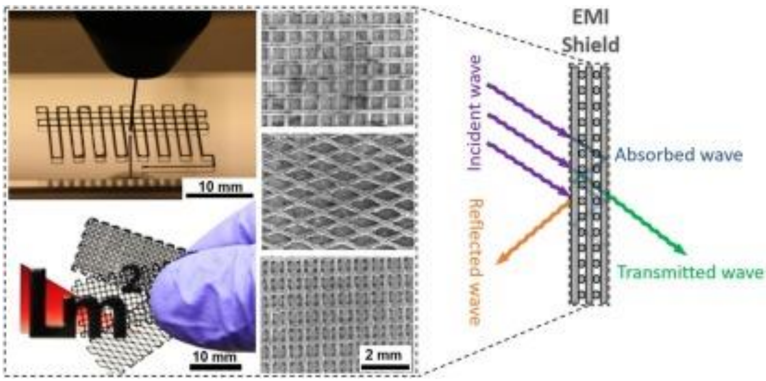


Figure 2.3.5. 3D printed CNT/PLA nanocomposites for EMI shielding [13]

•**4D printing** (technology (figure 2.3.6) is used for composite materials and represents a combination of 3D printing technology and the dimension of transformation over time (smart materials).

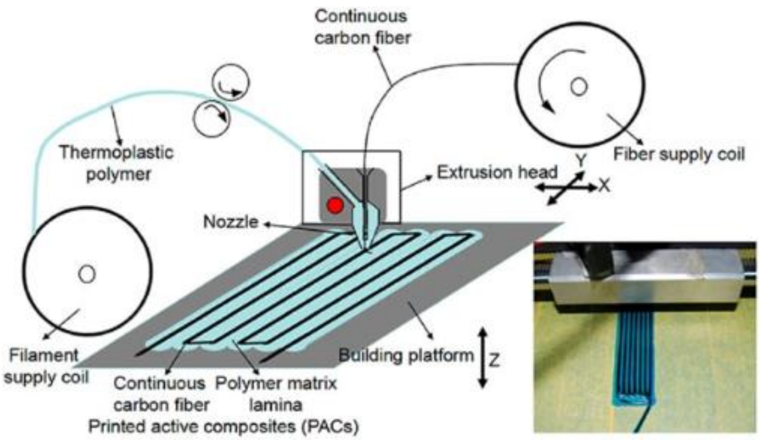


Figure 2.3.6. 4D printing - modified FDM process for PACs [14]

• **Surface coating** technologies such as PVD (plasma sputtering), CVD (Chemical Vapor Deposition), electroless metal plating (silver, copper, and nickel, gold) and lamination are used for fabrication of the e-textiles.

➔Electroless plating is a deposition method in electronic packaging. However, the stability of electroless plating depends on the substrate material, the pretreatment process, the type of solution used, and the pH and temperature during plating. By electroless Ag plating (figure 2.3.7), silver layers have a good adhesion and washing resistance only on Nylon fibers.

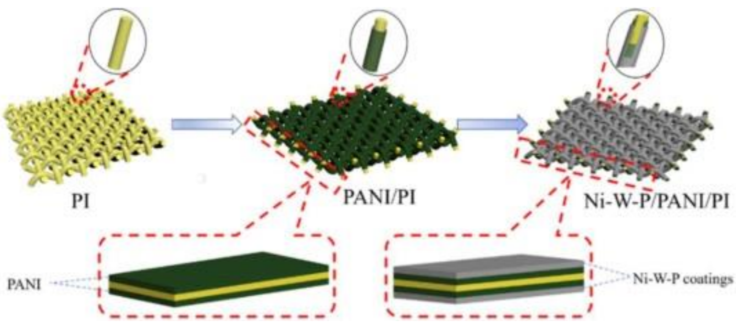


Figure 2.3.7. EMS fabric prepared by nickel-tungsten-phosphorus electroless plating [16]

➔ Plasma sputtering (figure 2.3.8) is an environment-friendly technology that can be used for textile metallization by deposition of metals such as copper (figure 2.3.9), silver in order to improve electrical conductivity of the textiles. The metal deposition by plasma sputtering allows cleaning and metal deposition in one-step with low amount of silver. Sputtering is a particle vapor deposition (PVD) method and is based on the theory that ion collisions dislodge nanoparticles from the target material, which are deposited on the textile surface. The sputtering deposition is performed in a vacuum chamber by using argon gas and a metal target.

➔ **Lamination** of the stretchable thin-film transistor (TFT) driven LED display laminated into textiles developed by Holst Centre, IMEC and CSMT – figure 2.3.10.a.

➔ Coating fibers with LED/OLED layers (Fraunhofer IZM) – figure 2.3.10.b.

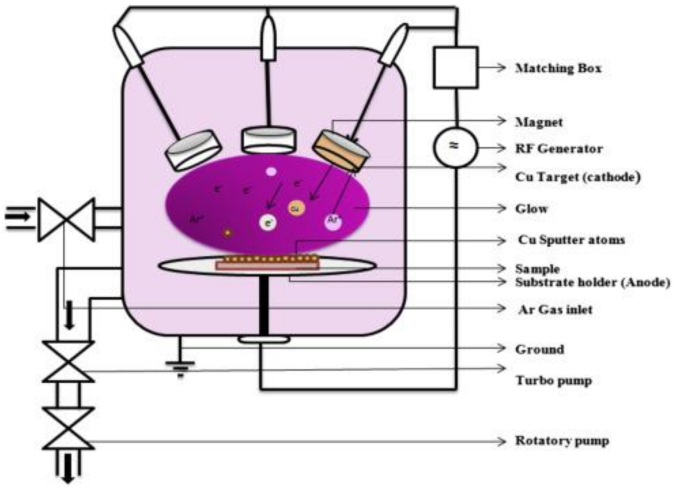
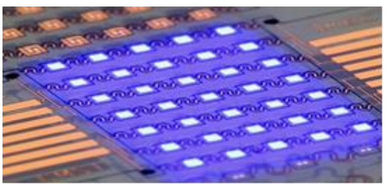
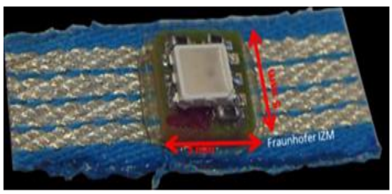


Figure 2.3.8. Schematic diagram of plasma sputtering [17]

Figure 2.3.9. Uncoated/coated copper fabrics [17]



a. TFT laminated into textiles [18]



b. Smart LED pixel bonded to textile using NCA [19]

Figure 2.3.10. Coating lamination textiles with TFT/ LED / OLED

• Electrospinning is "a voltage-driven technique involving electrostatic driven process used to create electrospun fibers" and can be used to fabricated transparent nanofibers for transpared LED e-textiles (figure 2.3.11 and 2.3.12). In addition, using these technologies, are obtaining the e-textile such as:

➔ Sensors based on the modified surface sensing properties (capacitive, resistive, optical)

➔ Actuators based on the modified surface actuating properties (electroactive fabrics and auxetic
Fabrics)

➔ Batteries and energy harvesting (fabrics that act as capacitors storing the kinetic, piezoelectric and thermal energy in order to generate electrical power).

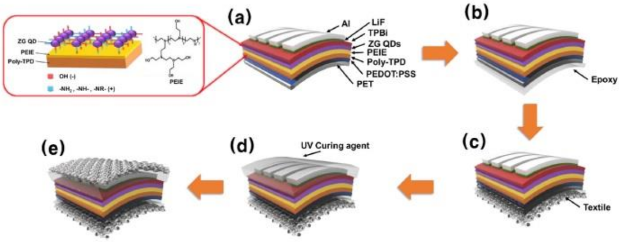


Figure 2.3.11. The fabrication process of transparent nanofiber textiles with intercalated ZnO @graphene QD LEDs (a-e) [20]

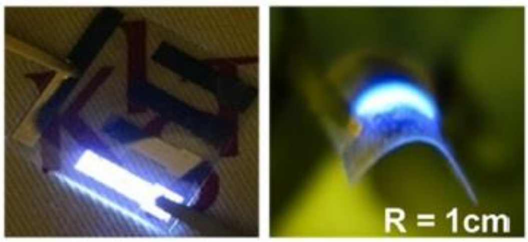


Figure 2.3.12. Blue light emission from textile/LED/textile structure devices and after bending (radius of curvature: R = 1 cm) [20]

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2.4. Advanced Knitting Technologies

Mariana Ursache and Luminita Ciobanu, "Gheorghe Asachi" Technical University of Iasi, Romania

Introduction

Knitting is the one of the two methods of producing textile structures besides weaving. In case of knitting the fabrics are produced by converting the yarn into interconnected loops in weft or warp direction. Besides their most important use for garments, knitted fabrics are now gaining more and more ground in the area of technical textiles such as geotextiles, automotive textiles, medical textiles, sports textiles, agricultural textiles, aerospace industry, protective textiles, and so on.

Knitted fabrics are divided into two large groups i. e. warp and weft on the basis of yarn feeding and direction of movement of yarn in fabric with respect to the fabric formation direction. In the weft knitting technique the loops are formed horizontally from the same yarn, as shown in figure 2.4.1.a. In the warp knitting technique the loops that are formed are connected in the warp direction and movement of yarn is also in the warp direction, as shown in figure 2.4.1.b.

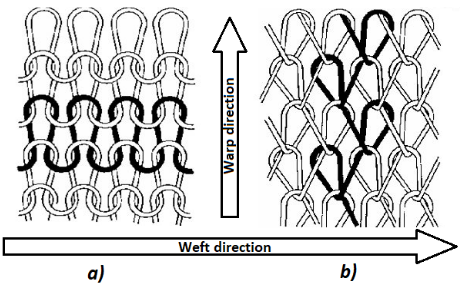


Figure 2.4.1. Basic weft and warp knitted structures

In correlation with these two groups of knitted structures and techniques, there are two broad knitting technologies, namely weft knitting and warp knitting. A general classification of the knitting technologies that takes into account the two groups of structures as well as the knitting machines, the shape and number of the needle beds, is illustrated in figure 2.4.2.

With innovative technical developments and a modern production environment, the actual knitting processes enable the fabrication of a large spectrum of knitted products to cover actual trends of their end use.

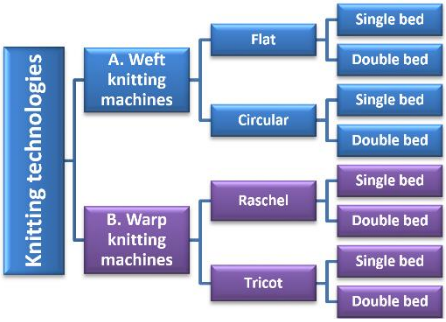


Figure 2.4.2. General classification of knitting technologies and machines

The following paragraphs present significant advances in the knitting technologies that take into consideration the latest developments concerning the applications of the knitted products as well as the technical issues to be considered in the machine manufacturing.

Advances in weft knitting technologies

In the last decades, the leading knitting machines manufacturers have included in their product portfolio 3D knitting machines and patterning software which are used for the production of fabrics for fashion as well as for technical applications.

Product developers come to machine manufacturers to produce industrial and technical fabrics and 3D knitted forms for medical, sportswear, automotive, aviation and upholstery fields.

a) Developments in flat knitting technologies

• *Developments related to fashion industry*

Over the last 20 years, there has been spectacular technical developments of machines and software in the production of knitted fashion garments, especially on flat machines. These developments have made it possible to rationalize design and production of knitted garments.

The manufacturing process of flat knitted garments can be divided into three different production methods (as presented in figure 2.4.3):

A. Cut & Sew/Cut Stitched Shape;

B. Fully Fashioned Garment/ Integral Fully Fashionned;

C. Seamless technologies / Wholegarment / Knit and Wear.

The seamless technologies have become more and more popular being seen as an alternative to conventional knitting. Their main benefits include a better fit and comfort through 3D shaping, an improved draping through elimination of seams, a quick-response production and minimum material usage through one-piece construction.

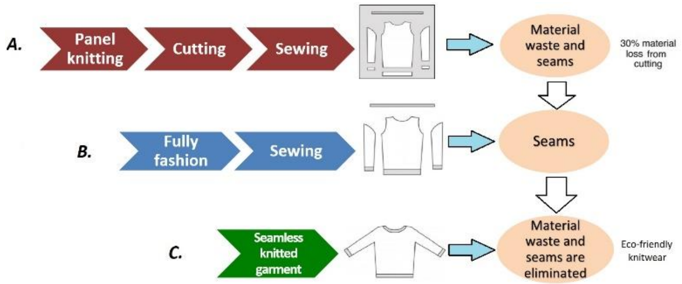


Figure 2.4.3. Comparison of three different technologies of producing flat knitted garment

Shima Seiki is considered the pioneer of this technology by launching, in 1995, the patented Wholegarment technology that enables three-dimensional shaping of garments. A similar technology, under the name of „Knit and Wear", was launched by Stoll in 1997, the main competitor of Shima Seiki.

• *Technical innovations for increasing machines' potential*

In the same time, the new technologies are not only considering the capability of producing seamless products but utilising the machines' full potential that has dramatically improved through the application of the newest technical innovations, such as: four-needle bed configuration, slide needles, contra sinkers, spring-type sinkers, holding down sinkers, presser foot, transfer jacks, loop presser, stitch presser, new computer-controlled takedown system, auxiliary take down mechanism etc. A selection of these developments is presented below.

<u>The four needlebed configuration</u> of the modern computerized flatbed knitting machines MACH2XS of Shima Seiki significantly expand the capabilities in knit and transfer allowing the unprecedent design and patterning in Wholegarment production. This new needlebed configuration (see figure 2.4.4) consists in 2 extra beds (1 and 3) on top of the conventional V-beds (2 and 4). All four beds are equipped with the new original Slide Needle. The machines are capable of knitting Wholegarment using all needles in the working area.

<u>The new Slide Needle</u> of Shima Seiki is an entirely new needle design that enables practically unlimited stitch designs (figure 2.4.5). A flexible two-piece slider, that replaces the latch, splits and extends beyond the needle hook and extends knitting potential especially by facilitating complex transfers [4]. The transfer action does not require the transfer clip on the needle therefore, the needles are centrally positioned in the needle grooves (figure 2.4.6.b). This positioning results in perfectly symmetrical loop formation and high-quality fabrics.

<u>The new Contra-Sinkers</u> with their counter-movement reduce the total movement of the SlideNeedle leading to significant improvements in productivity and a better quality of fabrics while using a wider variety of yarns .

The <u>new computer-controlled takedown system</u> is the newest technical innovation applied for taking-down the fabric when knitting 3D applications or wholegarment.

The system is able to controll the takedown tension for the two sides of the fabric that permits three-dimensional shaping resulting in garments with more accurate dimensions which conforms better to the body shape.

Figure 2.4.4. Four needlebed configuration

Figure 2.4.5. The new Slide Needle of Shima Seiki

a) Conventional latch needles and sinkers   b) Slide needles and contra-sinkers

Figure 2.4.6. Needle and sinker positioning

<u>Two Loop Presser Beds</u>, developped by Shima Seiki on SRY series, improve the loop formation by controlling the pressdown of individual loops [6]. The loop presser beds are placed above both front and back needlebeds. This new technique presents great capability in knitwear. Specialty yarns such as metallic yarns can be knit thus offering great opportunities for applications in other areas than fashion.

<u>New computerized warp/weft hybrid flat knitting machine</u>, from Shima Seiki (LAPIS®), combines warp insertion capability with the latest developments in weft shaping technology. Warp insertion is performed with the use of special plating cams located on each side of the single-Knitran® system on the front carriage.

b) Developments in circular knitting technologies

Circular knitting machines are widely used in the knitting industry to produce knitted fabrics. They can be built in a large variety of diameters.

• *Seamless knitting technology*

Seamless circular knitting machines differ from seamless flat knitting machines.

They can produce more than one tube that have to be joined together. The complete garments knitted on circular machines may also only need a minimal cutting operation. Also, seamless circular machines require different diameters in order to fit the garment size. Consequently, seamless knitting on circular machines is not true seamless knitting. The most representative machine manufacturers in this area are Santoni, Sangiacomo, and Orizio Santoni. The seamless machine "Santoni", a four-feed single-jersey electronic circular machine, knits seamless tubular body-sized and enables the creation of a shaped garment by reciprocal movement. The machines produce swimwear, sportswear, outerwear, underwear.

• *Spin-knit technology*

Recently, three circular knitting machines manufacturers (Mayer&Cie, Terrot and Pai Lung) presented their spin-knit machines that spin the yarn from rovings that are mounted close to the machine and knit the fabric from the spun yarn on the same machine (exemplified in Figure 2.4.7). In this way, the production process is shortened, leading to lower production costs, less energy consumption than the conventional process, lower CO2 emission level.

Figure 2.4.7. The Spin-knit machine Spinit 3.0 E from Mayer & Cie

Advances in warp knitting technologies

Warp knitting is a versatile technology that presents several advantages: extremely high productivity (similar to or even higher than weaving); possibility of producing a large range of fabric structures, from closed to open, with applications varying from clothing to decorative products, to technical applications (like medical knits, sport wear, packing, agriculture, composite reinforcement, etc.); possibility of inserting in-lays yarns (warp, weft, multiaxial); perfectly suited to produce net structures; excellent control of properties (in plane and through thickness); the fabrics have very good dimensional stability, no risk of unroving. Tricot technology presents several advancements that improved machine performance, like increased knitting speed (up to 3000 rpm), finer gauges (up to 44E), working width (up to 6.60 m), electronic control for all mechanisms, etc.

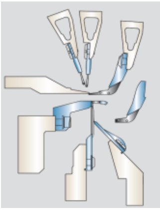
Double-bar Raschel machines are used for producing a large range of three-dimensional textiles (Figure 2.4.8). For increased productivity, the latch needles were replaced with compound needles.

Figure 2.4.8. Double bar machine – knitting elements

The spacer fabrics are produced by knitting two independent layers (with separate guide bars), connected by pile yarns fed by1-2 guide bars knitting on both needle bars (Figure 2.4.9). The gap between the beds determines the fabric thickness which normally vary between 1 to 15 mm. High distance double bar machines (with flexible trick plates) can produce spacer fabrics with increased thickness (20 to 65 mm). The main applications for these materials are mattresses, shoes, upholstery for car seats.

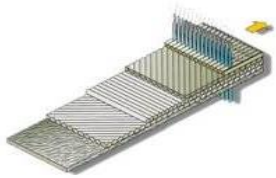
Figure 2.4.9. Spacer fabric - cross section

Seamless warp knitting is another development with high market potential - functional sportswear, underwear, hosiery and fashionable outerwear.
Apart from the possibility to control the tubular shape according to the shape of the product, the use of the piezo jacquard technology allows for limitless structure patterning. Jacquard bars have piezo elements that can be displaced individually, both overlapping and underlapping, to the right or left, modifying the normal yarn evolution by feeding it to the neighbouring needle, affecting the compactness of the fabric. The bars were first developed for lace machines but now their use is widely spread due to the patterning possibilities they offer.
Technology for multiaxial warp knitted fabrics for composite reinforcement is another significant development. The technology is based on the formation of layers (standard 3) of glass or carbon rovings, one placed at 90° (weft insertion) and the other at different angles (adjustable) that are fed in the knitting area, where filler threads are added and the knitted stitches (pillar or tricot evolutions) connect the resulting fabric (Figure 2.4.10). The non-crimp layers of yarns are fed using special carriages that move across the table, placing the yarns at the precise angle needed in the application.



a) Knitting elements

b) Carrier to unwind the non-crimp yarns



c) Aspect of the layers, with a mat of chopped fibres at the bottom

Figure 2.4.10. Multiaxial non-crimp warp knitted fabrics

Even if flat knitting is predominant, there are circular warp knitting machines using small diameters cylinders. These machines produce tubular netting for packing, fish growing factories and net stockings.

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2.5. Plasma Treatments

Andrea Zille, Antonio P. Souto, Universidade do Minho, Portugal
Fernando R. Oliviera, Federal University of Santa Catarina (UFSC), Brazil

Introduction

In recent years, plasma technology has assumed a great importance among all available textile surface modifications processes. It is a dry, environmentally- and worker-friendly method to achieve surface alteration without modifies the bulk properties of different materials. The plasma state also known as the fourth state of matter, is an electrically neutral ionized gas composed of neutral energy species, ions, photons and excited species not bound to an atom or molecule. More than 99% of the known universe is in the plasma state, except for the celestial cold bodies and planetary systems. The most used plasma classification divide plasmas in two categories: thermal plasma, when species are in thermal equilibrium, and cold plasma, when species are not in thermal equilibrium. Thermal plasmas are characterized by very high temperatures of electrons and heavy particles close to high ionization level. Temperatures can range from 4000 K, where species such as Cesium is easily ionized, to 20000K for species of difficult ionization, such as helium. Thermal equilibrium implies that the temperature of all species (electrons, ions, neutral species) must be the same. Some examples are: electric arcs, plasma jets from rocket motors and thermonuclear plasma-generating reactions. Thermal plasma is obtained at high gas pressures, which implies many collisions in the plasma since the average free path of the species is small. In this way, the energy exchange between the species of the plasma is efficient maintaining equal temperatures among the species. Cold plasma, also called non-thermal plasma, is composed of low-temperature particles (charged and neutral molecules and atomic species) and relatively high electron temperatures that are associated with low ionization. For cold plasmas, low pressure is used, which results in a few collisions of the plasma species, since the average free path is long. Consequently inefficiencies occur in the energy transfer, caused in the different temperatures of the plasma species. Cold plasmas are particularly appropriate for textile surface modification and processing because most fiber-based materials are heat sensitive polymers. Cold plasma treatments can be used to improve the fibre-matrix adhesion by introducing polar groups, by deposition of a new layer of the same polymer or by changing the surface roughness of the substrate. These characteristics may favour the formation of strong bonds between the fibre and polymeric matrix. Such forms of discharge have the major advantage of inducing significant surface chemical and morphological modifications improving hydrophilicity and making fibers more accessible to various chemical species without altering the bulk properties of the materials. Cold plasmas may be divided into atmospheric pressure plasmas and vacuum or low-pressure plasmas (Figure 2.5.1).

Low-pressure plasma remains the preferred technology to achieve various effects by etching, polymerization or formation of free radicals on the surface of the textile substrate as in the case of superhydrophobic and flame retardant coatings. Moreover, in the case of polyester and polypropylene fabrics dyeing the low-pressure plasma technologies showed the best results, especially for disperse dyes. However, low-pressure plasma treatments require expensive vacuum systems, therefore making it difficult to upscale and obtain continuous processing.

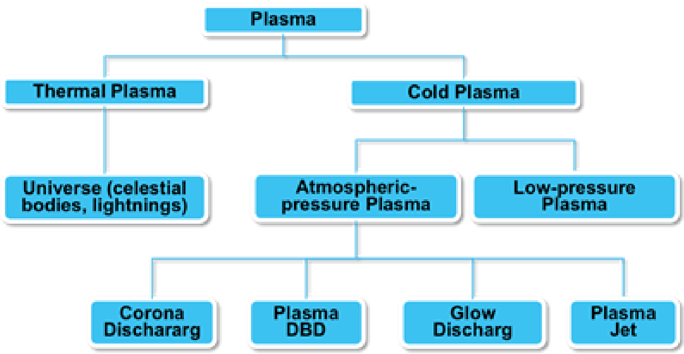

Figure 2.5.1. Plasma classification

Atmospheric plasma is an alternative and cost-competitive method to low-pressure plasma and wet chemical treatments, avoiding the need of expensive vacuum equipment and allowing continuous and uniform processing of fibers surfaces. The dielectric barrier discharge technology (DBD) is one of the most effective non-thermal atmospheric plasma sources and has been attracting increasing interest for industrial textile applications. Recently, both surface activation and deposition of thin functional coating by means of DBD atmospheric pressure plasma have been investigated in order to confer to textiles various properties (Figure 2.5.2), such as affinity for painting and dyeing, stain-resistance, antibacterial, no-shrinking and no-felting character. At this purpose different feeding gas mixtures have been used, from non-polymerizing ones (air, Ar, He, N2, O2), to hydrocarbon, fluorocarbon and organosilicon precursors.

Due to the intrinsic sterility of the treated surface, plasma processes are also attractive for applications in biology and medicine. In medical, food and textile fields, bacterial adhesion and subsequent surface growth is a persistent problem that leads to infection and biomaterial failure. Medical textiles are used in a range of applications from bandages, dressings, suture and surgical clothing to implants such as scaffolds, stents and meshes. Infections associated with these devices are responsible for at least 2-7% of post-operational complications increasing mortality and healthcare costs. In the last decade, due to operation at atmospheric pressure and mild conditions, and to its ability to ignite plasma in small volumes, several efforts are being exerted to develop the dielectric barrier discharges (DBD) plasma processes for biomedical applications such as environmentally friendly non-fouling and antibacterial coatings. Several strategies using DBD plasma have been employed to impart antimicrobial properties to textiles materials (Figure 2.5.3). Silver (Ag) or Ag ion and quaternary ammonium salt are the most investigated antimicrobial agents. There is increasing interest in use of metals, especially silver and copper in a form of ions and especially nanoparticles as antimicrobial finishing agents, because of their pronounced oligodynamic and biocidal activity.

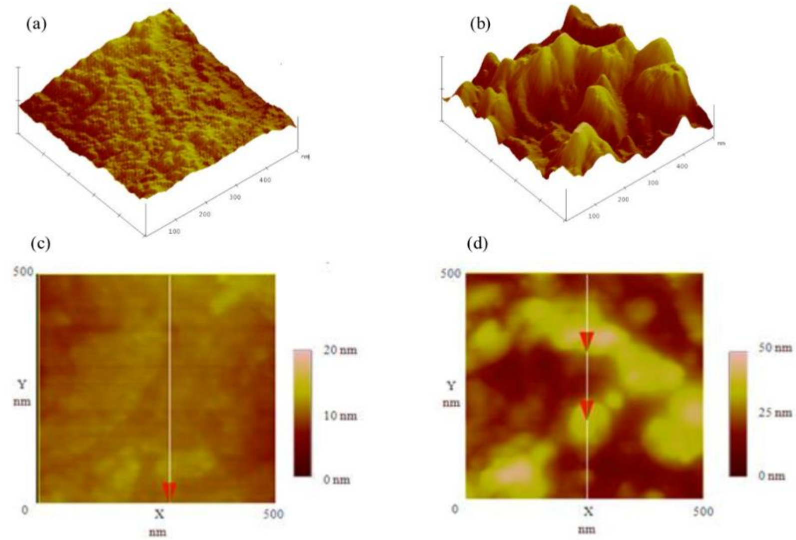

Figure 2.5.2. Example of a polyester fiber before (a,c) and after (b, d) DBD plasma treatment

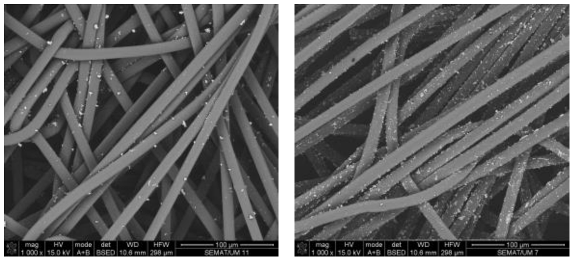

Figure 2.5.3. Example of AgNPs on polyester fiber before and after DBD plasma treatment

Notwithstanding the clear advantages of plasma technology application, its use in textile industry is limited. This is due to four main reasons: i) The traditional and not open to novelty of the textile industry sector; (ii) The contaminations or different surface conditions of the textile can influence negatively the surface cleanliness because plasma treatment only influences the top layer of the materials; (iii) The porous and 3D structure of textiles difficult the penetration of the plasma species deep into fabric structure as the wet processes; (iv) Textile materials have a large surface area, usually one order of magnitude larger than flat films. Despite that limitation, in the last decade due to constant technological and scientific developments, plasma technology is today used for several specific applications in technical textile industry and its use in improved devices for wider application is near to breakthrough. In the textile industry vacuum plasma technology is more advanced than atmospheric-pressure plasma technology because it is easier to control concentration, large volume of plasma, composition and process chemistry of the gas atmosphere in a closed system under vacuum. Several low-pressure plasmas company already commercialize equipment for the textile industry: the Italian (HTP Unitex, SAATI), Belgian (Europlasma), English (P2i) and Austrian (Textilveredelungs GmbH Grabher) manufacturers produce and sale roll-to- roll low-pressure gas plasma systems for surface activation in textiles to improve wettability and adhesion, and for a hydrophobic/oleophobic finishing with a plasma polymerization. Other European plasma equipment providers also develop low-pressure plasma products for the textile market such as Grinp, Softal, Iplas, Ahlbrandt Systems, and Arioli. In large roll-to-roll equipment low-pressure vacuum plasma treatment is in general economical viable. A typical full costing for plasma activation is in around 0.02 € m-2. On the other hand, the costs of plasma coating at low pressure are higher (0.05 € m-2) because of the lower web speed and the more expensive process gases. Despite the obvious advantage of low-pressure plasma in numerous applications, vacuum plasma must operate off-line in batch mode. Atmospheric pressure plasmas have a major advantage in textile process that operate at higher processing speeds, for treat full width textiles (2 meter or wider) in continuous on-line mode allowing the easy integration in the conventional textile finishing lines. Some example of commercial atmospheric-pressure plasma technologies based on corona, DBD, Glow Discharge and new atmospheric devices are available: i) an industrial prototype DBD apparatus build by the German company Softal in collaboration with the textile engineering department of the University of Minho (Portugal) was tested by a textile industry in order to replace the sizing, scouring and bleaching pre-treatments of cotton (Figure 2.5.4). The total costs of DBD were compared using a Jet and Pad-steam methods in a continuous process. All the costs of the conventional methods (between 0.147 and 0.055 € kg-1) resulted higher than DBD (0.013 € kg-1) [22]; ii) The company Softal, claims a payback time of only 9 months single-shift operation for its Aldyne plasma adhesion primer system versus conventional liquid priming; iii) The Swiss compay Sefar

AG/Switzerland uses the world largest atmospheric pressure plasma systems for industrial applications in the production of high-performance filtration solutions; iv) APJET (USA) company commercialize a proprietary all-dry APPJ technology to produce textile fabrics repelling oil and water on the outside, while retaining its original qualities and comfort on the inside; v) The Green Theme Technologies LLC company (USA) designed a so called ChemStik technology to be compatible with a DBD plasma, that could be operated using less expensive gases than helium such as nitrogen, oxygen and argon eliminating the need for a costly gas recycling system; vi) the atmospheric pressure non-equilibrium plasma (APNEP) developed by EA Technology Ltd. in conjunction with the University of Surrey. With the constant rise of the costs of raw materials, energy and water, the increasing cost advantages of atmospheric plasmas over wet processing in terms of low power, water and chemicals consumption, there is no doubt that atmospheric pressure plasmas stand on the edge of a revolution in textile processing.

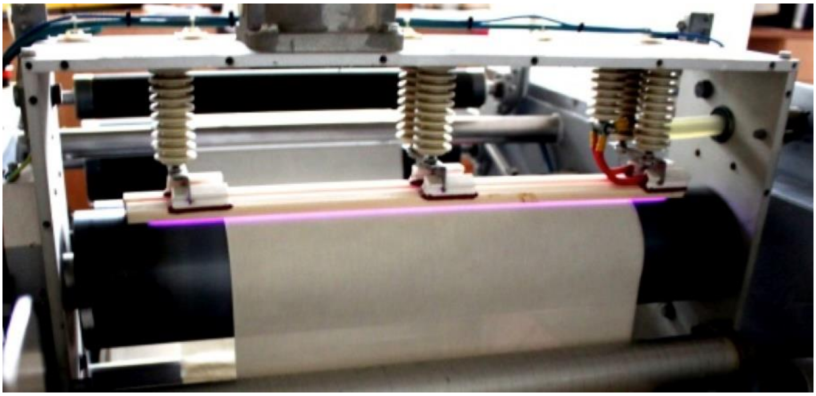

Figure 2.5.4. Semi-industrial prototype installed at the University of Minho

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2.6. Plasma technology: PVD methods in textile manufacturing

Margarida M. Fernandes, Andrea Zille, University of Minho, Portugal

The functionalization of the surface of materials with thin layers, typically in the range of few nanometers to several micrometers is typically applied to impart new and unique properties to a substrate, a strategy that has long been used in technological breakthrough areas such as electronic semiconductor devices, development of optical devices, UV lasers and green LEDs, creation of antireflective coatings, as well as for both energy generation and storage. It is also being applied to biomedicine, through the development of thin-film drug delivery systems. To obtain such films, the physical vapour deposition (PVD) technique, has been widely explored. This is an environmentally friendly process that consists on the condensation of a vaporized form of the film material onto a substrate. Typically, the process consists in three different processing steps: i) a solid source is vaporized onto the material, assisted by high temperature and vacuum or gaseous plasma; ii) transportation of the vapour under vacuum to the surface of the substrate and iii) condensation of the vapour onto the substrate to generate the thin films (Figure 2.6.1).

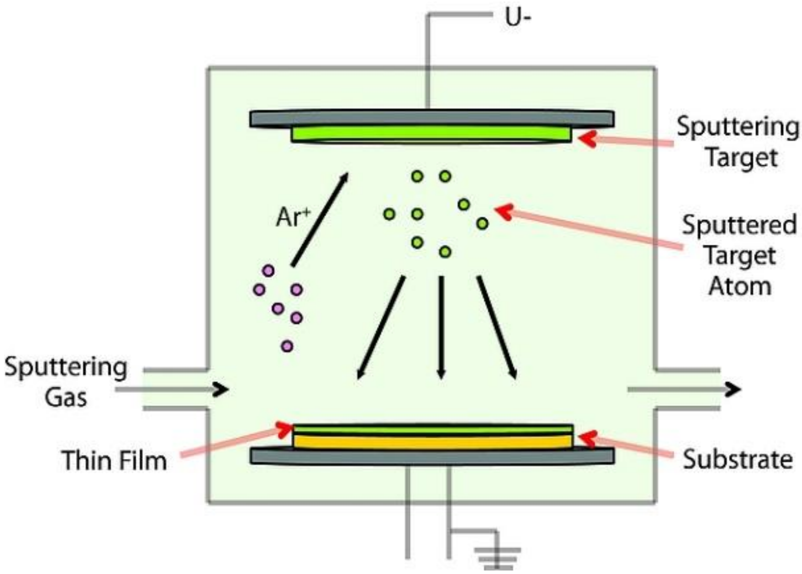

Figure 2.6.1. Schematic representation of a plasma-assisted physical vapour deposition process

Textile industry has been taking advantage on the use of these technologies to add value to their products, so they can meet the highly competitive market needs.

Highly advanced textile materials are continuously being brought to industry owed to the increasing functional properties that nano- and micro-coatings may impart to the materials. In fact, the development of protective garments, that protect against microbes, chemicals, pesticides, UV light and pollutants in growing in the last years. Table 2.6.1 shows typical applications of PVD techniques on textiles.

Table 2.6.1. Typical applications of PVD techniques on textiles.

Application	**Type of PVD**	**Fibres and coating obtained**
Anti-microbial textiles	Magnetron sputter coating	SiO_2 fibres coated with silver, copper, platinum, platinum/rhodium and gold
	Plasma sputtering	ET fabrics coated with silver nanoparticles
	RF-Plasma	Polyester–polyamide Ag-loaded textiles
	Magnetron sputter coating	Silver coated polyester fabric
UV light protection coatings	Pulsed laser deposition	Cotton woven fabrics coated with ZnO
Hydrophobicity improvement-water repellent textiles	Magnetron sputter coating	Woven silk fabric coated with PTFE (polytetrafluoroethylene)
Conductivity	Magnetron sputter coating	Nonwoven material coated with metal aluminium (Al)
Textile dyeing improvement	Plasma sputtering	polyester/wool fabrics coated with copper particles
Electromagnetic radiation protection coatings	Arc -PVD process	natural, synthetic and artificial fibres coated with Cu, Ti and Cr
Electronics in textiles	Thermal evaporation	Polyimide coated on both sides with PVC
Protective clothing	Arc -PVD process	Polyamide fabrics coated with titanium and zirconium
Photocatalysis	Pulsed laser deposition	TiO_2 nanoparticles were evenly applied on the surface of a glass fibre mat

PVD techniques may be categorized in five different techniques:

1) Sputter deposition: The most commonly used PVD process in textiles is the sputter deposition technique despite being also widely used in glass, ceramic and microelectronic devices industries. This technique is based on the application of a glow plasma discharge (usually localized around the “target” by a magnet) and bombards the material with accelerated gaseous ions (typically Argon), sputtering some away as a vapor for subsequent deposition. The sputtered atoms have high energy and when they target the surface, they form a very thin surface coating with superior adhesion to substrates. Moreover, it is a simple and time-saving process that is capable of developing very thin ceramic or metallic coatings on to a wide range of substrates. Sputter deposition possesses many advantages since almost every alloys, elements and compound can be sputtered and deposited, providing a stable vaporization source. Nevertheless, it also possesses some disadvantages including the fact that sputtering rates are low when compared to thermal evaporation methods and the targets are usually very expensive. Also, most of the energy that hits the target gets very heated during the process which must be removed.

The subtype magnetron sputtering technology overcomes some of these disadvantages since it uses powerful magnets that restrict the “glow discharge” plasma to the region of the target plate, thus improving the deposition rate. This is attained because it maintains a higher density of ions, which makes the electron/gas molecule collision process much more efficient.

This technique may impart conductivity to textile products which is a growing technological area since conductive yarns may be applied in electronic textiles, data transfer, imaging, protection against corrosion and electromagnetic shielding since it is commonly reported to deposit common conductive metals including gold, platinum and gold-palladium. In fact, nearly all-metallic elements can be deposited on textile substrates via sputtering. Silver is an example of a commonly used metal for textile functionalization. Silver-based coatings is one of the most widely used in textile industry to provide bacteria killing effect apart from imparting conductivity, UV protection and hydrophobic properties to textiles. Antimicrobial materials are critical to control pathogenic microorganisms and thus very important in clinical settings to avoid nosocomial infections in patients.

2) Evaporative deposition: Thermal evaporation process allows for vapour particles of the material to be deposited directly from target the substrate, forming a functional coating when these condense back to a solid state. Thus, the process involves mainly 2 steps in industrial environment, this technique creates coatings at 0.5µm/min, by using a vapour pressure of 10 mtorr. The high purity films that it form and cost-effectiveness are the main advantages of this method. Evaporative deposition is based on two simple steps: the evaporation of the material and the condensation on the substrate. To prevent the collision of the evaporated particles with the background gas, vacuum is used. This technique is mainly used develop flexible substrates for thin conductive film deposition, namely a non-elastic woven coated on both side with PVC, for integrating electronics in textiles.

3) Cathodic arc plasma deposition: This technique is one of the oldest PVD coating technologies which uses a high-power electric arc discharge onto the material to be deposited producing a highly ionized vapour that is further deposited onto the substrate. Cathodic arc deposition, or Arc-PVD, has been widely used to deposit metallic, ceramic and composite films on various substrates and since the material are fully ionized with very energetic ions it promotes better adhesion to the substrate and the formation of dense films. Nitrides and some oxides are commonly used with this technique for the development of wear- and corrosion- resistant coatings and protection against electromagnetic radiation. Cu, Ti and Cr coatings were used to coat textile materials using Arc-PVD and it was observed that unlike other methods of metallization this method is able to adjust the thickness of the coating and thus resistance and EMI shielding effect. With Arc-PVD technique it is possible to use multiple cathodes and thus control the composition of coatings. Depending on the evaporation conditions, a chemical and textural changes at the substrate surface has been observed inducing a better layer adhesion between the coating and the fibres.

4) Electron beam physical vapour deposition: In this technique, a target anode is bombarded with an electron beam given off by a charged tungsten filament under high vacuum. The electron beam causes atoms from the target to transform into the gaseous phase. These atoms then precipitate into a solid form, coating everything in the vacuum chamber with a thin layer of the anode material.

Electron-beam evaporation can be used to develop a sufficiently large flux of evaporate from refractory materials. The effect of this technique on cellulose has been studied and its depolymerisation, with an increase of oxidized groups also, has been suggested due to the irradiation application. While this technique seems to cause harm to textiles the electron beam radiation has been applied to enhance the biodegradability of wastewaters from textile industry, activating the sludge process.

5) Pulsed layer deposition: In this technique, a high power pulsed laser beam is applied to vaporise the material in a plasma environment then depositing a thin film on a substrate, a process that may occur in an ultra-high vacuum or in the presence of a background gas such as oxygen. The latter is usually used to deposit oxides. The physical phenomena involved in this process, related with the laser-target interaction and film growth, are rather complex. When the target absorbs the laser pulse, an electronic excitation occurs that later on is transformed into thermal, chemical and mechanical energy, which results in evaporation, ablation, plasma formation and even exfoliation. The expelled species expand into the surrounding vacuum environment in the form of a cloud that contains many active species including atoms, molecules, electrons, ions, clusters, particulates and molten globules, before depositing on the typically hot substrate. Oxide samples such as ZnO and TiO2 have been reported to form stable films with this technique, for UV protection and photocatalytic purposes.

The plasma assisted-PVD techniques are of great interest among the scientific community since the obtained nano and micro coatings allow a much larger surface area with improved functionality and durability, and without any adverse effect on the fabric feel. The fabrics are thin light and flexible in contrast to other conventional methods of finish application such as pad-dry-cure that are usually accompanied by excessive weight add on, loss of feel and drape, poor durability to washing and loss. Moreover, is a dry and eco-friendly technology, which offers an attractive alternative to add new functionalities such as water repellency, long-term hydrophilicity, mechanical, electrical and antibacterial properties as well as biocompatibility due to the nano-scaled modification on textiles and fibre [20]. Thus it may be applied in a wide range of industrial applications such as aerospace, automotive, surgical/medical and dyes for all manner of material processing, cutting tools, firearms, optics, watches, thin films (window tints, food packaging, etc.) and in the textile industry.

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CHAPTER 3

Circular economy and sustainability

Edited by:

Sofia Papakonstantinou
&
Rimvydas Milašius

3.1. Circular materials for the Textiles & Clothing sector - An introduction to new materials for a circular fashion

Anna Pellizzari, Executive Director MCI, Italy

Introduction

The fashion industry is a complex system based on the single materials of which garments are made: materials for textiles, usually grouped into 5 main categories (cotton, wool, flax, man-made cellulosic, man-made based on oil); leathers and furs; materials for other components (zippers, buttons, tapes, labels, etc.), such as various kinds of plastics, metals, crystals, and more. Of all these materials, textiles account for the majority of consumption. Data show that starting from the 60ies the production of textiles for the fashion industry has seen a dramatic increase, particularly evident in the last 15 years. We are now around a yearly textiles consumption of 13kg per capita, compared to 5 of 1960 and 8 of 2000. This increase is due to several factors: from the rise of average income in previously poor countries (resulting in more people accessing a “westernized” lifestyle with its patterns of consumption), and a general higher expenditure in fashion, to the booming of the so-called “fast fashion”, impressing a much higher speed in the linear model production-consumption-disposal also for garments. According to the Ellen MacArthur Foundation, the average number of times a garment is worn before it ceases to be used has declined of 20% in the last 15 years, while at the same time clothing sales almost doubled.

It is a trend that is seriously stressing the production system in its whole supply chain: from raw matter, to the use of energy and water during the various manufacturing steps (fibres, yarns, textiles, garments), to the products’ end of life. According to most public institutions and private associations of manufacturers, shifting to a circular economy model appears to be the only viable choice to correct this direction and to help reduce the depletion of fundamental natural resources.

Applying policies of circular economy means intervening in all the product’s life cycle - from design, manufacturing, logistics, retail, and use, to after use, with a number of practices to manage a product’s post-life, such as reuse, repair, and recycle. Additional strategies of circular economy include the setting of a circular supply chain; the extensions of a product’s life; the development of sharing platforms; and the shift from products to services. Of all this complex system of actions and policies, this chapter focuses on materials, and specifically on material innovation applied to implementing practices of circular economy and to reducing the environmental impact of the fashion industry in the whole.

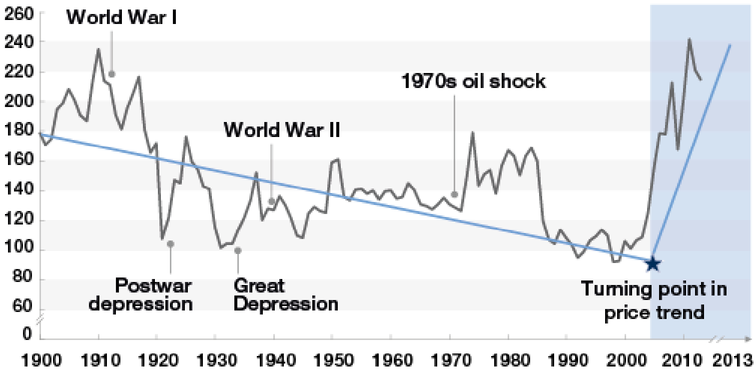

Figure 3.1.1. Sharp price increases in commodities since 2000 have erased all the real price declines of the 20th century

A number of materials are already available, and many more are under development, to support a circular approach to the fashion industry by:

- developing yarns from bio-based sources other than cotton, which has proved to have a significant environmental impact;
- replacing harmful chemicals with bio-based, biodegradable alternatives;
- introducing recycled materials and new recycling processes;
- using biodegradable and compostable resins (be them bio-based or not) both to create filament yarns, and to manufacture accessories.

Despite the percentage of "circular materials" is still very low, it is interesting to notice how the materials mentioned below are not just experimental, niche products, but are often proposed by international corporations and major players in the polymer, fibre, yarn, and textile markets, and can provide performances that are similar, and in some cases even superior, to standard ones.

Materials as key players

Why materials? The material is the "physical protagonist" of industrial manufacturing and, as such, it carries its tangible burden in terms of consumption of primary resources, being it the key component of a product – e.g. a garment – and a product itself. Materials therefore play a key role in the development of practices of circular economy. The book "Neomaterials in the circular economy" goes at the root of how materials are made of and where they come from, and proposes a taxonomy of circular materials defining three main categories:

- *Bio-based*, innovative materials deriving from an organic, living feedstock, and therefore renewable as such, that can effectively replace oil-based materials, resulting in a containment or reduction in the use of plastics and chemicals in general;

- *Neo-classical*, those materials deriving from well-established recycling streams, such as those of paper, aluminium, steel, glass, and recently also PET and other regenerated plastics;
- *Ex-novo*, all materials, mostly experimental, obtained from wastes at the very end of the recycling chain, such as for instance incineration dusts, paper slurry, sewage sludge and gas, scraps from various industries that cannot be re-introduced into the manufacturing cycle via standard recycling processes, and which currently have no application.

Also, materials for the fashion industry, and particularly textiles, can be viewed at in this perspective. The following chapters will provide an overview of recent material innovations available on the market, or at an advanced development stage.

Bio-based: replacing oil-based with renewable solutions

Natural, renewable materials are widely used in the fashion industry. Cotton is the second largest source of fibres after oil, and even though its consumption has little grown in the last 15 years reducing its percentage on the total amount of fibres used in apparel to 27% in 2015, it is still a major player with an over 27m tonnes raw material traded in 2016. Despite being a renewable material, cotton is known for its devastating impact on the environment, especially for its enormous consumption of water throughout its process of transformation into a garment, and particularly in growing, cleaning, spinning, and dyeing. It takes in fact 2,700 litres of water to make a t-shirt, an amount that corresponds to the average consumption of drinking water of a person for 2 ½ years.

Innovative textiles responding to the need for a more sustainable cotton include those using fibres from organically grown plants, or blends mixing cotton with other natural fibres such as hemp. Knit and woven hemp/organic cotton blends (up to 55% hemp), for instance, can provide good breathability, durability, odour control, and anti-bacterial properties. Hemp is one of the most environmentally-friendly natural fibres in terms of land, water, and pesticide usage, and its fibres have improved strength, durability, and anti-bacterial properties when compared to cotton. Researches also address new sources of raw materials for bio-based yarns. These include cellulosic, bio-based filament yarns from sustainably harvested soft woods provided through certified forestry sources (FSC). Cellulosic fibres are produced from wood pulp and acetyl chemicals and extruded into continuous filament yarn, used for sustainable textiles, and provided with inherent properties including moisture management, cool hand, easy care, hypoallergenic, and low pilling.

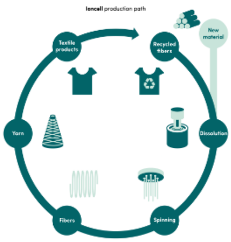

Figure 3.1.2. The Ioncell production pat*h*

Figure 3.1.3. Textile made with Ioncell-F yarn

Another interesting, non-traditional feedstock that is being studied and experimented is Kelp. Kelp has a natural content of alginate, a readily abundant biopolymer, which can be turned into yarns through a process that begins by adding water and complementary biopolymers to enhance the material's strength and to form a paste. The obtained filament can be knitted or woven to produce a finished textile, and testing shows that the filament has sufficient strength and stretch to be hand or machine knit in an existing textile manufacturing infrastructure. "Spider Silk" is an example of a new fibre with impressive elasticity, durability, and softness. The artificial silk production mirrors the biological process that spiders use to create their fibres. During the manufacturing process, genetic material from spiders is inserted into yeast to form proteins that can be spun into fibres.

Figure 3.1.4. Yarn made of Kelp

Figure 3.1.5. Yarn made of Spider Silk

Neo-classical: the importance of a functional supply chain

Today, textiles can hardly be included in the neo-classical category as recycling, despite recent actions to support a more circular fashion put into place by important brands, still accounts for minimal percentages of overall production. The fashion industry employs only 2% of recycled feedstock from other industries (typically PET), to which as few as 1% of closed-loop recycling can be added. 12% of fibres from fashion textiles are recycled into other, lower value applications, while 76% is landfilled or incinerated. If it comes to chemical recycling of post-consumer fabrics and garment the only process commercially available today on the market is Teijin's ECO CIRCLE: a closed loop garment to garment recycling process. Though technically possible the need to know exactly what is in the polyester (composition, finishes) makes it impossible to chemically recycle generic fabric waste from different and not traceable origins such as post-consumer waste. Currently Teijin takes back only their own polyester which is free from chemical substances. Teijin works with selected companies that use their ECO CIRCLE13 polyester in their product range. Acquafil SpA developed a radical regeneration and purification process, to recycle nylon waste back to its original purity; its ECONYL® regenerated nylon is exactly the same quality as virgin nylon.

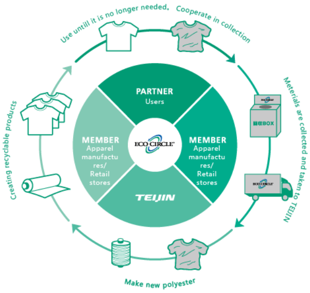

Figure 3.1.6. Teijin's ECO CIRCLE

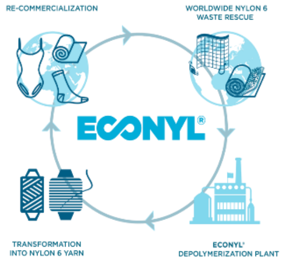

Figure 3.1.7. The ECONYL® regeneration process

Recycling is also particularly valuable for those natural materials having an inherent value, such as down or precious wools. Reclaimed down relies on a complex supply chain and is supplied by several companies which obtain it from cushions, bedding, and other used items that cannot be resold. Some companies are developing specific certification programmes to identify their down as post-consumer recycled, in order to differentiate it from that deriving from pre-consumer, industrial leftovers. Recycled down can reach quality standards comparable to those of virgin down (fill power in the range of 700-800). The cashmere market is also developing supply chains to re-introduce used cashmere wool in various sectors. Cashmere, in fact, once an exclusive, luxury material, has seen a boost in consumption due to growth in demand from the so-called fast fashion industry, resulting in environmental threat to the goat species providing the wool, and to the region where goats are bred. Various companies are therefore introducing blends between used and virgin cashmere or using reclaimed and re-processed cashmere for high-quality filling for the making of outerwear.

Ex-novo: designing new materials from waste

Due to its broadness and quantities involved in this industry, fashion is a sector where several experimental projects of materials design are developed. Material design can be approached in a chemical perspective, by creating new processes to "grow" materials, typically using bacteria that are fed with agricultural wastes; or in a craftsmanship perspective, by remodelling scraps into objects with a high creativity content. In the first case, interesting examples include the use of oranges to grow polymers suitable for the extrusion on filament yarns that have been recently turned into top quality fabrics applied to high fashion capsule collections. The Agraloop Bio-Refinery turns food crops waste into biofibers that supplement existing cellulose-based fibres, and estimates that the readily accessible waste from five crops (pineapple, banana, flax, hemp, and cane) has the potential to create enough fiber to exceed the current global fibre demand.

Figure 3.1.8. Jade Sapphire's 100% recycled cashmere yarn

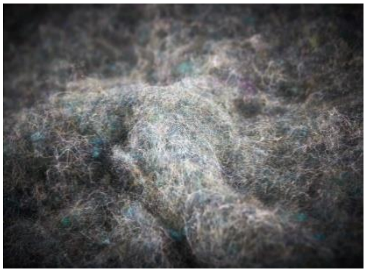

Figure 3.1.9. ISPO TEXTRENDS Fall/Winter

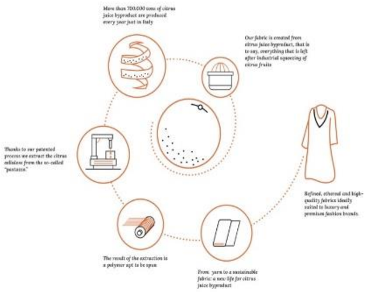

Figure 3.1.10. Orange Fibre process

Figure 3.1.11. Ferragamo Orange Fibre collection

The fashion industry also produces scraps and wastes that can hardly be re-introduced in the garments value chain, either for lack of demand, or for post-consumer loss of mechanical properties that makes the material unsuitable for reuse. These leftovers are often used to create bio-composites for accessories or felted into new materials for interiors, typically used for sound absorption or insulation. A different approach privileges exploiting the inherent aesthetic value of the waste materials by suggesting applications where the recycled material content is clearly identifiable and characterizing feature of the final product.

Figure 3.1.12. Muji's Reused Yarn product line (T-shirt, socks, toys)

Figure 3.1.13. Yarns and fabrics made from upcycled cotton

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3.2. Bio-based synthetics

Gancho Kolaksazov, ITTI, Bulgaria

Introduction

Fabrics are typically made of natural or man-made fibers. Global fiber consumption globally was estimated at 95.6 million tons in 2015. The majority of which are polyester fibers – comprise the largest share at 62.1%, followed by cotton with a 25.2% share, according to a report by Lenzing AG, a leading manufacturer of synthetic fiber.

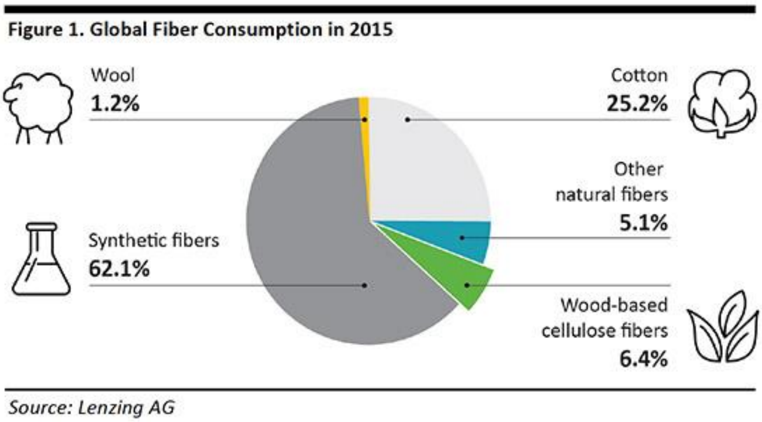

Figure 3.2.1. Global Fiber Consumption in 2015

The fabric material landscape has been transformed over the past couple of decades with ongoing innovations in new or enhanced fabric materials. One of the key innovations in fabric materials in the 20th century was polyester. Since then, polyester fabric has gradually proliferated the textile industry. It overtook cotton as the most-produced fabric material in 2002, with 20.8 million tons manufactured worldwide. Polyester fiber production has continued to grow, more than doubling to reach an estimated 48 million tons in 2015. By 2025, it is expected to reach 90.5 million tons, a four-fold increase from 2002.

Many other innovations in fabric materials have emerged over the past couple of decades as well, from heat insulating to water-proof fabrics, creating new possibilities in apparel design and production. The main difference between bio-based synthetics and conventional synthetics lies in the raw materials used. Bio-based synthetics, as the name suggests, are made from bio-based raw materials such as sugar cane, corn sugars and agricultural waste. Conventional synthetics such as polyester, nylon and acrylic use raw materials derived from fossil fuels such as petroleum, natural gas and coal.

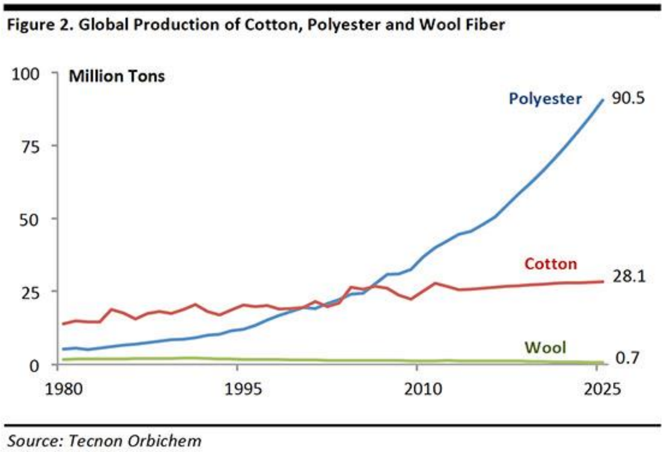

Figure 3.2.2. Global production of cotton, polyester and wool fiber

Bio-based Polyester (BBP)

Virent, a US bio-based chemical company, showcased the world's first 100% bio-based polyester shirt this year at the TESC (Textile Exchange Sustainability Conference). Bio-based polyester's performance is similar to regular polyester, and it can be processed using the same equipment, according to Ralph Lerner, the company's business development director.

The production process begins with Virent's BioFormPX paraxylene, a compound produced from plant sugars that resembles the chemical components of petroleum. The bio-based paraxylene is then converted into bio-polyester fabric. Virent works with Far Eastern New Century (FENC), a leading Taiwanese polyester manufacturer.

Synthetic spider silk

Spider silk is regarded as one of nature's wonder materials because of its extraordinary mechanical properties. It is tougher than Kevlar – a high-strength synthetic fiber used in racing tires and body armor – and has a comparable tensile strength to high-grade alloy steel, but is much lighter.

The first reference to the use of spider silk dates back to the early 18th century in France, where attempts were made to use it to make stockings and gloves. Mass production for commercial applications, however, was an obstacle for centuries. Spiders are cannibals and tend to eat each other when enclosed in a small area, making it impossible to farm them like silkworms. This has made spider silk the object of research for many years, with significant research papers dating back as early as the 1960s.

Figure 4. Physical Properties of Spider Silk, Kevlar and Steel

Material	Material Toughness	Tensile Strength	Weight
Spider Silk	120,000–160,000 J/kg	1,100–2,900 MPa	1.18–1.36 g/cm^3
Kevlar	30,000–50,000 J/kg	2,600–4,100 MPa	1.44 g/cm^3
Steel	2,000–6,000 J/kg	300–2,000 MPa	7.84 g/cm^3

Source: Kraig Biocraft

Figure 3.2.3. Physical properties of spider silk, Kevlar and steel

Various attempts have been made to produce spider silk. One such attempt was made in 2009. It took one million golden orb spiders to produce 80 feet of silk, or put another way, it took 14,000 spiders to spin one ounce of silk.

Another attempt used genetically modified goats to produce milk containing protein similar to that of the golden orb spider. However, it was not successful, as the quality of the silk produced was far below the quality of natural spider silk. Since then, several companies have been racing to commercialize spider silk fiber, also using techniques based on genetic engineering, but with a different approach. We discuss three of these – Kraig Biocraft, Bolt Threads and Spiber Inc.

Transgenic Silkworms (TS)

Kraig Biocraft a Michigan-based company has inserted modified spider genes into silkworms to produce spider silk. Unlike spiders, silkworms can be domesticated and have been used to mass produce silk fiber for centuries. This allows the company to produce a large amount of spider silk efficiently and cost effectively.

Kraig Biocraft has created approximately 20 different genetically engineered spider silk fibers based on genetic designs. Dragon Silk is the company's lead product, with a very high tensile strength and elasticity, making it one of the toughest fibers and an ideal material for many applications, according to company COO Jon Rice.

Its synthetic spider silk has already seen potential application in military apparel – the company received a contract of close to US$1 million from the US military in July this year. Kraig Biocraft will deliver Dragon Silk-based ballistic shoot packs for performance testing. The armed forces have been relying on nylon for its strength, but nylon is dangerous for soldiers because at high temperatures it melts rather than burns, according to Steve Arcidiacono, a microbiologist at the US Army's Natick Solider Systems Center.

Source: Kraig Biocraft

Figure 3.2.4. Genetically engineering next-generation polymers with unprecedented capabilities

Transgenic Microorganisms (TM)

Bolt Threads and Spiber Inc., these two startups take a different approach to producing spider silk. Instead of modifying the genes of silkworms to produce the material, they have harnessed genetically engineered microorganisms to produce the protein through fermentation, which serves as the raw material to make the synthetic spider silk. The main difference between the two startups is in the microorganisms they use – Bolt Threads uses genetically modified yeast, while Spiber uses genetically modified E. coli bacteria.

Bolt Threads is a California-based startup founded in 2009 with the aim of producing affordable synthetic spider silk. The startup claims to have a lower raw material cost by using significantly less expensive yeast rather than E. coli, according to Sue Levin, its chief marketing officer. Bolt Threads expects to produce the spider silk yarn at a price of US$100 per kg, comparable and competitive with high-end natural fibers such as cashmere, silk and mohair at a similar price range. In May 2016, Bolt Threads announced a partnership with outdoor clothing company Patagonia to further develop the fabric, and has already started producing the synthetic spider silk in large scale.

Spiber Inc. is a Japan-based startup founded in 2007 that aims to drastically lower the production cost of spider silk to make it practical for commercial use. Although the absolute production cost has not been disclosed, Spiber claims that productivity has increased by 4,500 times, and its manufacturing cost is only 1/53,000 when compared with eight years ago, when the startup first began to research the fermentation process. In September 2015, the startup collaborated with The North Face to create the world's first outerwear jacket made with synthetic spider silk, the Moon Parka which retails at US$1,000. The jacket is based on The North Face's Antarctica Parka, which uses conventional material and is sold at $736, about one third cheaper than Moon Parka.

Figure 3.2.5. Moon Parka

Growing Trend in Fiber Innovation

Synthetic fibers, an innovation from the past century, account for over half of global fiber consumption. However, as synthetics are produced from petroleum-based material, the finite supply of petroleum means that the production cost of synthetic fabrics could be subject to market volatility.

More importantly, petroleum-based products leave a significant carbon footprint during the production process. They are also not biodegradable and cause significant damage to the environment. Tiny fibers from synthetic fabrics also have the potential to poison the food chain. According to a study by the University of New South Wales in 2011, microfibers made up 85% of man-made debris found on shorelines around the world.

Consumers have become increasingly aware of a product's sustainability, and this is especially true among millennials. As covered in GRT (Global Retail Trends) for 2016 report, millennials place a higher weighting on corporate responsibility and sustainability in their purchasing decisions than do other generations. Synthetic fabric substitutes include bio-based synthetics and protein-based spider silk, which are based on renewable resources such as plants and microorganisms. Water- and stain-resistant cotton fabrics also help to promote sustainability, as they can reduce the water and energy used in the washing process.

New innovations involve investment in R&D, and, in most cases, a higher manufacturing cost. For example, the production cost of synthetic spider silk is $100/kg while the threshold price for mass adoption is US$20-30/kg, according to estimated figures from Spiber. Even though consumers are willing to pay a premium for sustainable offerings, it is important to strike a balance between price premium and affordability and many fiber innovations are not relevant for the mass apparel market just yet.

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3.3. The value chain: sustainability issues from textile fibers production to the usage of final products

Sofia Papakonstantinou, CRE.THI.DEV., Greece

Introduction

Sustainable Fashion can be defined as "An emerging set of design philosophies and business practices for managing triple bottom line impacts (economic, social and environmental) linked to the lifecycle of apparel, footwear, accessories and other fashion goods". At the same time, Sustainable Fashion Consumption is: "The use of clothing for purposes beyond utilitarian needs, for purposes that include "identity making," and which is achieved without jeopardizing the ability of future generations to meet their needs".

The current 'take-make-dispose' clothing system is extremely wasteful and very polluting. Beyond laudable ongoing efforts, a new system for the textiles economy is needed and this report proposes a vision aligned with circular economy principles. In such a model, clothes, fabric, and fibres re-enter the economy after use and never end up as waste. This vision relies on four ambitions that would lead to better economic, environmental, and social outcomes, capturing opportunities missed by the current linear textiles system.

- *Phase out substances of concern and microfibre release*, by aligning industry efforts and coordinate innovation to create safe material cycles.
- *Transform the way clothes are designed, sold and used to break free from their increasingly disposable nature*, by scaling up closing rental schemes; making durability more attractive; and increasing clothing utilisation through brand commitments and policy.
- *Radically improve recycling by transforming clothing design, collection and reprocessing*; pursuing innovation to improve the economics and quality of recycling; stimulating demand for recycling materials; and implementing clothing collection at scale.
- *Make effective use of resources and move to renewable inputs*.

Circular economy and resource efficiency

Learning to make more with less

The Textile and Clothing industry like any other manufacturing sector is in the business of transforming resources – materials, energy, water, chemicals – into value added products for professional or private end users. Several textile production processes, such as dyeing and finishing, are indeed very resource-intensive. As the consumption of these resources is not free, companies have a natural incentive to use them as efficiently as possible. In addition, tightening legislation on energy efficiency, CO2 emission, water use, waste water quality or air pollution makes the industry seek better technology to combine economic with ecological benefits while complying with the law. Finally, better environmental performance in production also starts to be more and more rewarded in the marketplace by increasing consumer interest in more sustainable textile products.

To reach tougher resource efficiency targets, the textile industry pursues incremental as well as radical innovation approaches. Incremental approaches include regular production technology upgrade, employment of better monitoring and control systems, use of energy- saving or energy recovery installations, water or chemical re-use systems, better waste water treatment facilities or a generally more resource efficiency driven production planning and worker education. Radical technological innovation approaches involve the move from wet to dry textile processing replacing conventional dyeing, printing or finishing by digital printing, dyeing with supercritical CO2, plasma, laser or coating processes. Also, material waste can be radically reduced by move from cut-and-sew assembly to seamless manufacturing for instance in knitwear or direct joint-free 3D production of technical textile or composite parts.

Making a chain move in circles

When discussing innovation and market potential, "the Circular Economy" is rapidly becoming one of the most used terms in the European textile and clothing industry. It provides a guideline for the industry, when making investments in production technology (cleaner and less resource-consuming), product development (more sustainable products, focus on recyclability) and in respect to the selection of textile materials (more focus on the use of sustainable fibres). However, the industry still faces tough challenges in the transition from a traditional linear production and consumption model (take – make – dispose) to a circular model.

Figure 3.3.1. Schematic approach of circular economy

In a circular model it is essential to cooperate with all stakeholders in production, retail and waste processing. Due to its fragmented, SME-dominated structure, the industry lacks the authority to enforce such a corporation with other essential stakeholders in the value chain. Therefore, essential innovations are not yet implemented on a large scale, due to uncertainties in the required investments and long-term economic viability of circular business models and the absence of long term commitments with retail and waste processors. Also the European legislative framework is not (yet) favourable for circular systems, although the circular economy roadmap of the EU might trigger changes with respect to green procurement and legislation (product liability).

However, there are also important barriers still to be overcome for an effective recycling of post-use textiles through new technologies for sorting and recycling of textile waste, better used textile collection systems in Europe, better consumer education and easier access for designers and product developers to high-quality, cost-competitive recycled textile materials.

Natural solutions to protect the environment
Approximately 70% of all textile fibres produced in the world today as well as most textile processing chemicals are fossil-based. Natural fibres, while clearly renewable, are not automatically the more sustainable solution as the case of conventional cotton demonstrates much of which is grown with heavy use of water and pesticides in some of the world's most environmentally challenged regions.

Market interest in EU-grown natural fibres such as flax, hemp as well as European wool and cotton is rising due to an appreciation of their favourable sustainability profiles and interesting potential of their application in growing textile fibre end markets such as composites for the construction or automotive sector, functional clothing and interiors for allergy suffers or generally health-conscious consumers or naturally flame-retardant material (i.e. wool) for protective clothing. As agricultural products, natural fibres typically find themselves at a production efficiency disadvantage compared to man-made fibres which are produced in large-scale controlled industrial processes. They also suffer from greater variability due to impact of changing weather and other natural conditions beyond the control of the producer. Rapid agricultural productivity progress and new biomass processing technologies represent a strong two-pronged approach to improve the competitive position of European bio-based textile fibres. European forest-based and agricultural waste resources are an abundant, sustainable and economic feedstock for textile fibres as well as bio-chemistry used in textile processing and functionalisation. Apart from being fully renewable these bio-economy routes to textile and clothing products also help to reduce hazardous and toxic chemicals from the textile industry and facilitate circular economy concepts through better recycling or biodegradation of material waste and easier treatment of wastewaters.

Sustainability challenges

There exist four Keys to Unblocking Consumers' Contribution to Sustainable Fashion Consumption. Each of those has different approach towards the consumer, as well as different requirements for the industry to commit, as the following table demonstrates.

Table3.3.1 Approaches towards Sustainable Fashion

	Approaches towards consumer	Industry commitment
Re-Think: Sustainability becomes a core part of consumer mindset (e.g. while dressing and shopping)	- increase fashion literacy - increase product quality and longevity - change attitudes toward previously used products	- fund the development of secondary education - partnerships to run consumer campaigns using gamification / trend-setting - standardize and require labels on quality - incentivize warranties
Reduce: Decrease impacts related to production and consumption stages	-Production: environmental and social impact accounting - Consumption: better care and repair	- Legislate product transparency - Tighten regulation of chemicals - Improve / standardize care labels and reinforce manufacturing adherence - Fund the development of primary education / skills / craftsmanship
(Re-)Use: Better wardrobe stewardship and increased sharing / swapping and re-selling of garments	- Enable social exchange and upgrade second-hand markets and shops	- develop markets / instruments for exchange - develop program for small business assistance
Recycle: Extend useful lives of garments and divert garments from landfill Approaches	- recycling and upcycling re-manufacturing	- incentivize collections of unwearable garments - develop markets / instruments for recovered materials

Sustainability through durability

There exist two types of durability:

1. **Physical durability** Garment design and construction to create products that can resist damage and wear. For a knitwear garment, for example, physical durability might be determined by the degree of pilling which occurs over time; for socks, the gauge may be colour fading.
2. **Emotional durability** Garment design that takes into account relevance and desirability to the consumer – does it still fit, or is it no longer to their taste?

At a time when many clothing business models are based on frequent, low-cost purchases, manufacturing for durability may seem counter-productive. However, this view misses the business opportunity that comes with taking the lead. Clothing designed to withstand wear and tear and to appeal to the customer for longer also helps to promote brand loyalty, confidence, and customer satisfaction. In a saturated marketplace, quality and durability will help retain customers while attracting new buyers from your competitors.

Sustainability and producers

Design and technology considerations: Designers and technologists have a key role to play to improve clothing sustainability. They should work together to ensure they select the most suitable materials (yarns, fabrics and components) from reputable suppliers who understand the brand's performance requirements. Researching and identifying the most suitable processes is also key to ensure the final product performs well. The design stage is pivotal to the eventual durability of a garment, with choices about style and cut, fit, fibre and yarn, construction and trimmings all having an impact on the final product. Physical durability is often governed by the weakest link in the chain – perhaps not the chosen fabric or fibre, but a poorly specified aspect of construction or manufacturing.

Style and cut: Tailored and semi-tailored garments last longer because they frame the form well aesthetically, while oversized knits and kimono shapes that can be worn with a belt are versatile and 'comfortable' and, therefore, potentially wearable for longer. From a fashion perspective, 'classic' styles (e.g. the little black dress, tailored shirts, pencil skirts, chino-style trousers, v-neck jumpers) will tend to be longer lasting, especially if core colours such as black, white, navy, grey or red are used.

Fit: Customers do not come in standard sizes and all have the same preferences in terms of comfort and fit. One way to embrace these differences is to offer built-in size adjustment. This might involve the use of strategic fastenings, for example, to increase or decrease the size or length of side seams or hems.

Raw materials: Since fabric quality depends on many variables, such as fibre type, yarn blends, yarn structure, fabric construction, dyeing and finishing, fabrics with the same description (e.g. '100% cotton') often vary greatly in performance and durability. One way that design teams can influence the durability of a garment is to identify key standards the fabric must meet – and then task buyers to source fabrics that have been tested to meet these standards. Specifying standards that align with the way the product will be used can act as a safety net, ensuring that component failures do not undermine the benefits of a well-specified fabric. For example, specifying collarbones and collar tip construction that minimise abrasion, or the use of woven rather than non-woven interlinings and the use of button whipping, can all ensure that shirt durability is maximised.

Colouration and dye selection: Colour is one of the most important influences when customers are choosing new clothes; it also plays a significant role in deciding when a garment has reached the end of its life. Dye selection, methods of application and processing conditions (e.g. pH, temperature and use of leveling agents) all have a huge impact on colour fastness. Using standard test methods to determine the characteristics of the selected dye prior to bulk production is quick and cheap to complete. For example, fading due to the action of washing powders can be tested via oxidative bleaching tests. Technical support for dyestuff selection, testing and performance can be requested from a number of dyestuff manufacturers.

Fabric finishing: Finishing processes are used to improve the look, performance, or 'hand' (feel) of the finished textile or clothing. Many finishing treatments can affect performance and durability, or help extend the active use of a garment. For many brands and retailers, greater use of cotton and cotton blends in knitwear and knitted fabrics has led to a rise in the number of garments prematurely returned or disposed of due to pilling. Pilling is caused by abrasion that disrupts the fabric surface, causing unsightly bobbles of entangled fibres. Treating fabrics with an additional process called bio-polishing can reduce the abrasion that causes pilling, to extend the life of the product.

Manufacturing: Designers have numerous stitch types, sewing threads, machine models and settings to choose from, as well as an array of methods for garment construction. Each technique will be best suited to a particular fabric or garment type and can be exploited to achieve greater durability. Co-ordinating design and manufacture to align specifications will also improve the durability of the product. For example, choosing the correct stitch density for seams will minimise fabric slippage and puckering, while making sure that the correct operating procedures are in place for the application of linings helps to avoid delamination.

Product testing: A number of industry standard tests now exist for fabrics and garments. These cover physical testing, colour fastness, chemical testing and flammability1 and can form part of a product specification. Physical tests include: seam rupture; tear strength; burst strength; pilling; abrasion; elasticity; and seam slippage. Standards may be British (BSI), European (CEN) or international (ISO), and even retailer-specific. Marks & Spencer, for example, led the development of clothing technology standards. The use of clearly defined testing protocols for components and manufacturing elements can be built into product specifications to ensure the consistency of quality leading to stable product durability, not just within individual manufacturing batches but across many consignments.

Wearer trials: A good way to find out how suitable a fabric may be for its intended use is through pre-production wearer trials. This method can be used to assess a range of issues that directly affect the durability of the garment, such as: how well it withstands washing; susceptibility to staining; durability of fabric; and understanding of care instructions.

Sustainability and Consumers

Customer education and messaging: Given a little direction, customers would be able to gauge the quality and potential durability of garments before they buy. Instructions include:

- evaluating seams, including advice on looking for loose threads and broken stitches. Consumers could be made aware that a higher density of stitches per inch is generally better, that should be relatively tight, and that serged seams or double straight seams are usually stronger and may last longer than an equivalent with single straight seams;
- examining garment linings and reinforcement. For example, looking at facing around zips, buttons, or other high-use areas;
- understanding that fibre content will play a role in clothing durability. For example, natural fibres may last longer and launder more easily in some garment applications than synthetic alternatives;
- reading care instructions, and ensuring that they are followed – garments should be dry cleaned when necessary, cold washed and/ or dried flat if appropriate; and
- looking for stains, rips, stitching and
- other obvious damage caused in store or in transit before sale.

Wash and wear guidance: The way that people wash their clothes at home has the potential to change the characteristics of fibres and fabrics and, as a result, to reduce durability. Despite marketing campaigns, evidence suggests that many people still do not colour sort washing and often launder delicate fabrics at the wrong temperature. Improving care information on labels, packaging and point of purchase or online information portals is a low-cost way to increase durability. Research suggests that consumers are often receptive to warnings about the potential impact of not following care instructions. Advice could include:

- wash coordinating products together (for example suits, twin-sets or lingerie), and remove accessories before washing;
- dry clean garments when necessary;
- consider steam clean options;
- wash when necessary rather than after each wear;
- airing garments as a means of freshening;
- avoid rubbing stains and marks to avoid causing damage to the fabric;
- avoid the use of solvents for spot cleaning as they can cause discolouration;
- store appropriately, for example on hangers; using any garment loops or other features provided; folding, and removing from sunlight when not in use;

- use moth balls when storing;
- use a specialist laundry bag for delicate items; and
- iron garments at the right temperature and reverse those with motifs to avoid damage.

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3.4. CSR for fashion companies: definitions, reasoning and best practices

Desiree Scalia, CIAPE, Italy

Introduction

Within this topic, you will learn about the concept of CSR (corporate social responsibility) and about its objectives. Moreover, you will discover few examples of what can be done by textile and clothing companies in this sense and what has been done in this field by some of the most famous brands in textile and clothing. Finally, you will be informed about the evolution of the concept of CSR and about steps needed to follow new trends.

CSR for fashion companies: definitions, reasoning and best practices.

Corporate Social Responsibility (CSR) involves achieving business success in ways that honour ethical values and respect people, communities and the natural environment. There is not a common and complete definition of CSR but we can focus on the European commission one: "*The Corporate Social Responsibility is an important concept created to help companies and to integrate social and environmental issues with business activities and stakeholders' relations*."

In the definition given by the European Commission two aspects can be found: firstly, the recognition that the company cannot be limited to the pursuit of profit and respect for the law but must operate ethically responsible and develop a "social sensibility" towards the themes of collective interest; secondly, the awareness that each company sets itself in the middle of a network of relationships, each of which involves actors that must be taken into account as they influence the company's dynamics.

Society and business are depending on each other: businesses provide jobs, products, and taxes while society provides workers, consumers, and infrastructure. Neither can survive without the other so it makes sense for business and society to work together for the benefit of both.

The development of CSR must therefore be guided by companies, but other actors play a key role alongside them. Public authorities, both at national and local level, can intervene by creating market incentives to support responsible business conduct and to encourage the so called "corporate accountability", that means, the attitude of companies to respond to their behaviour towards stakeholders and consumers. Trade unions play an important role in promoting agreements aimed at improving working conditions; on the other hand, consumers and investors influence entrepreneurial choices through the purchase and investment decisions they adopt. Lastly, the media have a key role, as they carry out awareness actions on particular topics and contribute to spreading a particular image, both positive and negative, among the buyers.

For a company, the objective of CSR is therefore: to maximize the creation of shared value between owners/shareholders and other stakeholders and the society in general and to identify, prevent and mitigate possible negative effects of its activity through a precise risk analysis.

Figure 3.4.1. CRS and connected terms

Benefits for a textile & clothing company implementing CSR actions

Interestingly, various statistic sources show that companies with a strong focus on business ethics do better financially than other companies. Several manufacturing textiles brands, which are implementing CSR policies, demonstrated a strong positive correlation between CSR and profitability.

Besides the positive economic impact, the question whether an organisation acts ethically responsible or not, is becoming increasingly important for prospective employees. In order to attract top-level candidates, a good track record of CSR may be necessary, as people prefer working for companies that care not only for themselves, but also for their employees and customers as well as for environment.

Also consumers are the more and more concerned with how companies make their money and are expecting businesses to be responsible for their social, ethical, and environmental impact on society and community. They preferably choose textiles manufactures, which take concrete measures in this regard and communicate about them to existing and potential customers.

The first area of application of the CSR is certainly within the company and regards the responsible management of human resources and investments aimed at improving the conditions of workers and their families. In this logic, companies should contribute to increase the level of psycho-physical wellbeing of their employees, safeguarding their safety and providing a safe working environment; more over they should also help them to increase their skills and improve their lifestyle. This also includes “Corporate Family Responsibility” initiatives aimed to create a better balance between work and private life of workers and, above all, women workers.

The company's commitment to the local community and its contribution to the socio-economic development of the territory, as well as the creation of economic activity, can be achieved through sponsorship of cultural and sport events, social solidarity initiatives and granting of philanthropic contributions.

Figure 3. 4. 2. The CSR tree

Best practices

Brunello Cucinelli and his “humanistic enterprise”

An example of excellence in “responsible management of the company”, in “enhancement of human capital” and in “respect and integration with the territory”, is represented by Brunello Cucinelli Spa, an Italian fashion company specialized in cashmere, which today is one of the most exclusive brands in the international fashion market. Brunello Cucinelli has always pursued an entrepreneurial model with ethical and humanistic vocation both inside and outside the company, where part of the profit is reinvested in initiatives aimed at improving the condition of workers and the community, paying more attention to values such as legality, transparency, quality, sustainability and responsibility towards the community.

“In my organization the focal point is the common good, which is the guiding force in pursuing prudent and courageous actions. In my business, people are at the very centre of every production process, because I am convinced that human dignity is restored solely through the rediscovery of the conscience. Work elevates human dignity and the emotional ties that derive from it” Brunello Cucinelli says.

Among the most significant initiatives oriented to the local socio-economic development, the rehabilitation of the medieval village of Solomeo certainly falls within what the entrepreneur has achieved over the years both directly and through collaborations with public institutions and organizations.

Figure 3.4.3. Local community and employees at the centre of CSR actions

The company's commitment to the local community is also visible in “Foro delle Arti”, a system created for meeting, creativity and culture, which is designed to be left behind as a patrimony for future generations. Foro delle Arti represents the place in which the Teatro Cucinelli found a voice in recent years; it hosts cultural events and outdoor performances and a set of aerial terraces called "Giardino dei Filosofi" overlooking the Umbrian valley; finaly the “Accademia Neoumanistica” with a library inside it.

In a view of respect and integration with the territory, the Group is also in the list of companies participating in “Impronta Ambientale”, a program promoted by the Italian Ministry of the Environment aimed at experimenting and optimizing the different methodologies for measuring the environmental performance of companies, addressed in particular at calculating carbon footprint and at the reduction of greenhouse gas emissions, in order to be able to harmonize and make them replicable.

Moreover, the renovation of the village and the related cultural and humanistic activities, together with the accurate protection of the landscape and the environment and the careful management of relationship with employees, who works alongside quality production, represent a strongly distinctive and characterizing element of the company with significant advantages in terms of image.

H&M and the CSR

H&M Hennes & Mauritz is a Swedish joint stock company based in Stockholm and founded in 1947. The company's success starts from Vasteras, a south-eastern town in Sweden, where Hennes women's clothing store was opened. The philosophy of

Mr Persson, owner of Hennes was to “beat the competition and make the fashion world accessible to everyone without neglecting the quality”, a belief that even today the company carries on with conviction. In 1952, the unexpected and precocious success of the boutique convinced Persson to invest in a new store in Stockholm that allows the company to increase its visibility and generated more sales. Since the 1970s, the path to H&M's success has been achieved always brighter.

Despite the transition from a small boutique to a global colossus, the company's goal is always the one of exceeding the expectations of its customers by offering them fashion products, with an innovative design and an affordable price while maintaining the quality of the materials and production processes. This philosophy, on which the company has built its competitive advantage, is appropriately supported by different business strategies.

The company's success also comes from knowing how to adapt to the dynamics of the fashion market, currently characterized by a fast fashion and low cost business model, based on the speed of design and production and very low costs. Flexible planning and efficient logistics are therefore the basis of the company's success; they allow a continuous adjustment of the range for customers. In addition, over the years, the brand has been able to improve its offer in a strategic way, creating new brands and expanding its target.

The H&M Group is nowadays present in 55 countries with more than 3500 stores. H&M has been active in the field of sustainability for many years, and since 2002, it has been writing an annual report that allows stakeholders to learn about the actions taken by the company and about the objectives achieved in the environmental and social fields. As confirmation of its commitment and its considerable investments in these issues, the company has been present for many years within the main rankings of the most sustainable companies in the world.

Karl-Johan Persson, CEO of H&M and son of the current president, recently issued an interview regarding the concept of sustainability for the company and the actions taken in this regard.

"*My grandfather [...] has often talked about the importance of long-term thinking, not just of maximizing short-term profits. He wanted to look at our customers and colleagues and feel well with the company, see that everything had been done in the right way. This means to me that we offer our customers excellent value for money, but also that we have a positive impact on the world. Our business idea is to offer fashion and quality at the best price. It is the best value, not the cheapest price. Sustainability is an important part of this.*

We know that our customers, as well as our colleagues, are increasingly worried about this theme, [...] I am convinced that it will become an important differentiation for the future. The fashion industry is too dependent on natural resources [...] we want to move from one linear production model with a circular one. At the same time, we must make sure that our growth helps millions of people along our entire value chain. Production clothing can be a development escalator to show communities the way out of poverty. Creating jobs is a good start, but we must ensure that these are good and contribute to the development of people and their communities.

We continue our dialogue with governments, for example, to set minimum wages and create legal frameworks for fair and functional collective bargaining processes. We made another important step to align ourselves with other brands on a common approach towards wages of life. Last but not least, we are investing a lot of resources to provide workers with better skills to enable them to negotiate wages and working conditions directly with their own bosses."

Transparency is another key objective for the company. H&M works with other brands of the Sustainable Apparel Coalition, the most important alliance of the textile industry for a sustainable production. The main objective of the coalition is the construction of the Higg Index4, a supply chain measurement tool, standardized for all operators in the sector, which makes it possible to evaluate the environmental and social impacts of the production and sale of products and services. By measuring sustainability performance, industry can address inefficiencies, solve harmful practices and attain environmental and social transparency for consumers. By joining forces in a coalition, companies are able to tackle urgent challenges that they could not solve on their own.

Among the most important initiatives taken by the company, it is important to mention the "Recycle your clothes" initiative. H&M was the first brand to launch this initiative at a full scale, with garment-collecting boxes in all stores around the world. The ambition has always been to make it as easy as possible for the customers to give their garments a new life.

Prada Foundation

In 2015, Prada introduced a new integrated strategy for social responsibility and sustainability and for a new ethic of the company. The sustainability project that is monitored through a dedicated website, refers to sustainability, culture, respect for traditions and the territory. Moreover, Prada project especially aims to the construction of an integrated value chain, which is considered fundamental to combine quality and innovation. According to the president of the Board of Directors of Prada Group, Carlo Mazzi, this result will lead to the rediscovery of the true value of the company, which is social responsibility, through the control of quality and ethical standards:

"We believe that it is part of corporate social responsibility to broaden horizons by also looking at the impact of our activities so that they direct economic development towards more sustainable balances. It is an ambitious goal that we want to pursue not only through constant attention in the management of the company, but also as promoters of culture in its various shapes: as a source of inspiration, as an opportunity for expression and sharing of interests between people".

The website contains an introductory section, "Corporate Social Responsibility" which provides an overview of the activities through texts, info-graphics, maps, reports and figures. The site is then divided into three main sections:

- "Work" as an expression of craftsmanship and innovation, safeguarding know-how and transmitting skills: In this section, you can find pictures of employees creating, bags, clothes, example of high quality goods. Moreover, there is also the introduction of a future project: The Prada Academy, to train young technicians who can learn and tranfer their know-how in the luxury manufacturing sector.
- "Territory" as a cure for the places in which the company operates through a respectful dialogue between architecture and environment. By clicking on it, you can start a virtual tour in the Montevarchi and Valvigna establishments (Tuscany) and in Montegranaro (Marche): real "garden factories" where craftsmen work in natural light filtered from the roof
- "Culture" as heritage for the future, safeguarding the artistic heritage, disseminating culture and revitalizing peripheral urban areas, to support young talents. An example above all: the restoration of the Gallery and the new Prada Foundation in Milan.

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3.5. CSR and ethical production and consumption

Sofia Papakonstantinou, CRE.THI.DEV., Greece

Introduction

The pyramid of Corporate Social Responsibility is a tool with the form of a pyramid suggesting what types of activities that are fundamental for CSR and which ones that should be prioritized. The four social responsibilities that build up the pyramid are economic responsibility, legal responsibility, ethical responsibility, and philanthropic responsibility. These different layers help the managers in the companies to see the different types of responsibilities that the society expects from them.

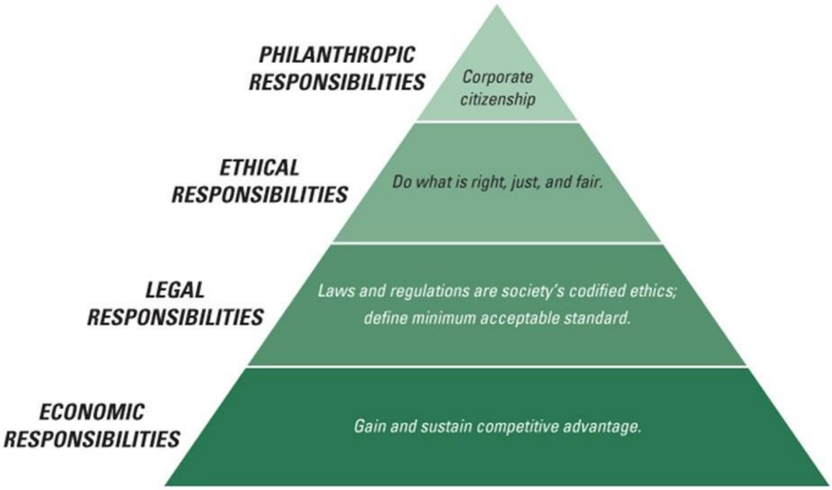

Figure 3.5.1. The pyramid of Corporate Social Responsibility

One of the main concerns with regard to the shift to fast fashion has been the sustainability of such a method of production in terms of labour and material resources. As items purchased are so cheap, consumers are purchasing items more often but wearing them less frequently. This results in increasing amounts of textile waste ending up in landfill each year and fast fashion being associated with the term 'disposable fashion'. The shift to offshore production and the cheapness of products has led to further questions on the ethics and Corporate Social Responsibility (CSR) issues surrounding fast-fashion production, most notably the working conditions in factories and the use of child labour. Although many consumers appear to champion socially responsible practices which impact upon their perceptions of fashion brands, fast fashion is the exception to the rule. This is confirmed by recent research, which indicates that consumers are well aware of the ethical issues but are drawn to the trendier, price-driven offerings of these retailers thereby ‘aesthetics trumps ethics’.

By the late 2000s the term ‘slow fashion’ began to be used as an alternative to fast fashion in much the same way as farmer’s markets and organic food were a reaction to the fast-food revolution. Some of the earlier interpretations of slow fashion relate to local quality crafted products and/or through embracing CSR principles, especially environmental principles in production and recycling. Not surprisingly such a view with respect to quality and associated heritage craftsmanship led to associations with luxury retailers. The slow-fashion process embraces sustainable and socially responsible practices that are applied at the three levels of design, production and consumption. That means that slow fashion can be applied to the fast-fashion sector, i.e. companies such as Zara and H&M have embraced some elements of slow fashion in their supply chains. As an example, H&M has developed initiatives at each stage of the supply chain, from encouraging designers to consider the long-term impacts of the products chosen for designs, to support for CSR practices in textile production, to finally educating consumers on disposal and recycling of clothing. As a practical example, H&M encourages customers to bring in their discarded clothes to recycle in exchange for a discount on new merchandise. Moreover, H&M produces an annual sustainability report and is relatively transparent in its sourcing strategy through the publication of a list of all factories and ratings of supplier compliance.

Ethical production and consumption

Fashion supply chains are predominantly driven by fast clothing and disposability; they rely on the ability of manufacturers to switch production on and off and the ability of the brand to relocate for speed to market and margin pressures. However, public pressure from campaigners and NGOs (non-government organizations) has created a major force for change. Retailers are being forced to pay closer attention to the ways in which their goods are produced: bad publicity surrounding ethics is not good for business.

Fashion retailers and manufacturers must consider their global impact as they continue to develop products overseas and expand in new markets (both in terms of selling and manufacturing). The ethics of local and global supply, associated labour issues and their impact upon local communities are increasingly important.

The development of good relationships between retailers and apparel brands, manufacturers and outsourcing is crucial for the future success of supply chain management. All parties need to work together to formulate the best way of working. This is not an easy dynamic at times when the pressure to reduce cost and optimize speed is the main criteria in a competitive fashion retail environment.

However, in today's environmentally concerned society it is simply unacceptable to exploit those, such as factory workers in developing countries, who have less of a voice.

Millions of people work in the fashion industry and there are a number of important issues that need to be catered for.

Human rights

Forced labour, child labour, sexual harassment, discrimination and dangerous working conditions. These are some of the things that the people who make our clothes have to go through. Despite there being international standards and national laws that should protect people, human rights abuses are prevalent throughout the fashion industry. The Global Slavery Index estimates that 36 million people are living in some form of modern slavery today; lots of these people are making clothes for western brands.

Fair pay: The legal minimum wage in most garment-producing countries is rarely enough for workers to live on. For example, in Bangladesh, it's estimated that the minimum wage only covers 60% of the cost of living in a slum. Low wages keep garment workers in a cycle of poverty and add to the pressure to work long overtime hours, which impacts on their health and safety, as well as the quality of clothes.

Figure 3.5.2. The low wages issue

Artisan craft: Mass-produced clothing and accessories have eroded the artisanal, heritage craft skills passed down through generations in communities around the world. Millions of people in the developing world – mainly women – depend on the handicraft trade. But right now, that trade faces an uncertain future.

The demand for ethical goods

The views of consumers can influence and pressurize retailers and their suppliers. There is increased market demand for fair trade and organic products and traceability of raw materials. According to a report in 2009, the UK's ethical fashion industry was worth approximately £175 million, and according to the Co-operative (2008), ethical fashion in the UK is growing faster than almost any other ethical sector, at 71% per year.

However, consumers may often say one thing and do another, especially when they want to buy fashion items at a good price. The style and cost of the garment is often the decision-making factor, not its ethical credentials. In times of economic uncertainty, consumer demand for cheap clothing remains high and the expectations are for immediacy or instant gratification in fashion retail purchasing behaviour. It remains that one of the most important issues for retailers is to provide customers with the right products at a realistic cost.

CSR and business ethics

CSR and business ethics are often used interchangeably but are quite different. CSR is related to the social contract between a business and the society in which it operates. It sets out the intentions of the business to behave and operate responsibly with its sourcing and supply chain and in its overall business strategy. Most large businesses, such as Marks & Spencer, Monsoon, H&M and Gap, will have a CSR policy within their corporate and marketing strategy and this will generally be widely promoted. CSR policy can usually be found on a company's website, illustrating how that brand or retailer implements it within its business. Businesses are increasingly using CSR as part of their key performance measures and this can have an impact on the bottom line: profit.

Cause-related marketing (CRM) is an offshoot of CSR. The idea is that aligning companies with certain causes will create social capital in the business. A great example of this is the RED campaign, which helps those with Aids in Africa, in which GAP, American Express and Motorola are involved, amongst others. Many fashion retailers use ethical initiatives and turn them into valuable marketing and corporate strategy, which may then be used to gain competitive advantage.

It is clear that some fashion brands do far more than others to enhance the visibility and ethical nature of their supply chains. However, whilst responsible retailers may take an ethical stance in their marketing campaigns, this, alongside a demand for fast fashion can present challenges: the two do not sit comfortably together.

The role of NGOs

NGOs are defined by the World Bank as 'private organizations that pursue activities to relieve suffering, promote the interests of the poor, protect the environment, provide basic social services, or undertake community development.'

Labour issues in the garment industry are well documented and it is the role of the NGOs to work with fashion retailers to establish and improve their labour policies and to help protect workers' rights. Examples include Oxfam, which works in the interest of creating rights for workers and conditions overseas. The International Labour Organization (ILO), a UN agency established in 1919, is jointly governed by government, employer and worker representatives. Its mission is to raise global awareness and understanding of labour issues, to eliminate forced and child labour. Labour Behind the Label is a network of organizations that support workers worldwide, helping them to 'improve their working conditions, through awareness raising, information provision and encouraging international solidarity between workers and consumers.' In addition to working in the industry, Labour Behind the Label works with colleges and fashion students to promote knowledge and understanding of the issues that may confront buyers, merchandisers, designers and anyone else involved in sourcing.

The Ethical Trading Initiative

Fashion retailers' policies vary wildly but should all be based on the guidelines set out by the World Trade Organization (WTO). A member organization called the Ethical Trading Initiative (ETI) is a good example of an NGO that is influencing and helping shape retail policy. The initiative, launched in the UK in 1997, bases its policies on WTO guidelines.

It is relevant to note here that there is little, if any, legislation in place to force retailers and manufacturers to join an organization such as the ETI and to adhere to guidelines. But by becoming a member, a company is making a commitment to tackle issues within its supply chains. The ETI's member companies are expected to report annually on their efforts and results and to show improvement in their ethical trade performance. Company members include Asda (Walmart-owned), Debenhams, Gap, Inditex (which owns Zara), Levi Strauss, Marks & Spencer, Monsoon, Mothercare, Next, New Look, Primark and Tesco.

Some fashion brands do far more than others in order to make the necessary changes and improve conditions for workers. Sourcing policy varies between different retailers and brands and although there are similar codes of practice to those of the ETI they are open to interpretation.

It is essential that retailers work closely with suppliers, giving them time and help in order to achieve the required standards. Monitoring suppliers, minimizing risk and solving short-term problems together can make fashion businesses more efficient as well as ethical. It may mean a rise in costs but should also mean an increase in sales and profit margins.

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3.6. Environmental management systems and the impact of textile processes on the environment

Laura Chiriac, Ion Razvan Radulescu
INCDTP, Romania

Introduction

In recent years, environmental issues are an integral part of the strategy of companies around the world. Each economic unit seeks to achieve and demonstrate alongside economic growth and a high level of environmental protection to comply with environmental legislation.

Environmental policy is an ensemble of environmental objectives and priorities, regulatory methods and implementation tools designed to ensure sustainable use of natural resources and prevent environmental degradation. European environmental policy is based on the principles of precaution, prevention, correction of pollution at source and “polluter pays”. Environmental management is the management of those activities that have environment impact.

Environmental management systems

The International Organization for Standardization (ISO) defines an environmental management system (EMS) as “part of the management system used to manage environmental aspects, fulfill compliance obligations, and address risks and opportunities.” EMS of an organization aims to accomplish its environmental policy, implement its environmental management program and achieve the proposed objectives.

One of the most important activities in the world is the development of environmental standards, especially those of the International Standardization Organization's Technical Committee 207 (ISO 14000 series). Environmental management is presented in two main groups: one referring to the organization (e.g. Environmental management systems - ISO 14001, ISO 14004; Environmental performance evaluation - ISO 14031; Environmental auditing and related environmental investigations - ISO 19011), the other referring to products and technologies (e.g. Life cycle assessment - ISO 14040 standards; Environmental labeling - ISO 14020 standards; Environmental aspects in product standards - ISO 14060).

Environmental management systems are addressed directly in a number of three standards: ISO 14001, ISO 14004 and ISO 19011. Of these, the only one containing auditable requirements is ISO 14001. It is the reference standard for EMS, which means that only its requirements are mandatory for certification. The other two standards support this standard, ISO 14004 with recommendations and application techniques, ISO 19011 with the EMS audit methodology.

ISO 14001 specifies the requirements for a company's EMS that seeks to increase its environmental performance, manage its environmental responsibilities in a systematic manner and achieve its intended results with the aim of contributing to the environmental pillar of sustainability. The framework in the ISO 14001 standard can be used within a Plan-Do-Check-Act (PDCA) approach to continuous improvement.

The new 2015 edition of the ISO 14001 standard has a new structure and introduces new requirements for strategy, leadership, environmental issues, evaluation, communication and new terms such as: sustainable development, life cycle, environmental performance, performance indicator, risks and opportunities, value chain, supply chain etc. ISO 14001:2015 covers the following sections: Context of the organization, Leadership, Planning, Support, Operation, Performance evaluation, Improvement.

Other environmental management tools developed by ISO/TC 207 refer to EMS in small-and medium-sized enterprises (ISO 14005:2010), management of ecodesign as part of an EMS (ISO 14006:2011), environmental performance evaluation (ISO 14031:2013), environmental labels and declarations, including eco-labels, self-declared environmental claims and quantified environmental information about products and services (ISO 14020 series of standards), addressing the environmental aspects and potential impacts on the environment during the life cycle of the products and services (LCA) “from raw material to final disposal” (ISO 14040 standards), eco-efficiency assessment for product systems (ISO 14045:2012), water footprint assessment of products, processes and organizations based on LCA (ISO 14046:2014 and ISO/TR 14073:2017), quantification, reporting and reducing of greenhouse gases (GHGs) associated with products – carbon footprint assessment of products (ISO 14060 family).

One of the techniques developed with regard to environmental protection and the possible impacts associated with manufactured and consumed products is LCA. This is presented in the ISO 14040 family of standards and can be used in the textile industry to identify, quantify and asses the impact of textile products on the environment. Its aim is to collect the input (e.g. raw materials, energy and natural resources) and output (e.g. emissions into water, soil or air) data from the system and to perform software-based computing of this data, in order to get the environmental impact. There are many LCA software programs available, having various features. Such a software is addressing a data basis with elementary products and processes and their impact on the environment and performs links and calculation to the inputs and outputs into the system. An example of data basis is the Swiss ECOINVENT v.3, containing over 10.000 processes. Examples of LCA software programs with various features and price-performance ratios are: Sima-Pro, GaBi, EarthSmart, Sustainable Minds, Enviance system, Umberto. These software programs usually transform the input/output data into environmental impact on certain impact categories. The impact categories are grouped within methods. For instance the method Eco-indicator 99 (E), describes the environmental impact on following categories: carcinogens, respiratory (in-) organics, climate change, radiation, ozone layer, eco toxicity, minerals, fossil fuels. The data from the Life Cycle Impact Assessment (LCIA) computation is assessed within the Interpretation step using the diagrams issued by the software.

The Eco-Management and Audit Scheme (EMAS) is the EU's voluntary tool designed for companies and other organizations committing themselves to evaluate, manage, reduce their environmental impact of the activities and continuously improve their environmental performance. EMAS is the most credible and robust environmental management system on the market. In order to register with EMAS, organizations should carry out the steps outlined in the EU EMAS-Regulation.

The main benefits offered by the EMS are: prevention of pollution, improving process efficiency, meet legal obligations, credibility, new business opportunities, attracting investments, improving relations with all partners, improving global management and economic performance and reducing the risk of environmental accidents.

The EU Ecolabel is another tool of environmental EU policy designed to encourage economic operators to market goods / services with a low environmental impact. EU Ecolabel identifies environmental performance of a product or service based on LCA. The EU Ecolabel is a graphic symbol, whether or not accompanied by a short descriptive text applied to the product, packaging or accompanying information document that provides data on environmental impact.

The impact of textile processes on the environment

The textile industry is one of the industrial sectors with significant environmental impact because of the large quantities of water consumed for processing as well as due to the highly polluted wastewater. Textile processes that contribute to contaminating wastewater are those that come from chemical finishing, especially from desizing, scouring, mercerizing, bleaching, dyeing, printing and finishing. A wide variety of chemicals (detergents, alkalis, acids, dyes, resins, polymers, fungicides, fire retardants, emollients etc.) is used in the processing of textile materials. The waste water from the textile finishing units raises serious problems with the amount of dissolved solids (DS), suspended solids (SS), pH, temperature, color, bio-chemical oxygen demand (BOD), chemical oxygen demand (COD), heavy metals and non-biodegradable dissolved organic matter. Also, the wastewater can contain bacteria and other pathogens from the processing of wool or pesticides. Due to the diversity of production structure, the quality of wastewater varies not only from one commercial company to another, but sometimes depending on the period, even within the same company. European legislation requires severe depuration conditions of industrial wastewater before it is discharged by treating it in sewage treatment plants. Another source of environmental pollution is air emissions of nitrogen and sulfur oxides, hydrocarbons, formaldehyde and other volatile organic compounds (VOC), acid and alkaline vapors, dust or odor from various operations such as drying, condensation, calendering, printing or waste water treatment. The main textile processes and environmental impacts are presented in the following Table.

Table 3.6.1. Summary of the wastes generated during textiles manufacturing and the impact on environment

Process	Source	Pollutants	Environmental impact
Technological steam and energy generation	Emissions from boiler	Nitrous oxides (NOx), sulphur dioxide (SO2), carbon monoxide (CO), powders	Air Pollution, generation of the green house gases
Spinning preparation, carding, combing, weaving	Emissions from fabrics manufacturing	Dust and lint	Air pollution, noise
Sizing	Emission from using sizing compound	Starch, waxes, Carboxymethyl Cellulose (CMC), Polyvinyl Alcohol (PVA), wetting agents	Wastewater and air pollution
Melt spinning fiber	Emissions from polycondensation	Exhaust gases	Air pollution
Napping and carpet shearing	Emissions from processes	Dust and lint	Air pollution
Dry cleaning	Solvent processing operations	Solvent vapors	Air pollution - VOC
Carbonization of wool	Emission from using chemicals	Acid mist, Sulfuric acid, Sodium Hydroxide, natural impurities like vegetable and mineral compounds	Air and wastewater pollution
Raw wool cleaning	Emissions from using chemicals, emissions from wool fibers	Detergents, natural impurities like wool wax	Wastewater pollution - high BOD, COD, SS
Desizing	Emissions from using chemicals	Enzymes, wetting agents, starch, glucose, PVA, resins, fats, waxes	Wastewater pollution - high BOD, COD, SS, DS, aquatic toxicity

Scouring	Emissions from using scouring chemicals, emissions from cotton fibers	APEO, EDTA, DTPA, NTA chemical products, Sodium Hydroxide, soda ash, fats, waxes, short cotton fibers, alkali mist, high temperature of process	Wastewater pollution - high COD, BOD, SS, DS, high pH, eutrophication of groundwater, aquatic toxicity
Bleaching	Emission from using chlorine compounds	Chlorine, Chlorine Dioxide, Sodium Hydroxide, surfactants, Sodium Silicate, Sodium Phosphate, short cotton fibers	Wastewater pollution - high pH, high SS, low BOD
Mercerizing	Emission from using mercerizing chemicals	Sodium Hydroxide, cotton wax	Wastewater pollution - high pH, low BOD, high DS
Dyeing	Disperse dyeing using carriers, Sulphur dyeing, metal complex and acid dyeing Emissions from using dyes and chemicals	Carriers, Sulphide, Urea, mordants, reducing agents, Acetic Acid, detergents, wetting agents, heavy metals, neutral salts, unfixed dyes	Large volume of water, Wastewater pollution - strongly colored, high BOD, DS, SS, high salinity, release of Formaldehyde, aquatic toxicity, inhibitor in sewage treatment systems, accumulation in sludge of heavy metals
Printing	Emissions from mineral spirit solvents in print pastes or inks, dyes, thickeners, residual pastes	Hydrocarbons, Ammonia, Formaldehide, pastes, Urea, starches, gums, oils, binders, acids, thickeners, cross-linkers, reducing agents, alkali	Wastewater pollution, highly colored, high BOD, oily appearance, SS, slightly alkaline Air pollution – VOC
Washing and rinsing	Emissions from the main processes	High temperature of process, chemical products, reaction products, short fibers	High water consumption, wastewater pollution
Finishing	Emissions from using resins, polymers, catalysts	Formaldehyde, carriers, toxic polymers, lubricating oils, N-methylol reagents, chlorinated compounds, biocides, perfluorinated compounds with more than 8 carbon atoms, antistatic agents, flame retardant agents	Wastewater pollution, aquatic toxicity, bioaccumulation potential, low BOD
Coating, drying and curing	Emission from high temperature ovens	VOC	Air pollution, release of formaldehyde, high energy consumption

Waste water treatment	Emissions from treatment tanks and vessels	VOC, toxic emissions, wastewater with high COD, SS, DS	Odors, solid wastes, air pollution - VOC

The EU's industrial emissions Directive (IPPC) sets the general framework for industrial pollution control, based on the Best Available Techniques (BAT) concept. The overall objective of the IPPC Directive is to prevent and control emissions into air, water and soil, waste management, energy efficiency and prevention of environmental accidents for industrial installations, through an integrated approach. The best available techniques are described in BAT reference documents (BREF). BAT in the textile industry refers to the most efficient technologies for pollution prevention, wastewater treatment, overall achievement of a high level of environmental protection in its entirety. In the BREF, textile industry covers wool scouring sector, textile finishing (excluding floor covering) and carpet sector. Within each of these sectors, a variety of wet processes is applied. BAT are elaborated for each of these processes. In addition, there are some generic BAT such as selection and use of chemicals, water and energy management etc.

The following general measures can be applied to all activities involving textile processing industry to prevent pollution:

- pollution control by using of BAT;
- process and equipment optimization;
- optimizing chemicals and using environmentally friendly finishing solutions;
- using unconventional, innovative technologies;
- reducing water and energy consumption;
- effluent treatment and waste disposal;
- energy efficiency improvement;
- continuous improvement of environmental management;
- compliance with environmental legislation.

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3.7. Textile waste recovering: Strategies and sorting technologies to close the loop in the Textile & Clothing sector

Micol Costi, Veronica Sarbach, MCI, Italy

Introduction

With finite land, water, and energy resources, the textile and clothing industry needs to reduce its waste considerably. Moving the industry toward a circular economy can yield tremendous environmental benefits for the fashion industry while mitigating the effects of greater demand for garments due to a rising world population. In the past decades the industry has raised awareness about the risks that have to be faced in the upcoming years if the T&C sector sticks to a linear economy and thus is largely investigating strategies and technologies to produce textiles in a more sustainable manner: new recycling and regeneration technologies for existing fibres are developed, investments in Research and Development of new fibres from renewable resources are willingly financed, less impacting dyeing and finishing processes are introduced and new business models to avoid overproduction are studied. In this context, recycling of pre- and post-consumer textile waste is identified as the missing link to close the loop and implement a circular economy for textiles and fashion on an industrial scale. In the following pages a short overview highlight issues of currently applied sorting technologies and indicates some routes on how to overcome them through innovative solutions.

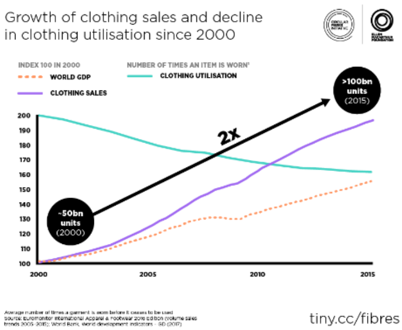

Figure 3.7.1 Growth of clothing sales and decline in clothing utilisation since 2000

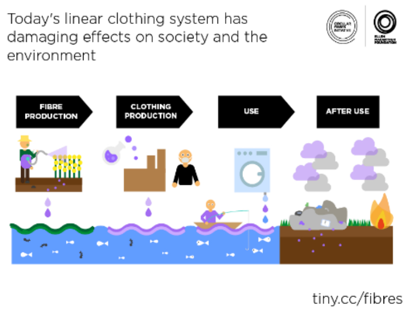

Figure 3.7.2. The current clothing system is extremely wasteful and polluting

Output quality of recycling: different levels of recycling from production to consumption

Recycling textiles is an extremely challenging activity for several reasons: from collection, to sorting, to the technological difficulties in obtaining a raw material able to provide a sufficient performance. A new systematic approach needs to be implemented in order to offer recycled materials that guarantee second raw material which can compete with virgin materials on cost and quality. Moreover, recycling can happen in different moments during the lifespan of a product from fibre production, to production, to use and after use, where quality of the obtained second raw material essentially depends on purity of the recycled material feedstock, that is to say the transformation level undergone by the virgin material.

The raw material for textile recycling processes can originate from post-production or post-consumer feeds. A clear distinction must be made between these two streams. The post-production textile material is generated during the production processes and often consists of fibres, yarns and textile clippings, whereas the post-consumer materials are garments or household textiles that consumers have discarded. These garments can be unused, used or mutilated.

There is a huge technical difference in the recycling of post-production and post-consumer textiles. For recycling of post-production textiles, the information regarding the blend and composition is easy to collect, since a specification of the received material can be retrieved from the producer. Post-consumer textiles, in contrast, consists of a mixture of all types of fibre blends, and the information on their composition, originally recorded on a label attached to the garment, is often missing or misleading.

Focusing on textile products, several stages of product transformation are identified where recycling can happen, starting from a finished garment or textile product zooming into by-products resulting from fabric production to yarns and fibres up to the Nano level of polymers and monomers, each demanding for different approaches and presenting different difficulties:

- *Garment recycling* is mainly referred to re-use of intact garments through reselling at second hand markets or donating to charity. Consumers of the western countries (EU + USA) report to largely contribute to provide a second life to their discarded wearable garments. This behaviour is also exploited by companies engaging their consumers through in-store garment recycling by offering discounts for future purchases. Literal recycling of non-wearable garments would be possible, if the clothing industry could provide monomaterial products where all components are made of the same material thus recyclable within a single material stream.
- *Fabric recycling* takes pieces of complete fabric and re-sews them to create (parts of) a new garment. This level of recycling is sometimes also referred to as ‘remanufacturing’. It can take the form of utilising factory offcuts and leftover materials, or large parts of post use garments that are disassembled and reused in a new garment while keeping the fabric intact. If a change in colour is needed, the fabric can be treated with bleaches or dyes in the process. This type of recycling does not require advanced

technologies, but only has limited applications as it is labour intensive, inconsistent supply of fabrics will not allow for largescale production, and the fabric is often too small to be made into another garment or the quality is too low.

- *Yarn recycling* refers to the unravelling of the yarns used to make knitted garments. To be able to unravel a garment, it must be knit in a way that makes it possible to get the yarn back in a small number of pieces. Therefore, yarn recycling is only feasible for specific types of garments, which need to be collected separately or separated out.

The key differentiation is between 'mechanical fibre recycling, which will degrade with each recycling (down-cycling) and 'chemical fibre recycling' which in some cases can produce fibres of equal quality to virgin ones.

- *Mechanical fibre recycling* is traditionally indicated as the recycling process for textiles. Fabric is torn apart using carding machines to obtain the fibre. Natural fibres particularly suffer from this traditional recycling as the fibres' length is shortened in the process, generating weaker yarns after spinning. New, interesting processes have been studied and have recently entered the market that use cotton scraps together with wood to obtain regenerated cellulose fibre through chemical recycling. Other manufacturers have developed processes to provide yarns without including virgin fibres, such as Ecotec yarn produced by Marchi & Fildi which transforms pre-consumer clippings (production waste from weaving and knitting companies) into a 100% cotton yarn applying an exclusive traceable and certified production process with record savings in water and energy consumption. By design, mechanical fibre-recycling processes cannot separate blends or filter out dyes and contaminants and rely thus on the suppliers for information about materials and chemical substances.
- *Chemical fibre recycling* essentially means breaking the fibre down on a molecular level thus refers to processes for polymers and monomers: Polymer recycling takes fibres back to the polymer level, destroying the fibres but keeping the chemical structure of the material intact. *Chemical polymer recycling* dissolves textiles with chemicals after the garments have been de-buttoned, de-zipped, shredded, and in some cases de-coloured. This technology can be applied to plastic- and cellulose based fibres or a mix of both. Cellulose – the polymer that is the main component of cotton – and polyester are extracted separately for further treatment. Cellulose pulp can then be transformed into new cellulose-based fibres and plastic polymers are treated separately to bring them back to virgin-equivalent quality. Dyes, non-target fibres in small quantities, and other contaminants can be removed during the process.

Today, the most commonly available recycled synthetic fibre is polyester made from plastic bottles. In order to obtain a fibre from the bottle first a mechanical process is applied (crushing the bottle into flakes) followed by a chemical recycling process which involves breaking down the material at the molecular level and then re-polymerize the feedstock. While chemical recycling is more energy intensive than mechanical pulling, the resulting fibre tends to be more of predictable quality. The polyester fibre obtained today from chemical recycling can achieve the same quality than virgin polyester fibres.

Innovation in recycling often can be found more in the recycling process itself than in the fibre that is obtained. *Mechanical polymer recycling* is carried out via melting and extruding of textiles made from mono-material plastic-based fibres. By design, this process cannot filter out dyes and contaminants, such as substances of concern. *Chemical monomer recycling* breaks down polymers into individual monomers or other constituent materials that can then serve as feedstock to produce virgin-quality polymers.

Dyes, non-target fibres in small quantities, and other contaminants can be removed during the process. Most clothes consist of a combination of blended fibres. One such example is polycotton, a combination of typically 35% polyester and 65% cotton. Separating mixed fibres during the recycling process is often a challenge. WornAgain hopes to overcome this obstacle and provide a technology to separate fibres, dyes, and other contaminants from the fabric.

Manual sorting for textile recycling has been performed for a very long time, e.g. in Prato in Italy and in Panipat in India. The industry in Prato is known for recycling of wool and cashmere blends, whereas Panipat is known for recycling of cotton, polyester and also many other textile types. Garments are recycled to new yarn by mechanical recycling (shredding or garneting).

This recycling process reduces the original fibre length and the produced yarn is therefore of lower quality than yarn from virgin fibres. Only yarns produced from garments of one single fibre type can be used (mostly mixed with virgin fibres) in textile-to-textile products to achieve similar quality as virgin textile products. Yarns produced from garments with different fibre types can be used in textile-to-textile recycling, but in products of lower quality such as backings of carpets or blankets.

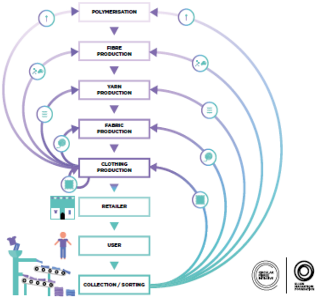

Figure 3.7.3. Textiles recycling can capture value at various levels

Figure 3.7.4. «cenciaioli» - Rug merchants of Prato

Sorting Technologies of garments and household textile waste

Post-consumer garments and household textiles are currently collected through various routes such as charity donations, municipality bins, retailer in-store collections, online take-back activities and door-to-door charity bag collections. These collection routes are common to most countries in Europe, but it must be recognised that a wide variety is found from country to country concerning their levels of development and efficiency, partly reflecting differences in commitment from both public bodies and consumers. Usually, a minority of the collected goods is sold domestically on the second-hand market, while the remainder of the wearables is exported to other countries. Non-wearables constitute a large fraction which may lie in the range of almost half of all the goods. Collected garments and household textiles are subsequently sent to graders, where they are sorted manually according to different criteria:

- Wearables (undamaged garments that can be worn again) or Non-wearables (recyclables).
- Wearables are then sorted according to quality/design/condition/style, e.g. by using up to 350 different criteria.
- Non-wearables are sorted according to different recycle stream criteria based on the type of material, such as materials made of one fibre type (pure cotton, pure wool etc.), majority fibre type (cotton-rich, wool-rich etc.) or fibre blends. These could also be further sorted according to colour.

At present, the sorting of post-consumer garment and household textile waste for recycling has limited accuracy. Manual sorting relies to a large extent on label information attached to the garment and such information is often missing in collected goods. Erroneous labels and human errors in the manual sorting add to the difficulties of achieving the requested quality. A central issue is whether the quality requirements of the recycling processes can be met. This is especially critical for textile-to-textile recycling, which generally requires high-quality sorted textile waste fractions. Potential chemical fibre recycling processes are likely to need high quality-sorted fractions of post-consumer textile waste to produce new textiles. Provided that a material recognition technology can sort for textile-to-textile applications, this technology would be a promising solution for the textile sorting industry.

Automated sorting means that a physical process line is built up to handle material streams, where software receives signals from a set of sensors and uses this information to take autonomous decisions on the further fate of each item. This could make it possible to achieve high throughput capacity. Automated technologies that could be able to sort textile fibre types and composition can be divided into two groups:

- Spectroscopic automated technologies which identify material by its fibre type and colour
- Information-based sorting, such as tagging with code carriers (QR or Radio-frequency identification (RFID), gives information about fibre type and colour, but also brings necessary information through the whole value chain.

Automated garment sorting: automated near-infrared (NIR) technology

Optical sorting technologies are broadly used in many sectors for sorting processes; initially develped for plastic sorting, Near InfraRed (NIR) technologies, such as hyperspectral imaging and visual spectroscopy (VIS) have been adapted to textiles in order to sort clothes by colour and material category and is currently the favoured recognition technology for automated material sorting of garments and household textile waste. Since tagging of textile products via code carriers is not implemented yet on an industrial scale, near-infrared technologies are the first candidates to further investigate for sorting of garments in a near time perspective. Such systems must be compared with and benchmarked against today's manual sorting, which has to rely on label information, to enable NIR sorting as a material recognition technology for textile sorting towards higher quality.

NIR spectroscopy is based on molecular absorptions measured in the near infrared part of the spectrum. The infrared light from a light source is partially and selectively absorbed by the studied surface, and the reflected light creates a characteristic spectrum of each fibre type or blend combination. The spectrum is then compared with a predefined database and thereby it is possible to identify the material composition of the textile material.

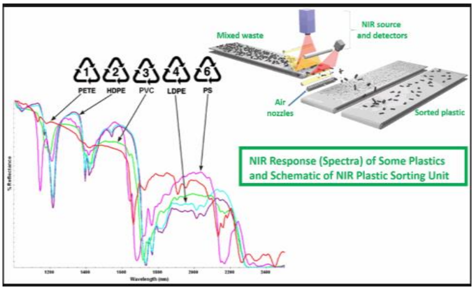

Figure 3.7.5. NIR spectroscopy enables to identify different types of plastics within seconds

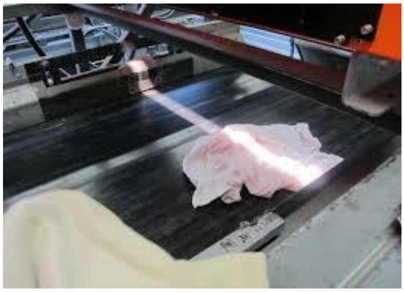

Figure 3.7.6 NIR spectroscopy applied to garment sorting, AUTOSORT (Tomra Sorting)

A limitation with NIR is that the near-infrared light can only penetrate very thin garments. In most cases the garments are too thick for deep penetration and the collected spectrum covers only the outermost layer of the garment. This means that the side of the garment that is scanned will determine the fibre information. Currently, numerous researches are conducted by individual companies and publicly financed project consortia working on pilot plants to define industrially viable technologies for accurate fibre recognition.

Projects recently concluded or currently running include:

- *SIPTex*, Swedish research project testing involving Boer Group to evaluate automated textile sorting by building and operating a pilot facility for 12 months. Recognition and sorting equipment are based on near-infrared (NIR) technology.
- *FIBERSORT*, project funded via EU's Interreg North-West Europe programme to validate the Fibersort technology by applying Valvan's NIR spectroscopic technology, to refine software models and to optimize the material library.
- *RESYNTEX*, research project funded by EU's Horizon 2020 programme led by SOEX group, the world's leading company in collecting and sorting of discarded textiles.

Automated garment sorting: Information-based technology

In order to guarantee high quality materials for textile-to-textile recycling, detailed information about the second raw materials need to be available, data that currently are not provided for post-consumer textile waste. Recent innovations linked to data management and the Internet of Things (IoT) offer several technologies potentially applicable to the textile sector in order to provide data linked to material composition and the undergone processes. In fact, digital technologies can support more accurate sorting of textiles through increased access to information, however, it is key that these are considered in the design or manufacture stage to be used effectively; adopting product passports and materials labelling at the design stage would significantly improve material recovery. While conscious garment producers are willing to provide information about material composition of their products and thus are including digital labelling technologies, major obstacle in spreading these technologies throughout the whole industry can be found at the lowest level of the supply chain that is the raw material suppliers, i.e. at fibre level. Nevertheless, Molecular tagging and authentication systems have been adopted by a wide variety of industries. SigNature DNA molecular tags can be embedded into raw materials or applied to the surface of almost any object. Each custom molecular tag is formulated specifically to adhere tenaciously and is optimized to support multiple authentications throughout the supply chain. Besides these recent innovations, once largely adapted, blockchain technologies will finally offer the possibility to identify and trace raw material origin and transformations following through the complete value chain: Blockchain technologies assign each product a unique digital ID or token that enables the tracking of materials or garments through the supply chain. Saving all data on a decentralized, distributed ledger makes the information throughout this process incorruptible.

Figure 3.7.7. Digital technology to identify and trace textile content

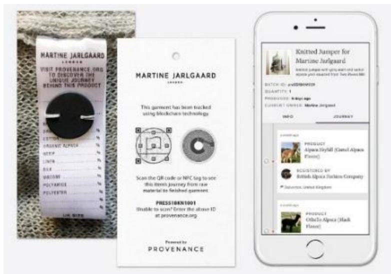

Figure 3.7.8. Product traceability thanks to blockchain

Future steps

The sorting of post-consumer garments and household textiles by material type is a huge challenge, and current procedures need improvement to increase the textile waste recycling/upcycling rates. Accurate and rapid sorting of garments would be greatly supported by universally aligned tracking and tracing technology. Until this is implemented at scale, continued development and introduction of optical sorting technologies could improve the speed of garment sorting, which is mostly carried out manually today. Moreover, Global common guidelines on clothing labelling would be required to ensure universal application to sorting of any material streams. Guidelines would also need to include information on the integration of new technologies, such as e-textiles or RFID, in a way that enables easy disassembly and recovery after use. But foremost, Designers have to take a product's full lifecycle into account to guarantee successful re-integration of textile waste as a second raw material into a closed looped fashion industry. Fortunately, a growing number of brands have indeed started training their design teams around product durability, reuse, and recycling, so that circularity can become core to the design briefs.

Strategies to overcome current barriers have to be implemented primarily at the design stage, addressing:

- *Controlling the supply chain* by using only in house produced materials or secured/closed recycling streams;
- *Tracing the materials* by assuring data about raw materials and transformation processes via material passport and digital technologies;
- *Designing for recycling* by creating monomaterial garments or permitting an easy disassembly and recognition of the used raw materials of the commercialised product.

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3.8. Substitution of hazardous chemicals

Josep Casamada, Ariadna Detrell, AEI Tèxtils, Spain

Introduction

Textile industry has long been using different chemical products for finishing and other textile processes (colors, functionalization). Some of those chemicals may have potentially harmful effects to the environment and to human health both for workers and end-consumers at different stages of their life cycle. The presence of some of those harmful chemicals also limits their recyclability and increases the overall environmental impact.

The Swedish chemical agency identified over 3.500 substances used in the textile industry. There is no information available for over 1.000 of them due to confidentiality of the diverse formulations used. About 10% of the identified substances (250+) have hazardous properties either for their impact to the environment or for human health.

Main substances of concern include:

- Formaldehyde can be released in finishing processes and for shrink resistance
- Perfluorinated chemicals used for water and stain repellence
- Brominated and halogenated products used in flame retardants
- Antimony trioxide used as auxiliary product in flame retardants
- Biocides to provide antimicrobial properties and reduce odors
- Certain dyes derived from Azo- chemistries
- Nanoparticles used for diverse applications

While some of those products have been already phased out, either voluntarily or through regulations and restrictions, there are still some in the market due to the lack of information on the products used and their potential impact.

Regulation of hazardous substances is harmonized within the European Union through the European Chemical Agency (ECHA) with the REACH regulation and the classification, labelling and packaging of substances and mixtures (CLP).

Approach to substitution

There are several approaches for mitigation of hazards, from physically eliminating it (i.e. not using the hazardous substance anymore in the product) to protective measures to reduce exposure using personal protective equipment.

If the hazard cannot be eliminated directly (i.e. not using the hazardous product) because the product needs that feature, then the second level of hazard reduction is substitution to replace the hazard for another with lower risk. To address this substitution, Tickner *et al* proposes the use of the different levels for functional substitution toward risk mitigation.

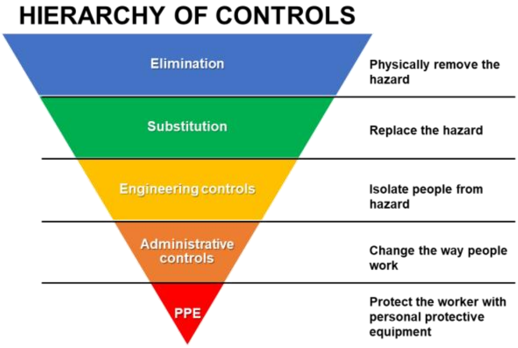

Figure 3.8.1. Hierarchy of controls

Table 3.8.1. Functional substitution approach. Adapted from Tickner et al.

Functional substitution level	Chemical in product or process
Chemical function (chemical change)	Is there a functionally equivalent chemical substitute? **Result: drop-in chemical replacement**
End use function (material, product, process change)	Is there another means to achieve the function of the chemical in the product/process? **Result: Redesign product/process, material changes**
Function as service (system change)	Is the function/process needed? Are there alternatives approaches that could achieve the same purpose? **Result: Alternative system/process**

Chemical function substitution needs to be properly addressed with informed studies that assess alternative chemicals with mitigated risk to avoid "regrettable" substitutions where the drop-in replacement is equally or even more hazardous than the initial substance. A typical example of regrettable substitution is the case of bisphenol A (BPA) by bisphenol S (BPS) where the later has been deemed equally toxic. Substances prioritized for substitution are typically well studied with identified hazards, but alternatives have little or no data available making the substitution assessment difficult.

Therefore, conducting a proper study of the alternatives needs to include technical and environmental aspects prior any substitution. This can be an expensive process for small and medium-sized companies to conduct by themselves. An approach to tackle this financial gap is by taking a cluster-based approach to find best available solutions collectively as the case of MIDWOR-LIFE and LIFE-FLAREX projects.

Case studies

Case study 1: MIDWOR-LIFE substitution of PFCs in water and oil repellents

DWORs, Durable Water and Oil Repellents, are textile finishing products mainly made of long chain fluorocarbon polymers (perfluorochemicals or PFCs) to provide fabrics with hydrophobic and/or oleophobic properties. Most commonly used products up to recent years were based on perfluorooctanoic acid (PFOA) and analogous products. Those have been found to be of high concern for human health and environment due to its toxicity for reproduction, its persistence and its bioaccumulation.

Release of PFCs to the environment may occur during the whole life of the textile products, from the production of the DWORs itself to the final disposal of the product at the end of its life. The great stability of the C-F bond gives perfluorinated compounds the properties needed for its wide industrial applications. This stability is responsible of the bioaccumulation of PFCs along the food chain and its global distribution. Long-range transportation and oxidation mechanisms has been widely analyzed in the past to determine the potential transport pathways of these compounds, its transformations and the risk to both human health and wildlife animal. PFCs have been reported in places such distant from the emission sources such the Arctic region. Unlike other persistent pollutants monitored in the environment, PFCs used in commercial products are not what are detected in the environment (PFCAs, PFSAs, etc.). In example, PFCAs and PFSAs are degradation compounds from commercial products (i.e. fluorinated phosphate surfactants) or from compounds used in the manufacture of commercial products (i.e. fluorinated alcohols and acrylates). PFOS and PFOA are the only compounds observed in the environment that have been manufactured in large quantities.

For those reasons, PFOA and derived products have been included in the restriction list (annex XVII form REACH) in the EU and have been classified in Stockholm convention as persistent organic pollutants (POPs). Other environmental agencies outside Europe have also included them in their respective regulations. Current substitutes in the market, mostly based on shorter chain fluorocarbon (C6) are also under the regulatory radar and some national authorities have started the procedure to include them into the REACH restriction list due to their similarities with longer chain PFCs and the potential of regrettable substitution.
In order to support textile companies addressing this issue, three textile clusters (AEI Tèxtils, Clutex and Pointex) joined forces with research centers (LEITAT, CETIM and CSIC-IQAC) in the MIDWOR-LIFE project with the aim to analyze the different alternatives both in technical perspective and their environmental impact to set

recommendations to industry and policymakers. The project was co-funded by the European Commission within the LIFE programme. Awareness raising to the textile industry was another of the objectives of the project to enable them to make informed substitution decisions.
A set of different alternatives and benchmark products was selected for five different textile applications: automotive, sportswear, fashion, workwear and home textiles.

Figure 3.8.2. Textile applications and fabrics' characteristics selected

In order to assess the environmental impact of the different products at relevant conditions, the team did perform tests at industrial scale in six companies that collaborated with the consortium: Inotex and Nanomembrane, from Czech Republic, Biella Manifatture Tessili and Tintoria Finissaggio 2000, from Italy, and E. Cima and Hidrocolor, from Spain.

Environmental impact of the different DWORs and their alternatives was addressed with Life Cycle Assessment methodology (LCA) with six scenarios to compare the footprint and the impact of three fluorinated DWORs (C8, C6 and perfluorosilicone) and three fluorine-free alternatives (silicone, dendrimer and paraffin). LCA results revealed the significantly higher impact of all fluorinated DWORs with a large contribution from human toxicity of PFC related compounds and the ozone depletion potential provided by fluorine. On the other hand, all fluorine-free products analyzed had a reduced environmental footprint with up to 97% less impact when compared to C8 products. While the LCA had some limitations due to the uncertainties on the exact composition of commercial products, its results provide enough proof of a mitigated impact between fluorinated and fluorine-free chemistries. However, between the different fluorine-free products analyzed, the results were in the same order of magnitude and a best product could not be identified.

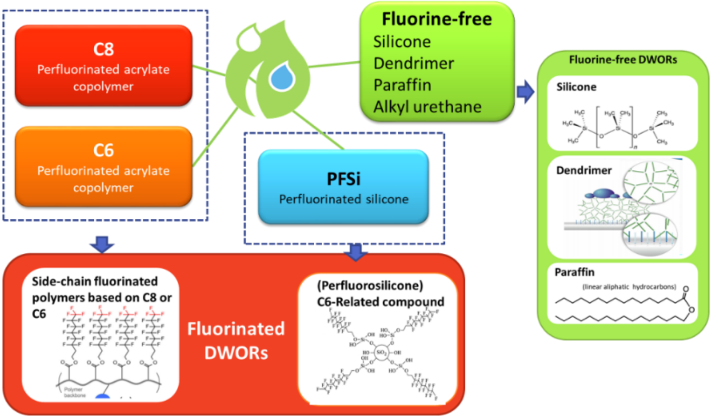

Figure 3.8.3. DWOR products analyzed in MIDWOR-LIFE project

Technical performance of the different products was assessed by spray test and oil test using industry-standards with the key results summarized in the Figure 3.8.4.

AATCC 22, UNE EN ISO 4920			AUTO Polyester nonwoven	SPORT / WORK Polyester knitted	HOME Polyester woven	FASHION Wool woven
Water repellency	PFCs	C8	**3,5**	**4,5**	**5**	3
		C6	**5**	**4,5**	3	**3**
		PFSi	2,5	**4,5**	**4,5**	not tested
	F-free	Silicone	**3**	2	not tested	not tested
		Dendrimer	2,5	**4,5**	2,5	**2**
		Paraffin	2	0,5	2,5	2,5
		Alkyl urethane	2	2	4,5	not tested

AATCC 118, UNE EN ISO 14419			Polyester nonwoven	Polyester knitted	Polyester woven	Wool woven
Oil repellency	PFCs	C8	**8**	**5,5**	**6,5**	0
		C6	**6,5**	**5,5**	2	**2,5**
		PFSi	6,5	**5**	**6**	not tested
	F-free	Silicone	**0**	0	not tested	not tested
		Dendrimer	0	**0**	0	**0**
		Paraffin	0	0	0	0
		Alkyl urethane	0	0	0	not tested
			Unwashed	*10 washing cycles + ironing*	*10 washing cycles + ironing**	*1 dry cleaning cycle + ironing*

** Only the industrial samples have been ironed* -- Bold indicates results from tests performed on the industrial demonstration

Figure 3.8.4. Technical results of different products tested in MIDWOR-LIFE project

Technical results revealed that alternative products could match performances of PFCs with the proper selection of product-fabric, making them viable drop-in substitutes for water repellence functionality. However, if the required functionality is oil repellency, none of the fluorine-free products could perform anywhere close to PFCs. Thus, coming back to the Tickner functional substitution table, one should question if the functionality is necessary or if it could be re-engineered for not needing that property. Some of the final applications tested could clearly avoid the functionality requirement (fashion, sportswear) as it is not an imperative aspect. However, protective wear in work field which may be exposed to oils it may be needed to still use a perfluorinated solution in the meantime. Therefore, additional review of worker' exposure to oil, i.e. engineering controls, may be needed to eliminate the necessity of this functional finishing.

Case study 2: LIFE-FLAREX toward safer flame retardants

Flame Retardants (FR) are products that inhibit, suppress, and/or delay the production of flames preventing the spread of fire that can be applied by textile finishing processes. This property is of utmost importance for increase safety by allowing an increased escape time in case of fire. Many of the high performance FR chemicals based on bromine, releasing formaldehyde or containing antimony are now recognized as global contaminants and are associated with adverse health effects in animals and humans, including endocrine and thyroid disruption, immunotoxicity, reproductive toxicity, cancer, and adverse effects on fetal and child development and neurologic function. ECHA has already restricted or banned several brominated FRs (PentaBDE, OctaBDE, TRIS, PBB, Deca-BDE, boric acid, Short Chain Chlorinated Paraffins, TCEP, HBCD).

Alternative products available to replace those products include formulations based on phosphorous and nitrogen compounds, nanotechnology (i.e. nanoclays), formaldehyde-free products, among others, which are seen as environmentally friendlier alternatives. However, they might lack of performance for the most demanding applications.

AEI Tčxtils launched LIFE-FLAREX project (co-funded by LIFE programme of the European Commission) in cooperation with three other clusters (ATEVAL, Clutex and Pointex) and three research institutions (LEITAT, CSIC-IQAC and Centexbel). The project methodology builds upon MIDWOR-LIFE outcomes in order to contribute to the mitigation of the environmental and health impacts on European ecosystems caused by FR toxic compounds used in textile industry focused on home textiles for public buildings (contract). In addition to technical and environmental assessment of alternatives, LIFE-FLAREX is also considering health impact and migration of products using in-vitro models. Additional novelties LIFE-FLAREX has used is the organization of a workshop with European stakeholders at an earlier stage that has allowed the engagement of several chemical companies to test and evaluate their potential substitutes and the textile companies to become early testers of those substitutes.

This project has adopted several relevant end-applications as target for the demonstration of safer FR alternatives: curtains, upholstery, mattress ticking and bedding sheets. Those end-uses have been selected due to the relevance (point of ignition or propagation of fires) and to provide a variety of textile materials.

Additionally, the project has also selected a group of “intermediate” substitutes, halogenated polymers, which are claimed by chemical manufacturers to be safer than regular halogenated compounds due to the polymeric nature but lack environmental and human health toxicity data required for informed decision. Those have been selected because of the increasing demand by the textile industry to use “analogous” or easy drop-in products. Therefore, the project team decided to add this “intermediate” solution to properly assess both performance and sustainability to allow industry make informed substitution.

The broad diversity of textile products and applications require the use of holistic assessments for addressing substitution of hazardous chemicals. The two case studies presented focused solutions toward certain particular applications that are deemed representative. Notwithstanding, there are plenty of additional applications and sub-applications of those products within those broad sectors both in terms of materials (i.e. other fabric compositions) and performance requirements.

The main recommendation and learnings from both projects is that there is a need to establish an equilibrium and rationalization of the requirements at the design stage to find a balance between environmental impact and technical properties according to the final application of the treated textile material.

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CHAPTER 4

E-commerce

Edited by:

Desiree Scalia
&
Rimvydas Milašius

4.1. Online (fashion) logistics

Sofia Papakonstantinou, CRE.THI.DEV., Greece

A small introduction

The pace of change over the last decade towards online shopping has been accelerating to the extent that multichannel developments offer the main challenge to fashion retailers at the present time. Recent reports demonstrate that in some countries such as the UK, nearly 50 per cent of consumers go online to shop for clothes. Initial reticence by retailers was due to the lack of belief in selling clothes and shoes online, especially for low-cost items. However, the rise and success of online players with international operations such as ASOS from the UK, Zalando (Germany) and Alibaba (China) has meant that fashion retailers in all sectors have had to embrace the digital revolution. Fast-fashion retailers were slow to recognize the potential of online sales primarily because their business models were geared to serving a store environment. Hence, Zara's belated entrance to online retailing in 2010. Similarly the upscale luxury fashion companies were concerned that such expensive items could be sold online. But an online presence is more than selling and as Burberry has shown it provides a vehicle for engaging with the customer through podcasting fashion shows and receiving feedback from customers on Facebook and Twitter.

Omni-channel

All fashion sectors are now embracing omnichannel retailing in that consumers desire knowledge of products from a variety of sources and are willing to purchase and return goods through a variety of channels. The retailer now has the challenge to integrate the whole business to serve this customer so that stores are no longer just functional units selling product but are information centres, inspirational showcases and pick-up points for online purchases and returns.

Figure 4.1. Omni-channel retailing representation

During the recession, store closures were documented in company reports as sales migrated online. This trend is now slowing down and indeed may be reversed in the future. Companies with a strong online presence are evaluating their store portfolios to maximize sales across channels so those with a strong click-and-collect offering will hope to enhance the brand and stimulate sales in store on pick up. In some cases it has been suggested that two different kinds of stores will be opened in the future: the flagship store which will be experiential, innovative and entertainment orientated, and multichannel hubs that focus more on functionality – click and collect and returns.

Social media

Achieving the correct balance of utilizing store, e/m-commerce and social media will drive future sales for fashion retailers. Although mobile technology has become more important in many purchasing decisions, in relation to fashion purchases, screen size and resolution make smart phones less of an option than tablets and laptops. However, sales are the final outcome of a research process that customers make, having been influenced by family and friends, including Facebook and other social media. Retailers are becoming more proactive in communicating with their customers with the advent of Web 2.0 technology so that feedback on new ranges, store experiences, website designs etcetera can help companies improve their retail offer.

One area that has become important here is the role of the fashion blog because 'fashion and trends are mainly driven by inspiration between peers. While fashion companies produce corporate blogs to give insights to new developments in their business to inform stakeholders, independent fashion bloggers are competing with traditional fashion magazines as opinion formers and a source of PR for fashion retailers. Bloggers have a strong influence on purchase behaviour with their electronic word-of-mouth recommendations. This has resulted in retailers collaborating with key bloggers in much the same way as fashion journalists by giving prime seats in designer fashion shows and providing products to feature in blogs. As bloggers generate many more pages to view than fashion magazines, they have been targeted by fashion companies in order to promote their brands.

Moreover, primary research has shown that women generally trust what other women have to say about clothes and usually seek for social acceptance of apparels. Many companies, like Pinterest and Fitbay, are providing social platforms to apparel shoppers for styling and connection. Take Fitbay for example, online consumers could input measurement and body shape information of themselves, and look for trendy bloggers of their similar body size and proportions. Pinterest does not focus on the apparel market, but many women use this platform to share their clothing taste.

Handling returns

The challenge is not only to survive, but also to grow in this overcrowded, and thus over-competitive environment. To do so, companies must cut costs and increase sales in a solid e-commerce platform. A major cost-related problem the industry is facing is the high return rate from their online sales. Returns add costs and complexity, and depress customer satisfaction and sales. Nearly 20-30% of apparel orders are being returned by the online consumers. The cost to handle each return order for repackaging, shipping, and restocking varies, ranging from $3 to $12 per order.

Retailers are devoting more attention and resources to reverse logistics as they seek to extract as much value as possible from returned goods. The average retailer's reverse logistics costs for consumer goods are equal to an average 8.1% of total sales.

To date, the problem of returns for apparel companies has raised to $1.4 billion US dollars, which has created huge business opportunities. Several companies have had different approaches to solving this problem, most of them focused in avoiding the return per se. Considering that close to 70% of returns are fit related, a crowd of companies is focused in improving the virtual fitting experience for consumers. Other companies are exploring the emerging social side of online shopping, while others are capitalizing from the growing return culture of online consumers.

Retail Reverse Logistics

Reverse logistics has traditionally been placed low in the supply chain hierarchy. Not until recently, apparel businesses have begun to understand that strategic reverse logistics management can have a large impact on overall operations. Returns have been a black hole—customers are left to their own devices, and companies don't get information proactively about products coming back to their warehouse. For apparel companies, in particular, growing online operations means they have to pay more attention to this process.

A friendly-to-use interface has become of vital importance for potential customers to make the first purchase, and an outstanding customer service (including returns policy) has demonstrated to be effective for previous customers to make another purchase. Nearly 90% of customers will return to shop where they had a positive return experience. Also a 357% increase of sales from returns has been reported, where even if returns cost money upfront, they increase profit in the long run from customer loyalty.

Retailers often do not have strong and efficient reverse logistics processes, and don't have the ability to proactively manage returns. The chore often falls on the consumer, who is responsible for packing up the order, shipping it back, and following up with the retailer for status. Retailers are often unable to analyze return data to gauge trends in what merchandise was being sent back, or prepare its warehouse ahead of time for a large volume of returns.

This comes as an opportunity to logistics experts. They make it easier and friendlier for customers to send back a return, and cut costs and complexity for retailers, allowing them to focus on sales. For example, Newgistics' SmartLabel is doing business out of this. Every order placed on their customer's web site comes with a pre-paid, pre-addressed, barcoded SmartLabel. When returning an order, customers add a SmartLabel to their package and drop it off at wherever the postal service retrieves mail. Returns are scanned three times during the cycle: at pickup, at Newgistics' regional facilities, and at the retailer's warehouse.

A dynamic bar code links the package to the customer's invoice and provides package visibility early in the returns process, enabling customer service representatives to proactively address customers' exchange or credit needs," says Dampier. This system also provides visibility to keep consumers updated on the status of their return, and exceptions can be managed. Visibility of this data also lets the company analyze returns trends to find poorly performing styles or colors, and forecast demand more effectively.

GENCO, a FedEx company, offers retailers to enhance returns processing to allow consumers to return their purchases to the channel of their choice, enabling a seamless experience. This company is the recognized leader in retail returns management. Over the last three decades, they have helped retailers achieve an average 20% reduction in costs related to returns processing. Through a proprietary software called R-Log, GENCO manages reverse flow of products, information and cash for any product sold. It optimizes inventory levels, cycle time, labor hours and overall return management, defining with the customer the appropriate product disposition method for each product.

Virtual Fitting Experience
Many companies are trying to solve the high return rate problem by providing a better fit. Various technologies are being used in this field, ranging from 3D scanning, augmented reality, virtual reality, and big data. Some companies, for example, generate 3D models of apparel shoppers either from body measurements they input into a computer or from scan booths. Based on the garment size from the system database and the accurate body measurements, the computer gives recommendations or virtual try-ons for the shoppers with the ease of a click of a mouse. Data-based companies, such as TrueFit, collect huge database of shoppers'

body sizes, preferences, and purchase histories, and are able to do big-data analysis and give recommendations.

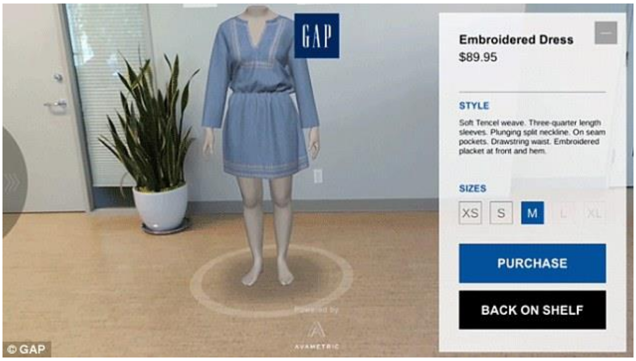

Figure 4.2. Gap Dressing Room

The virtual fitting industry is very crowded and competitive, regarding both its technology and operating models. The table below shows the main competitors and some key features.

Business Models Capitalizing on Returns

There's another set of companies that are not trying to solve the fitting problem or optimizing the reverse logistics. Instead, they are capitalizing on the rooted return culture. These companies are actually expecting the customer to make a return, so the price of the garments is higher to cover up the costs of the return. The customer perceives additional value with the style suggestions and the surprise garments. The customer creates a profile and inputs preferences and style. It will suggest garments, and the customer is sent a box with some chosen articles and some surprise articles, depending on the payment plan.

Another problem the industry is facing is that sometimes the consumer actually used the garment before returning it. A business that comes out from this idea is the garment rental company. In this model, the customer decides which garment to rent and sometimes for how long they will keep it. Then they send back the box with the used garment. There are several companies aiming at different market segments, like the ones explained next. The customer receives a box with the rented garment inside for them to use. These companies charge commission fees or a certain percentage of the price of the ordered garments.

Value chains at the service of the connected smart consumer

Mass production and distribution models in which collection developers, wholesalers, sourcing agents or retailers take decisions on what type of textile and fashion products their target consumer segments are most likely to purchase and place production orders many months before the consumer will ever see the product, are still largely the norm in the textile and clothing business – even in the so-called “fast fashion”. They are the source of much consumer frustration when products in the desired designs or sizes are unavailable. They also result in enormous costs for businesses when their forecasts prove wrong and their ordered product miss the fickle fashion zeitgeist or hit an unexpected weather pattern. They are also a burden on the environment when unsold or heavily marked-down products quickly land in waste streams or when large quantities of mass-produced materials and finished goods sit in stocks or transportation systems around the globe.

Today’s new consumer generation fully digitally connected, sophisticated, used to **personalised goods and services** or in search for authentic and sustainable consumption experiences will gradually drive the emergence of a different paradigm. A paradigm in which full personalisation of products is expected, in which sellers must be capable of delivering products to the consumer’s doorstep virtually the next day, in which regularly consumed products arrive automatically when needed in a subscription-like way, in which products may be rented for a limited period of time or shared in a community or in which products need to tell an authentic and transparent story about their making.

Such a paradigm will turn today’s textile and fashion business upside down. It will require new technologies for **consumer-driven design** and product development, new production technologies for flexible efficient and **local on-demand production** down to lot size 1, new business models facilitating **deep consumer interaction**, servitisation, easy product return or sharing options and seamless networks of designers, producers and service providers sharing resources, data and common business cultures.

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4.2. Web Marketing

Desiree Scalia, CIAPE, Italy

A small introduction

Within this topic, you will discover what is web marketing both for general and for textile and clothing companies. You will discover the most important steps for creating a website and how to exploit the potentiality of social networks for marketing purposes. Finally, you will learn more about e-shops and social commerce

Definition of Web Marketing

Today, web marketing is part of any sales strategy, so it has become almost useless to distinguish it from "marketing" in general.

But quite often, it is possible to confuse it with other kind of marketing, similar to the web one. Web marketing, using the web as a digital promotion tool, will be placed as a subset of the digital marketing, working side by side to the traditional promotion/sales strategies and offline market analysis, allowing starting a relationship with the audience of this channel (the web).

Implementing “web marketing” means studying a strategy that allows you to sell your product online. The sale can take place on the site, or even at your physical store, but the web marketing strategy must create an effective and long-lasting purchasing process. So, the general purpose of web marketing is to attract visitors interested in your products and/or services visible on the network.

Web marketing provides many strategies, depending on which tools are used, able to generate visits and then revenue on the web, from SEO to Facebook, from Influencers to YouTube and so on. But what you need to understand and what makes the difference are the basic principles that allow a company to achieve its goals: plan, create a site, generate traffic, convert, loyalty, analyse, improve. So, a company should make a careful analysis of the reference market, personalize and study the precise needs of the customers, carry out at the salient points to design a correct and effective Web Marketing strategy.

Web marketing strategy

Usually, web marketing activities are primarily translated in planning a project, then in the creation of a website and its promotion, in this way the company oversees the web channels attracting visitors interested in products and/or services.

1) Planning and creating a website. The design and development of a website, is still the reference of any activity of digital marketing. There are seven factors on which a quality model is based: web design, visual design

(communication), development, content marketing, web management, accessibility, usability.

2) Promoting a website:
    a. The promotion activity includes all the actions to generate qualified traffic to a specific website. There are several solutions to promote your website: search engine, advertising, campaigns, affiliation program, directory, e-mails, RSS feeds, social media, forum and newsgroup, press releases and marketing articles. Search engines are the best strategic choices to promote a site. The purpose is to bring to the site, through the search engines, the largest number of visitors really interested in its contents. This activity is called Search Engine Marketing (SEM).
    b. In order to assure visibility to your website, a SEO strategy is needed. In general, the earlier (or higher ranked on the search results page), and more frequently a website appears in the search results list, the more visitors it will receive from the search engine's users; these visitors can then be converted into customers.
    c. Among other activities, there are banner advertising campaigns and affiliation programs: the first one use paid spaces within a content of interest of the user in which to promote a product and/or service and an affiliation is an agreement between two sites that provides for the 'Resale' on the affiliate site of the products or services.
    d. Finally, to promote a website, a blog or a brand, social media are now essential: Social Media Optimization (SMO) is a very good approach for marketing, which allows you to increase the visibility of your website exploiting the potential of social media and online media community.
3) Measuring the campaign results. Interactions monitoring and measurability is one of the prerogative of a web marketing campaign but not typical of an offline marketing campaign. Web analytics (the statistical activity of measuring and analysing the performance of a website) becomes an essential part of business intelligence.

And what about **c**osts of web marketing? As the traditional marketing, also the web one has a price. Once you have set a budget for your web marketing campaign, you need to make sure that the investment constantly generates a positive result. Once you have created a stable, effective and repeatable purchasing process, to earn more you simply invest more.

Figure 4.2.1. Strategies of web marketing

Figure 4.2.2. Web marketing activities

There are 6 benefits of having a web marketing strategy:

- Building visibility and brand awareness
- Gaining wider target audience
- Customer acquisition
- Lower marketing cost
- Traceable and measurable results
- Customer retention

It is important to underline that the web marketing strategy shall be part of the marketing strategy as well. The overall marketing strategy of the company shall be build according to the following steps:

- Analyse the company situation and how this was achieved (Situation analysis)
- Synchronise its objectives with the company strategy (Marketing objectives)

- Define the main actions both in the short term and in the long term (Marketing strategy and tactics)
- Set performance specifications
- Estimate costs
- Schedule a delivery date

Figure 4.2.3. How to build a marketing plan

Web marketing of textile companies

The textile industry includes the design and manufacturing of textiles and other fabrics. Distribution channels include manufacturers, importers and retailers. As a result of the wide scope of distribution channels, as well as the variety of product and service segments, each web marketing plan will vary widely, and will be particularly tailored to each company's goals and objectives.

In order to draft the plan, at first, a textile company should identify its target market. A target market represents a specific type of buyer that a company has identified as potentially interested in the company's product or service. For example, a small manufacturer might tailor its design and production outputs to the home textiles market or to environmentally conscious consumers.

Having a strong online presence is essential for textile companies. It is very useful to make an SEO friendly website which ranked them higher in the search engine and make them easily available to the respective client (buyer, other manufacturer, etc.). Well optimized website not only give rank but also create a good impression to the customer.

Social media can be used in the following way:

- LinkedIn can be very useful for textile manufacturing companies to look for textile manufacturing related professionals and group companies

- You Tube can be exploited to publish videos related to production and quality control processes, ethical standard, which create good impression and awareness about the company.

Finally, a company can create some business-related content and publish them in textile related international blog or forum.

Summarising, textile industries need to apply digital marketing tactics in their marketing strategy. If companies merge traditional marketing and digital marketing in their marketing strategy, it will be more effective. By using digital marketing textile manufacturing companies easily find their customer and create a positive impression on customer mind, which help them to increase their sales and also maintain a good relationship with customer.

Web marketing of fashion companies

The online fashion sector is worth almost 332 billion brands today, representing 28% of the total e-commerce market. And this value is growing more and more. For brands, it is time to rethink their online presence, building sites that are more attractive to users, able to respond to their needs and to entertain them. Moreover, it is also time to regain control over sales, today in the hands of platforms and marketplaces.

According to the latest researches, e-commerce in the field of fashion will grow by 13.8% per year until 2021. The success of this sector is due to various advantages and services that online world offers, such as free shipments and returns, deliveries always more punctual and reliable, possibility to customize the shopping experience and to receive suggestions and feedbacks based on your preferences.
But, above all, growth is encouraged by the change in user habits that are increasingly shifting from “offline” to online, in the purchase step, but especially in the research one.

As in the offline world, also in the online one, we can find different kind of shops:

- E-shop owners of brands
- Brand marketplaces (eg. Zalando, Asos, etc.)
- Design e-shops (such as Yoox, Net a Porter that sell fashion luxury brands)
- Generalist e-shops (such as Amazon and Alibaba).

Among all these, the multi-brand stores (marketplace and design shop) are those that occupy the largest space in the fashion industry and those that have worked so far better. Some of them, for example, have so much power that they have launched capsule collections in collaboration with leading fashion brands. In addition, being able to count on many data collected among their users can intercept the trends, desires and preferences of their users and also develop their own collections.

The triumph of multi-brand e-commerce is due to several factors: "never-ending" choice, customer services, greater digitization of customers and growth opportunities for the brands. But the outcome of marketplaces is mainly due to the browsing experience they offer: they are platforms built around the user, offering contents and interesting suggestions. People visit these platforms out of curiosity and not just to complete a purchase.

In the recent years another element has hit the web marketing in the fashion industry with the explosion of social commerce. Users become influencers and clicks that generate sales are paid through social media. Instagram, for example, allows the repost of the contents on its own story. This new feature will change influencer marketing to make it even stronger because it will increase the visibility, traffic and engagement of influencers and brands.

An example of social-commerce is the Chirpify web site: it is an e-commerce platform that offers products that are sold on Twitter and Instagram from companies. The companies publish on the social media the sales' proposals and interested users only have to comment with "Buy" that the purchase is made immediate and faster, directly from the company website.

Figure 4.2.4. Chirpify e-commerce platform

And for the future (not too far away), the Virtual Fitting Room will become reality in which, through 3D avatars, it will be possible to "try" clothing items before buying them.

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4.3 Branding

Desiree Scalia, CIAPE, Italy

A small introduction

Within this topic, you will learn about the concept of branding and different key strategies to promote the company and its products. Moreover, you will discover few examples and best practices of what can be done by fashion companies in this sense. You will be also able to understand the most common branding tips and concepts, the main branding approaches and their evolution. Finally, you will understand the role of influencers and testimonials in nowadays marketing.

Branding is the process carried out by companies to differentiate their offer from similar ones, using distinctive names or symbols. Its main purpose is to promote the brand image and to encourage customer brand loyalty. Branding policies are also adopted to facilitate the commercial efforts of the company, since the promotion of each branded product indirectly promotes all the other products marketed with the same brand, including new products on the market. The use of the brand generates benefits for consumers as well as for companies. The brands, in fact, help buyers to identify specific products that meet their needs, reducing the time needed for the purchase. From the perspective of the selling company, on the other hand, branding facilitate the repetition of the purchase and the introduction of new products, as buyers are already familiar with the company's brands.

Branding tips

In marketing, the word ***portfolio*** can be generically used to indicate the set of products or services offered by a company, or it can refer specifically to all the brands managed by the organization (in this case, it takes the name of brand portfolio). In general, the concept of a portfolio is similar to the one of a **product mix,** even if the former is generally used with reference to strategic planning, while the latter is part of the marketing management optimization issue. In other words, a portfolio refers to an entity related to planning, while a product mix to an entity that refers to management. The portfolio analyses are intended to provide information for strategic business decisions and can be understood both as an assessment of the offer through measures of current profitability of products and lines, generally using the contribution margin, and as formalized techniques in logical models that allow to define the relative position of the products or brands according to parameters that are significant for the company's development.

Deciding on the branding strategy to be adopted for new products is very important for the development of the brand portfolio; in particular, the choice should be done between the launch of new brands or sub-brands and the extension of line or brand (eg. brand extension). This choice is necessarily influenced by the number of products and product lines that a company produces, by the features of its target markets, by the number and kinds of competitors' products, and by the amount of available resources.

In the brand extension policy, a company uses one of its existing brand names for an improved product or a new product, which often is in the same category of products to which the existing brand belongs. The co-branding policy occurs when two or more known brands are combined to realize a single product or marketed together through forms of joint marketing. The goal is to leverage the equity of several brands (generally, *hosted brand*) to increase the perceived value of the offer. A widespread branding strategy involves licensing the brand (**brand licensing**), an agreement in which a company allows another organization to use its brand on other products for a fee or royalty.

The most used model to highlight the information relevant to the company portfolio is the "Market growth/relative market share matrix", proposed by the Boston Consulting Group at the beginning of the Seventies.

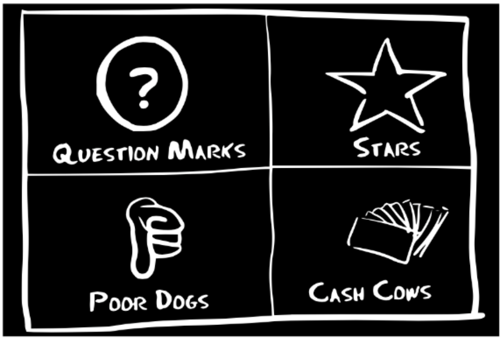

Figure 4.3.1. "Market growth/relative market share matrix" of Boston Consulting Group

The company's product portfolio can be analysed in different levels of aggregation from individual product, references, product types, product lines and business unit strategies. The analysis of the brand portfolio is based, instead, on the brand architecture (*brand architecture*), through which the roles are defined and the hierarchy relations and complementarities between the brands are organized. Within the brand architecture, a brand can express only one product (and in this case we talk about *individual brands* such as Nutella), a group of products with the same function (in this case we talk about family brands) or a group of products that perform different functions but belong to the same company (in this case we speak of *corporate brands* such as Disney).

Branding in fashion and textile
The brand today is a state of being, a series of intangible elements, where people find themselves, wholeness, and feels enveloped, involved, and the whole is united with the most inner part of the individual that is sought in the way of being and dressing.

The brand is vital in a complex and competitive context. The brand must help the product to be the first choice in a certain category in which there are other similar ones that are equivalent in price and performance.
There are no recipes to create a successful brand but there is a correct approach based on the ability to listen to the client, on a careful construction of the image, on corporate reputation, leadership and on the ability to communicate and to create long and lasting relationships. The brand must stand out for its innovative character.

However, there are rules to develop a successful brand valid in any market and which can be summed up in 4 points:
- Keep the initial promise in terms of quality and performance-service;
- Be innovative;
- Be a bearer of principles and values in which consumers recognize themselves, thus entering into a relationship with the company;
- Have an attractive capacity through a well-structured communication strategy based on listening to the market and the consumer;

Today's market requires to overcome the classic functional vision of the brand to assume a new, more narrative, able to tell stories that involve the brand. The specific identity of a specific brand is taken into the *brand identity*: a constructive process that leads to the identity of the brand.

Many companies link the brand to a testimonial. This strategy is particularly used in the fashion industry: famous people belonging to the world of entertainment, cinema, music or sports become characters associated with the brand or with a specific product and/or service of a particular brand. Another successful operation recently implemented by many companies has been the relaunch and revisiting of historical brands, recalling well-known brands from the past to bring them to the fore. The re-edition of "myth" brands that marked the years of the economic boom has been a strong case of success not only in the fashion industry. According to expert estimates, the relaunch of an already known brand allows to reduce the costs of the product launch of 40-70%. Among the most successful cases in fashion world there are Moncler and Lacoste.

Co-Branding

From a marketing point of view, there are several examples of collaborations between companies/brands; each brand owner involved aims at achieving the benefits generated by the union (in terms of increasing in attractiveness and evocative capacity or simple sharing of reputation). In order for implementing these strategies in a successful way, it is important to regulate some issues such as: trademark licenses potentially limited in time and with regard to specific products and/or services, exclusive agreements, rules that governs the payment of any royalties, distribution of revenues between the brand owners, deriving from the economic exploitation of brands (or rather simply from the production and marketing of the goods and services identified).

Typically, there are two kinds of co-branding: *functional co-branding* (when two or more brand owners produce or market a product or service in which both participated to the creation) and the *symbolic co-branding* in which one manufacturer's brand is with another as to determine new symbolic attributes to the former.

An example of functional co-branding is the famous Louboutin red sole shoes and the famous macaroons of Ladurée, united in a unique and exclusive box.

Figure 4.3.2. Louboutin- Ladurée co-branding

Symbolic co-branding is the association of well-known fashion brands to products, for example, food & beverages or automotive. They have often been used as a marketing strategy to evoke in the container product those characteristics of exclusivity and luxury of the associated brand coming from the fashion world (for example, Gucci and Fiat 500).

During the last year a new type of collaboration has been experimented, the so-called *co-branding fashion*. During the 2018 Milan fashion week, Fendi and Fila presented a fantastic innovation of the co-branding fashion technique, in fact, in this case, collaboration rose to a very high level, reaching a total contamination of one brand into the other, so as to give life to something totally new and original.

Figure4.3.3. Fendi – Fila co-branding fashion

Social Media Marketing in Fashion – Bloggers and Influencers

Everything began with web 2.0, thanks to which the user can start to interact more easily with the web: an interaction that has led not only to the rise of users as blog and forum authors, but also to the establishment of social networks. These have had a strong impact on various aspects of society, including the economy and above all on marketing; the new type of marketing has emerged, the so-called Social Media Marketing.

Social media marketing allows companies to interact directly with the consumer, so as to make him/her an active part of the promotional message, and not just a passive viewer. To reach a greater number of consumers, therefore, companies have started to use social networks, on which users spend most of their time (statistics show that users spent at least 3 hours a day with their smartphone; most of the time spent is on social networks).

Among the most visited social networks there are Facebook and Instagram, and it is on the latter, in particular, that fashion brands have started to invest a large part of their budget, as it allows to publish very accurate and creative images, similar to professional photographs. It is therefore on Instagram that the influencers were born: young women able to influence with their style the taste of their followers. They are important because their audience trust them, either because they are considered experts in the field, or because they are perceived as neutral in the sale of a product compared to the testimonials, who are linked directly to a specific brand.

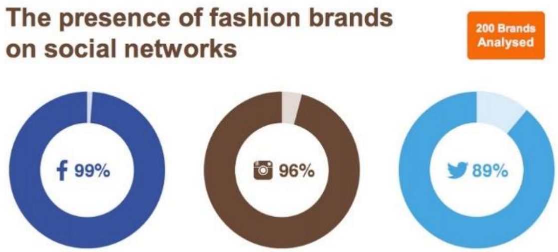

Figure 4.3.4. The presence of fashion brands on social networks

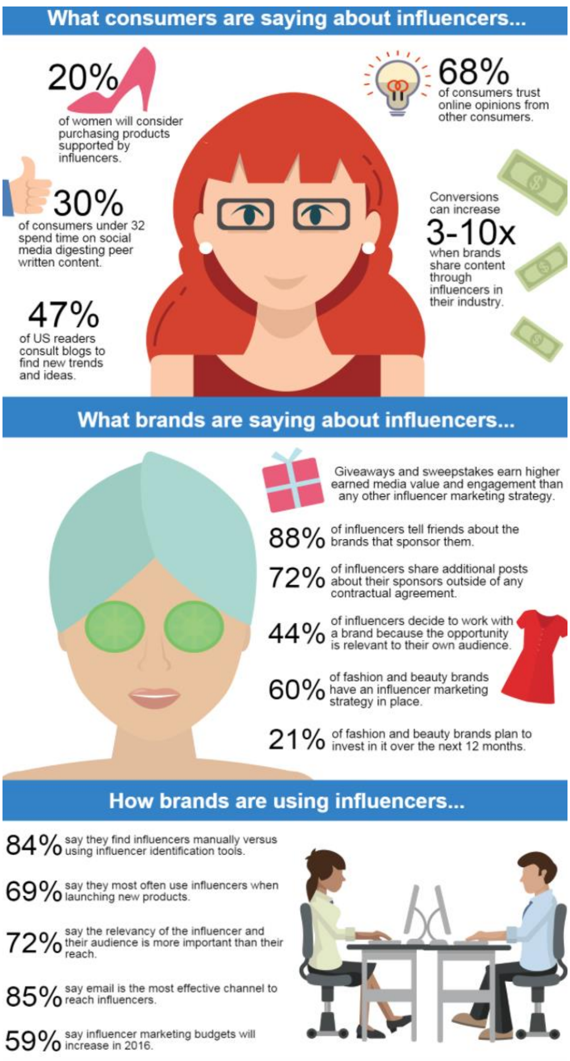

Figure 4.3.5. What consumers say about influencers

Consumers, more and more often, consider a campaign with influencer to be more reliable than a traditional advertisement with models or celebrities. Thus, according to the research carried out by the Launchmetrics platform, in 2016, 65% of luxury brands has chosen to collaborate with influencers for their advertising campaigns, with surprising results: 84% of the interviewed companies achieved greater visibility, while 74% have obtained directly an increase in sales. However, not all fashion companies have chosen to exploit such a marketing strategy, some of them because they did not have an adequate budget to support such an advertising campaign, others because of lack of tools to manage the collaboration.

Another successful kind of collaboration is storytelling. Storytelling has become a widely used mechanism in contemporary marketing, which has moved from an orientation towards the single product to one towards the story of the brand: the word marketing is almost no longer used and has left its place to concepts like brand management, storytelling management, digital storytelling management, strategic design or content marketing. All these words that at first sight seem to have something mysterious, in reality have the same meaning; they want to tell in the most sincere way the values of a brand or of a company making sure that they are credible to the final buyer. Storytelling is used, in practice, to come into contact with the final consumer directly. But, are bloggers and influencers the new media?

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4.4 Web analytics for online fashion

António Dinis Marques and João Pedro Bernardes, 2C2T – Centro de Ciência e Tecnologia Têxtil, Universidade do Minho, Portugal

A small introduction

The growing importance of the digital world in economy and society is undeniable and irreversible. Consumers increasingly use the different digital platforms to interact with their favorite brands, looking for more information (and transparency), more options and experiencing increasingly safe and effective purchase processes. Companies try to maximize the potential of this new digital reality, having to deal with a huge data set, with processing speeds that were unthinkable a few years ago, requiring new skills from organizations and their human resources. The designation of Industry 4.0 appears in this context of increasing digitization as a big umbrella that encompasses multiple structural and functional dimensions of enterprises, through the Cyber-physical systems (CPS), robotics, the Big Data Analytics, the Internet of things, augmented reality or Artificial Intelligence.

The enormous importance of this digital reality has been consolidated over the years, in a very extended way, and supported in social networks and its interface with the new customers.

The most recent data published in the report "*Digital in 2018*" by http://wearesocial.com are evidence of this reality. In January 2018, Internet users in the world was 4.021 billion (about 53% of the world's population), with a growing importance of users that use mobile phones and smart phones to access the Internet (3.722 billion, about 49% of the world‘s population). Increasing access speeds (in January 2018, the average speed of access in the world was about 40.7 Mbps, with a maximum in Singapore with approximately of 161 Mbps, and in Portugal with about of 54.5 Mbps) tries to keep up with the demands of new markets, the increase in the number of users and the average time of online presence of consumers/users.

With the rise of Facebook in 2004 opened a new chapter in the digital age and in the way the world communicates. Social networks are present in all countries, with very significant importance in most developed and in developing countries. The telephone and the mobile phone have been successively replaced by WhatsApp, FB Messenger or by Wechat, each of them with more than 1 billion users worldwide. The most important social networks is Facebook with about 2.2 billion of users, followed by Youtube with 1.5 billion and a little further down the line is Instagram and Tumblr with about of 800 million.

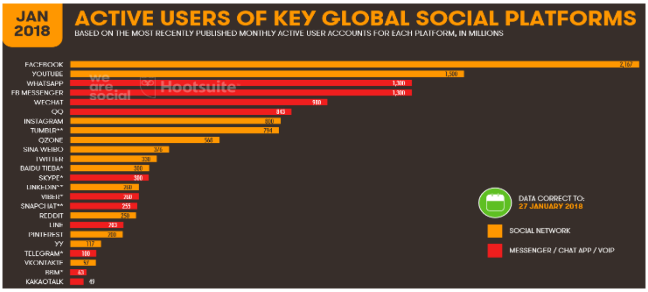

Figure 4.4.1. Active users of key global social platforms

In this scenario, it becomes imperative to meet and evaluate the performance of the brands or companies in these new platforms and social networks, by establishing metrics and safe and consistent evaluation methods. This way administrators/decision-makers and responsible of marketing can correctly set their strategies and allocate the human and financial resources of their organizations.

Avinash Kaushic was one of the first to consider this aspect in the lives of organizations and defined the concept Digital Analytics: “*Digital Analytics is the analysis of qualitative and quantitative data from your business and the competition to drive a continual improvement of the online experience that your costumers and potential customers have which translates to your desired outcomes (both online and offline)“.*

The proposed definition by Digital Analytics Association (DAA) claims that “*Web anlytics is the measurement, collection, analysis and reporting of Internet data for the purpose of understanding and optimizing web usage*“ and emphasizes the importance of analyzing the existing data in the business, and also the data obtained from consumers and users, irrespective of whether they are digital natives or new adopters and "converted".

Web Analytics

The advent of digital platforms made it possible to achieve results and notable performances in several functional areas or business enterprises. At the end of the previous millennium the first web counters solutions came up (web log analysis) through resident applications or via Application Service Providers, aka ASP. The first entrepreneurs and enterprises appeared (NetGenesis, Urchin, ComScore, Nedstat, IndexTools or WebAbacus, for example) and the Javascript Tag (1997) technology was introduced which allowed a segmented analysis on each page, enabling a better knowledge of the visitors.

In the new millennium, the first eMetrics Summit (2002) takes place, the Web Analytics Association (WAA) is created having as founders Google or Yahoo! and the first version of the Google Analytics Platform (2005) is released. Later other technology companies launched tools for analysis and measurement of performance on the web. Facebook was the first social network to launch a native platform of analytics (Facebook Insights in 2010). Youtube then launches its native platform version of analytics in 2011, followed by LinkedIn, Pinterest and Twitter in 2013. But the dominance of Google Analytics as a tool for data analysis in the digital world remains untarnished, making Google as the most important search engine throughout the world.

Measuring web activity (in fashion websites)
The structural flow of data between the website and the server of the analytics tool is organized into three levels of relationship and dependency:
(User) > > (Session) >> (Hit)

During a certain amount of time a user can start more than one session, and within each session more than an action or request to the server.

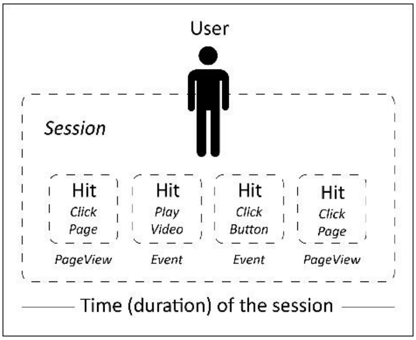

Figure 4.4.2. Data Flow in three levels

Cookies are data structures designed to store anonymous information (ID) about the given user access profile and play a key role in the whole process of reporting/measurement of user interaction in the web content. The technological possibilities of interaction between the content on the web and users has evolved over time, with a decrease of the importance of computers and an increase in mobile devices (tablets and smartphones). This reality led to the need to find criteria adjustable cross-reality device (mobile + desktop) to a single user. For companies, irrespective of the technological means used, the most important thing is to determine what is the content of a brand or company that is more viewed and how many visitors. And also the rejection rate (bounce rate), which corresponds to the percentage of visitors who leave the website after visiting the front page, is critical to analyze and understand.

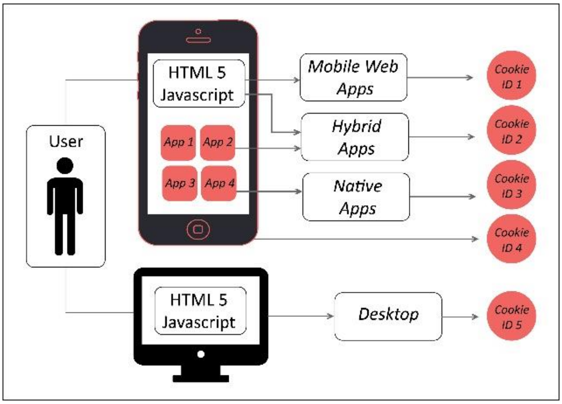

Figure 4.4.3. User measurement in cross-device (mobile + desktop)

Access to the website of a brand or company can be effected by different routes or procedures, which is also important to know:

- Organic Search, the user access by inserting words in search engines (Google, Yahoo!, Bing, etc)
- Social, that results from ads or posts placed in the various social networks (Facebook, LinkedIn, Instagram, etc).
- Email, making access by receiving marketing emails or newsletters.
- Direct, resulting from writing the direct URL, of the brand or organization website in the browser (browser).
- References, that corresponds to the access of visitors who arrived at the site of the brand through another site (direct link).
- Paid Searches, resulting from access to the site after clicking on a paid search engine advertising or other, marked as advertisement.

Data analysis must be supported in the same value that result for the Organization, based on the following phases: Understand what will be analyzed; Collect and verify the data; Report and check the reports; Analyze, communicate and frame; Optimize and predict; Demonstrate the economic value.

Going through these phases optimizes the management model, having as central objectives, in the case of brands, promoting a greater affinity to the brand and increasing its notoriety.

This designated data-driven strategy can be considered as the result of an evolutionary process, starting from the data and statistics, followed by the analysis and ending at Digital Intelligence

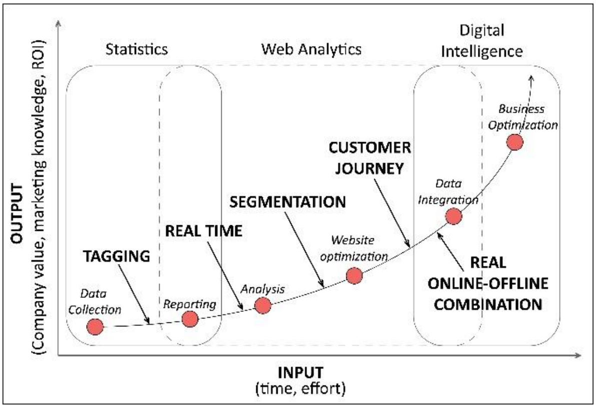

Figure 4.4.4. Digital Intelligence model

Metrics and Key Indicators

The metrics are normally numbers, and must have clear and objective reading, and properly analysed in context, in order to have meaning and value for the brands or companies. The measurement of a variable is important for controlling and monitoring the success of pre-defined goals. Key performance indicators (KPI) present the evolution of a particular business goal under the perspective of decision making. In table 4.4.1 is an example for a fashion brand (XPTO Fashion), a service company (ABCDE Services) and a school of fashion (ABCDEF School).

Table 4.4.1: *Metrics and KPI to the fashion business*

Brand/Service	Business Objectives	Metrics	Key Performance Indicators
XPTO Fashion	Increase in sales volume	Page views Visitors Unique Visitors Returning Visitors Bounce Rate Time on Site	Sale of Articles Site Visits
ABCDE Services	New contracts		Contracts/Visits
ABCDEF School	Increase in student enrolments		Performance Enrolments/Visits

The targeting of users is very important in order to facilitate the interpretation of the metrics and maximize the information obtained of the KPI of a particular organization. Therefore, the potential audience segmentation allows highlighting the data captured on the scope (reach) of certain targeted campaign for building communities. This is the case in fashion brands, which want to increase their followers on social networks.

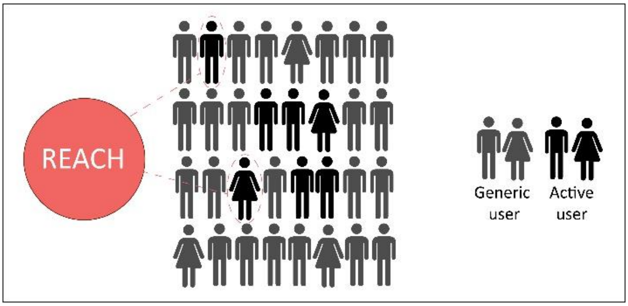

Figure 4.4.5. Potential audience through reach

Fashion Brands, Social Media and Web Analytics
Fashion brands are well aware of the importance of new technologies and the digital age, and in particular social networks. The financial resources needed to implement a communication strategy focused on digital platforms are significantly lower and with a very large potential range.

Digital marketing in the fashion industry makes use of different categories of metrics: Metrics of operational management, strategic performance and financial evaluation. These metrics may relate to three main phases of the process of interface between the brand and the user/visitor:

- Construction/Exposure; Trust/Involvement; Action/Conversion.
- On the Construction/Exposure phase, the most relevant operational metrics are Impressions, Viewers, Followers and Reach, and financial metrics are the CPM (cost per impression) and CPR (cost per reach).
- At the stage of Trust/Involvement, the most relevant metrics are: Engagement Rate, Clicks and Watch Time, and the financial metrics are CPE (cost per engagement), CPC (cost per click) and CPV (cost per view).

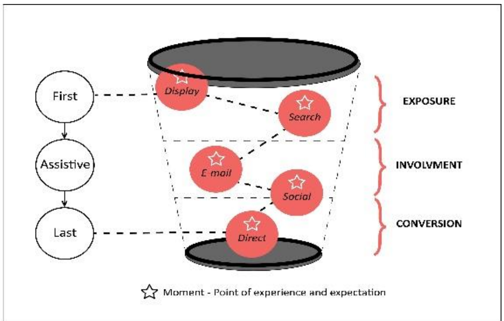

Figure 4.4.6. Journey from display (see) to action (buy)

The most used social networks by brands and fashion companies are Facebook and Instagram. The profile of users of these social networks are significantly different, therefore fashion brands suit their strategy and presence in each one of them according to their collections and target market. The frequent publication of content on the websites and social networks is the determining factor in the interaction with their followers. The reactions likes, shares and comments occur when the brands put their new proposals and new content, regardless of its category.

Table 4.2 Proposal of metrics for Facebook

CONSTRUCTION > EXPOSURE
Page views
Post Reach (paid, organic)
Audience (demography)
Page viewers (total visitors)
Influencers
Ad Impressions

TRUST > INVOLVEMENT
Page likes
Video views
Seconds video views
Post clicks
Post engagement (reactions, comments, shares)
Engagement rate (total likes, comments, shares, clicks)
Likes and Net likes
Comments
Shares
Reactions
Clicks
Event reach
Event page views
Total conversations (messages)
Ad reach
Ad frequency

ACTION > CONVERSION
Actions on page
Website tracking pixel
App tracking pixel
URL clicks
Ad click trough rate

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4.5. Best practices for the digital marketing ecosystem in fashion

Gancho Kolaksazov, ITTI, Bulgaria

A small introduction

The fashion industry has always mirrored socio-economic circumstances in its marketing strategy. It's impossible for such an industry to not reflect the world around them and be responsive to trends at play. This in itself is a perfect message for most b2c and many b2b brands. Being responsive in your digital marketing doesn't mean bending to every social user's will. It really is the perfect way to stay consistent, relatable and above all else likeable as a brand.

As we enter a new digital age, dominated by social influencers and political narratives, every customer focused industry has to make changes to their marketing strategy to accommodate trends. The fashion industry is no different. Having always been an indirect expression of cultural trends at play, now more than ever we can see the way in which digital campaigns have been both affected and in many ways improved by recent digital developments.

Digital Marketing Campaigns in the Fashion Industry

As we enter a new digital age, dominated by social influencers and political narratives, every customer focused industry has to make changes to their marketing strategy to accommodate trends. The fashion industry is no different. Having always been an indirect expression of cultural trends at play, now more than ever we can see the way in which digital campaigns have been both affected and in many ways improved by recent digital developments.

Here are some of our favorites:

<u>Gucci bans fur and the internet goes wild</u>

In 2017, the social media audience is probably one of the most vocal of our generation. With the power of opinion openly accessible to anyone and everyone, it is only natural that once a school of thought gains traction via social it becomes almost impossible for brands to ignore. This year, we saw the perfect example of such an issue. After releasing a much-discussed range of brogue sliders, featuring a real fur trim, big-name designer Gucci came under fire from PETA and other animal rights organisations, as well as a flurry of social media influencers, forcing them to seriously rethink any marketing campaign promoting such a product. Having famously been frequent users of real fur in their collections, it was an unexpected release that followed from the company. In October 2017 Gucci released a statement promising to ban fur from all its future collections, a move that rocked the fashion industry.

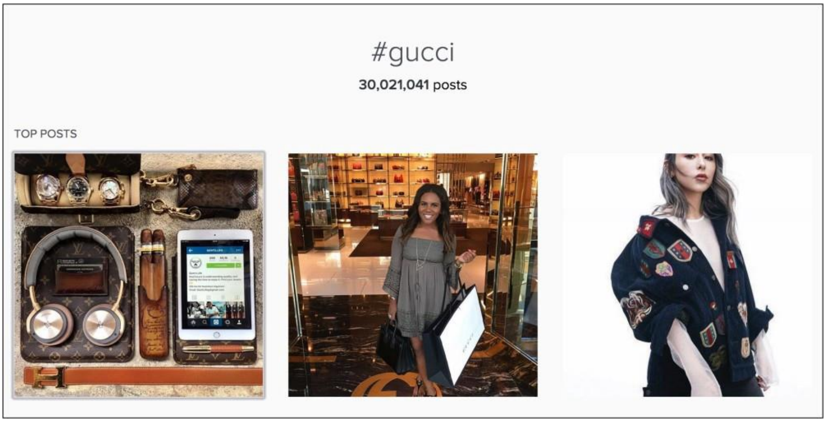

Figure 4.5.1. Gucci posts on Instagram

Why did it work?

Responding to calls from social to change deep-rooted brand traditions isn't something we'd recommend but, in order to stay relevant and brand aware, you must move with the times. Plus, showing you're a brand that listens when you audience demands action increase you market likeability and hence revenue.

<u>Topshop capitalizes on front row fashion</u>

You'll always find high street favourite Topshop at the forefront of digital advancements, they're social media team must work over time to make sure nothing is missed and we salute their constant 'on brand' attitude. Their latest digital feat took place over London fashion week, which enabled its users to shop real time trends. Billboards across the Uk capital were adorned with images of some of the biggest names in fashion and television, of course sporting the very latest Topshop pieces, however instead of simply promoting upcoming collections, the pieces were made available in all Topshop stores, encouraging the user to click through and instantly shop. Overall, featured products received a 75% sales uplift and the company reported an 11:1 ratio for return on investment.

Why did it work?

The social influencer has become a market leader in terms of the global advertising space. If you're looking to reach a young, spend orientated audience it's important you work with them and utilise the public figure for your own benefit. Plus offering real-time shopping options will always provide results that are easy to track.

<u>Dr Marten tells a brand story</u>

Footwear giant Dr Marten has always occupied a significant portion of its market and their name is synonymous with reliability, becoming ubiquitous as a brand. Their recent 'Stand for something' campaign set to captivate their audience with a real brand story. We're seeing a real increase in the use of emotive campaigns, brands are fighting to become most followed or most liked and watching sales increase from their rather than going straight in for the hard sell. Their charming and enchanting video content pulled in audiences both old and new and the technique of opening up the heart of the brand influenced a 30% sales uplift and they were 500% target impression expectations.

Figure 4.5.2. Stand for something campaign

Why did it work?
Being transparent with your brand personality is one of the best ways to not only gain social traffic but increase your revenue streams. Audiences buy into brands they believe in, with so many stories flooding ours news space surrounding the ways in which brands have been known to mislead their customers, offering yourself up as an open book buys a lot more than favour with your target market.

<u>H&M's closes the looks loop</u>
High street big wig H&M are often pioneers of campaigns and actions which put sustainability at the forefront. They're also a huge advocate for innovative and often somewhat rogue marketing tactics. So, it comes as no surprise they chose to put out the message of sustainable fashion buying using such tactics. In a viral campaign video featuring plus-size model, Tess Halliday, and Muslim model, Mariah Idrissi, the brand used a celebration of different cultures and aesthetics to highlight the issue of a sustainable fashion product. We are now firmly cemented in a millennial state of mind, which amongst other things, means that we don't have to subscribe to traditional advertising standards in terms of what's 'attractive'. Interpretation and body confidence has become far more important and in this way H&M allowed itself to be firmly placed at the forefront of the millennial mindset. The social media reaction to the campaign promoted a significant increase in brand awareness.

Why did it work?

Everyone expects a lot more from their favourite household brands these days, with an audience that is increasingly educated in terms of socio-economic influencers. In this case you as a brand, much like H&M have somewhat of a public duty to adhere to those factors in some way.

Nasty Gal get personal

Online fashion retailer Nasty Gal has a rich digital history. Rather than constantly reinventing their image they've worked hard to make their brand personality almost as big (if not bigger) then the product itself. The term 'Girl Boss' is frequently banded around cyberspace, supporting empowering notions of feminism and crushing such out-dated notions as the gender pay gap. That term 'Girl Boss' was born out of the story of the brands CEO Sophia Amaruso, who pioneered the rags to riches strategy and has now essentially created a whole empire from empowering women in the business world. The ideology has its own huge social following and the formidable sentiment has carried the Nasty Gal brand into a much more elusive market space.

Why did it work?

Creating a tagline or slogan synonymous with your brand image is one thing, forging its very own identity is a new level of brand presence. Subconsciously through the 'Girl boss' ideology, 'Nasty Gal' have cemented themselves as a multi-million-pound online fashion brand.

Digital Marketing Campaigns in the Fashion Industry

The fashion industry has always mirrored socio-economic circumstances in its marketing strategy. It's impossible for such an industry to not reflect the world around them and be responsive to trends at play. This in itself is a perfect message for most b2c and many b2b brands. Being responsive in your digital marketing doesn't mean bending to every social user's will. It really is the perfect way to stay consistent, relatable and above all else likeable as a brand.

Digital marketing (DM) for the fashion industry – 6 Trends in 2018

Brands to get consumer-centric!

While communicating with potential customers is a must. However, this upcoming year brands are planning to get more consumer-friendly. Presently, consumers are more attracted towards brands that appear more humane.

Therefore, setting aside the business etiquette, brands will try using softer tones to communicate more with target audiences.

More power to luxury fashion!

Previously luxury brands avoided online marketing because they didn't want to ruin their exclusiveness. However, with the implementation of successful digital marketing campaigns, consumers have shifted their attention to online platforms. Henceforth, the upcoming year luxury brands are planning to enter the fashion market by collaborating with sellers.

Social media influencers will dominate

2018, is a lucky year for social media influencers. These people are mostly fashionistas or celebrities who are the responsible trendsetters. Henceforth, brands to bring in more noteworthy faces to gather the attention of target audiences.

Moreover, with the recent trend of promoting body positivity, businesses will use influencers to change the face of fashion. Henceforth, the apparel market is now ready to challenge the stereotypical standards of beauty. Their motto stands "real is beautiful".

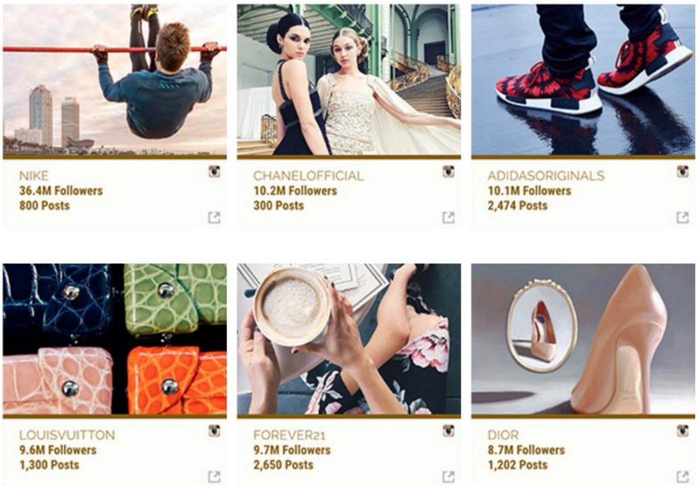

Figure 4.5.3. Top brands followers and posts

Content marketing is a must

Online content is part and parcel of every digital marketing policy. Likewise, the fashion industry is all set to use contents to sway customers. Be it articles, blogs, press release or social media posts, sellers are planning to choose reputed content marketing agencies to be their right hand in facilitating fashion business marketing.

Instagram is home ground!

Instagram presently is the hub for digital marketing agencies. Moreover, fashion industry compliments Instagram. With more than 7 billion active users and infinite fashion bloggers, Instagram becomes the home ground for fashion business advertising.

Further, businesses are planning to use Instagram tools and proper strategies, along with collaborations to get audience clicking on their apparel. Additionally, you could use Buzzoid's Instagram Followers service and buy instagram followers for your page. This should help improve the overall authority and feel of your account.

Men's online fashion to keep growing!

Before digital marketing for fashion was only women-centric, however, today many creative tactics have been introduced to market men's apparel. The upcoming year is targeting to enhance the sale of men's clothing.

Thus, more styles and choices will be introduced for publicizing men's wear online. Furthermore, with more brands endorsing the concept of embracing flawed beauty, the digital fashion campaigns are expected to get creatively controversial. However, what's undeniable is, 2018 is promising a rise for the digital fashion industry.

Popular Digital Marketing Tactics in the Fashion Industry

Everything and everyone seem to have virtual existence nowadays. In the fashion industry, where visual content and fast-changing trends are key components to lure consumers, it's easy to see why a successful marketing plan should involve making sure one's online presence is noticed.

Fashion businesses resort to digital marketing to help boost revenue. Here are the six most popular digital marketing tactics being practiced.

Content Click bait

- An intriguing title and interesting preview make for the perfect click bait. But it means nothing when the content is not worth spending time on. Good marketing strategy includes getting the attention of the target audience and making sure to keep them glued to great marketing content. Relevant videos, blogs, social media posts, and images can impact the buying behavior of consumers.

Personalized Emails

- When looking at the messages in one's inbox, which one do individuals tend to open and which do they instantly dismiss: the one with a vague, general subject or one with their name on it?

- Emails with PSL (personalized subject lines) have more chances to be opened by 26% compared to generic subject lines. Most businesses fall into the trap of sending mass emails.
- A good step would be personalizing messages from subject to body and making sure that any sign-up forms are appropriate for the recipient. For instance, female clients should be receiving catalogs for women. This simple seemingly human touch can create dramatic effects on how consumers respond.

Figure 4.5.4. Fashion and digital marketing

High-Quality Fashion Blogging

- Fashion brands hire professionals to create buzz among the community and market by consistently delivering high-quality fashion blogs.
- Topics touching on the latest trend in street fashion, a new line from designer brands or the recent red carpet looks are easily received. Blogging is a great way to incorporate new products and merchandise into the content.

SIP (Strategic Influencer Partnerships)

- Influencer marketing is one of today's most modern ways to drive a brand to a larger market. It involves key leaders who have huge social media following. Today's influencers are no longer limited to big names in sports and Hollywood.
- This style is highly applicable to industries like fashion. Consumers get a glimpse of the lifestyle of these influencers who subtly integrate brands and products in their posts and storytelling. Strategic influencer partnerships can increase brand equity significantly.

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4.6 E-CRM

Georgios Priniotakis, Yiannis Chronis, University of West Attica, Greece

A small introduction

This module deals with electronic Customer Relationship Management (e-CRM). Although customer relationship has always been an important process in business, the advance of information and communication technology has transformed the way it is implemented and on the other hand has multiplied the prospected benefits, independently of the company size and sector.

By completing the module, the learner will be able to:

- Set the basic points of the e-CRM strategy for the business
- Choose the basic features and parameters of an e-CRM system
- Incorporate -eCRM in the overall operation of the business and implement it in a way as to "take the most out it"

What is e-CRM?

CRM is the acronym for Customer Relationship Management. It is a standard function in a company or organization and is rellated to marketing and sales. The function of CRM is to transform data retrieved from the customer base into usefull information and feed this information not only to sales and marketing, but to the whole organization of the company.

E-CRM is enterprises using IT to integrate internal organization resources and external "marketing" strategies to understand and fulfill their customers needs. Comparing with traditional CRM, the integrated information for eCRM intraorganizational collaboration can be more efficient to communicate with customers.

So CRM deals with customers (existing and prospective ones), aiming to get "more out of them". This means understanding what they want (and what we can make them want) and offering it to them. But furthermore, CRM nowdays is the main sensory organ and brain of the *customer focused business*. Although CRM is in fact a business process that existed long before the ICT era, the introduction and spreading of ICT and software has redifined the term: nowdays, *CRM* means *e-CRM*.

A company that systematically employs an e-CRM, should expect (and seek for) the following benefits:

- Better efficiency in marketing actions
- Faster response to market needs and changes

- Definition of market segmentation: what is my market segment (my customers), where should I focus my products and services to, in what way should I approach my market?
- Customer retention and loyalty enhancement. It is much more efficient and economically profitable to retain an existing customer, than to gain a new one.
- Personalized marketing that enhances the customer experience

Functions of a e-CRM system

CRM appiles to customers-not only existing ones, but also to the potential ones. While in the pre-internet era, it would not be so easy to create relations with potential customers, in the social media era it is much more easier, because ICT and social media provide several relevant tools.

In a general overview, e-CRM employs the following business functions:

1. **Decision support**: analysis of the data from the customer and from the products data base, customers tracking, segmentation and analytics, products and services analytics (identification of trends and patterns)
2. **Personalized service** : enhancement of the customer-user experience (eg interactive shop, shopping recomendations)
3. **Management of the customer**: communication, motivation reward (by emails, newsletters, interactive help desk)

The C in CRM: Customers

The customers data base is the basis of the e-CRM system. Every company has a customer data base, but eCRM demands a more rich content than the data base of the sales department. e-CRM should allocate every customer in segments, based mainly to the customer typology. You can define the segments, according to geography, age, gender, body type, spending profile, life style, buying behavior and many more, depending on your market and your products.

Allocation of every single customer to segments, will allow personalized approach, better experience and finally customer loyalty. Keep in mind that each customer is allocated to several segments and this set of segments build the specific *customer profile.* And please do not forget that your customers change (age, body type, preferences, behavior, almost everything), which that means that their profile should revised and updated.

The R in eCRM: Relationship

e-CRM aims in creating and managing relationship with the customers, existing and potential. Customer relationships can be classified in the following categories:

- customer lowalty
- customer retention

- new customer attraction
- enhancement of existing relationships

A customer relationship is more than just sales. Employing software in order to just track sales, is an old and widely exercised business process and is not CRM. A company should go beyond this.

Nowadays, fashion products do not really cover the basic need of clothing but more a social need, based mainly in the emotion of self-valuation and self-confidence. This has to be fulfilled in order to (finally) promote sales.

Just think of the comparison between Amazon and the good old e-marketplaces. Although the idea of e-sales has been intorduced by the e-marketplaces, it is Amazon that surpassed and eliminated them. Why has this happened? Amazon established more and better relationships with its customers, by giving them several interactive features, like the opportunity to rate the product and the supplier, propose similar or related (add on) products, etc. The relationship between customer and seller became better in term of content, usefullness and (why not) fun.

The introduction of eCRM software in an organization, is the perfect chance to introduce new, novel innovative and meaningfull relationships with the customer base. It should not be the adoption of the default relationships that the softaware has in its faetures, unless of course these existing set of relationships fit your business and marketing strategy.

How do we identify these meanigfull relationships? Old time shopowners used to say that even if visitors of their store finally do not buy anything, the dust that they leave in the store is precious. So the time that a visitor spents in the company site, is a metric that can help. The same applies for engagement in the social media. A customer that engages with our products, maybe does not spent so much money, but she/he can be a good promoter of our products (in their own group of friends in Social media or even word of mouth).

Other relationships could be:

- Reward of loyal customers
- Customers that create content in the company Social Media
- Duration and frequency of engagement with our products
- Virtual events like launching of a new product or product collection that is open only to “ the few-good-old-loyal customers”.

The M in eCRM: Management

You should remember eCRM should not be the responbility of the technology department. It is about customers and "belongs" to marketing department.

Management of customer relationship, involves the following processes:

- Better, easier, rich in content, communication with the customer, via multiple channels
- Enhancement of customer engagement by monitoring of Social Media and customer paths in the (physical) Shop and e-shop, company site.
- Customized service and support

The e in eCRM: Electronic CRM systems

Information techologies and networking, provided the basis for the development and wide desimmination of e-CRM. The internet and social media have been the catalysts for the next generation of e-CRM systems. The imployment of software or web platforms for CRM provides the following benefits:

- Better integration with other computer systems in the company: sales, accounting, logistics, production
- Intergrated processing of data from sales, social media, web analytics.
- Significant operation cost reduction of the CRM busniess process
- Ability of new innovative marketing actions.
- Fast response thanks to the real time information
- Transparent operation through the whole of the organization.

Technological aspects

e-CRM relys on an ICT system, which by default consists of a software, hardware and the human operator. The main software components are:

- The customer and product-services data base
- The software (in modular structure, according to desired features capabilities of the system)
- The applications that connect the software with other software systems, internal or external to the company
- The server that hosts the data base aand the application
- Communication channels to/from other servers

Each component of the ICT eCRM system,can be owned, hired or leased and this decision does not only depend on the economics and the cost, but is choise for the business operation.

<u>Proprietary vs open sourse</u>

General consideration applicable to software, are also valid for this dillema. Although open sourse seems at first glance a cheaper option, one should have in mind that open sourse software is not a “for free software”. Open sourse software have great demands on support and service and comes at a significant cost.

Hosted locally vs web based (cloud computing).
Definatelly the trend is towards web based software and this is especcialy true for SME’s, that do not have the resourses to own and operate compicated computer systems. Cloud computing offers the possibiltity to transform the investment cost in operating cost and the flexibility to pay as you use.

Consider this: in most of the cases, an SME will choose an eCRM solution out of the existing pool of ventors and with implementations out of the ventor self. But if it implements eCRM in the same way that several other (similar-relevant-compiting) companies do, how can be really a benefit? It’s customer management will be the same between the competitors, then it is not a differantiation factor and obviously not an asset-advantange. In this aspect eCRM is not usefull at all.

Operation aspects.
This aspect relates to the way that customer data will be retieved and processed. One should not forget that the e-CRM operator is in fact the user of the system and users are not IT experts, but can be a telephone customer service assistant or the warhouse worker. A single unique customer profile, with easy to comperhend information dispays and user friently interface, are the basic requirements.

Business aspects.
This aspect relates to the connaction of e-CRM with the other business units and processes in the company: the e-CRM will produce value only if it communicates with the rest of the company processes, that means receive and deliver information from and to them. An obvious example is that e-CRM will receive sales data from the sales and deliver relevant information to the marketing people. An example not so obvious, is that the logistics department, could also benefit from this information and adjust the product delivery options in a more profitable way (by modifying delivery dates for instance). You should not overlook the obvious: e-CRM output can not be better that the input and this depends on the amount and quality of data input. The input in e-CRM comes from the rest of the business processes, so rich, clear and transparent communication between them is an essential factor for an efficient operation of the eCRM system.

Obstacles to e-CRM adoptaption

- Lack of capital for investment. On the “physical level”, e-CRM is an ICT system and as such requires assets and infrastracture. One option, is to adopt e-CRM as a service (Software As a Service) or a web based edition, which means that initial investment is minor and the cost is on a time basis (monthly, yearly).

- Poor undestanding of usefullness and approprientence. Especially SMEs, are always reluctant to novelties and would rather operate in the way they know. This is not enough any more in a globalished market and in an era of ICT and Internet. Another misunderstanding can be that e-CRM is not appropriate for B2B , which is missleading: a business customer is (still) a customer.
- Lack of human resourses. This is typical for SMEs and relates to all aspects of their operation. In the case of e-CRM, lack of human resourses can be the absense of personell that will
  - ✓ introduce the idea and state the usefullness of investing in e-CRM,
  - ✓ desing the system, specify the targets and the features of it
  - ✓ operate the e-CRM and succesfully introduce it to the operational scheme of the company (will create value”).

What you should avoid, when employing an e-CRM

Don‘t proceed in ecRM, before you define your customer strategy (retention and attraction). In order to define customer strategy you must classify your customer base in groups, from the most valuable-profitable ones, to the least ones. Think without technology in mind and start by giving answer to these questions:

1. What and how much, should we offer to our customers, in order to enhance their loyalty?
2. How much of this proposition is afforbable and appropriate for us? How much is really valuable for us?(not neccesarilly in strict economical terms)
3. How many assets and money can we afford for eCRM?

You should always have in mind, that e-CRM is not just a software or an IT platform- it is a business process, assisted or implemented by a software.

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4.7 E- Retail

Georgios Priniotakis, Marissa Sigala, University of West Attica, Greece

A small introduction

E-commerce has radically changed the way of shopping as millions of purchases are made electronically. This development offers employment challenges not only to big but also to small companies to have customers all over the world, wherever there is an Internet connection. So, as more goods and services are traded online, it becomes increasingly important for both small and large enterprises to have an online presence all over the world. Shoppers also have the chance to shop from their home from all over the world.

E-retail has been defined as the sale of goods via electronic channels or the internet by consumers for personal use. So, it refers only to "Business to Customer" (B2C) procedure and not to the "Business to Business" (B2B). According to Investopedia: "electronic retailing requires many product displays and specifications, giving shoppers a personal feel for the look and quality of the offerings without requiring them to be present in a store". Shopping online is very different from purchasing an item in-store. In the Internet age, the era of consumer-led marketing has begun as the world's retailing market is changing into a buyers' market from a seller' market. The rise of online retailers is rapidly changing the perspective of shopping and consumption. In e-Commerce context, a pure player is a company with products or services that are only digital and operates only on the Internet, but at the same time pure player can also mean "a player who serves and invests his resources in only one line or service of business, while excluding other market opportunities. For example, many electronic e- retailers are pure plays: they sell one particular type of product over the internet. E-retail is not selling to business customers, but to the individual consumer who will be using the product, that means that it is a Business to Consumer action (B2C) rather than B2B (Business to Business), according the governance principals. E-commerce can also included things which are not physical goods, such as services: for example, banking services, which is an e-commerce but not an e-retail function. At the store important points are the location and the window shop but in e-retail important are the presentation of the site of the company as well as the presentation of the products.

Pros and Cos of e-retail: E-selling action is not as powerful as face to face selling, so the presentation of the product should be a strong sensorial experience for the costumer in order to convince them to click and shop. In e-selling procedure the buyer has a sense of what he is buying, so the presentation and the total perspective of the product should be the strong points and not the other as: the seller, the shop- window, etc.

In e- retail there is a big variety of goods in a very competitive environment as the customers have the choice of many e-retails and unlimited time to compare and to choose. The obvious online advantages being: convenience for both sites: seller and buyers as they can interact each other from in privacy. Also, there is a reduction of the overhead costs as selling online can remove the need for customer-facing staff and expensive shop window every season. One major advantage for the buyer is there is the opportunity to expand their market beyond their local market very quickly. The cos of e-retail: - the unsustainable cost.

According to Barclaycard's research, more than a fifth (22%) of bricks and mortar retailers in UK in 2015 year, choose not to sell online due to concern about the costs of managing delivery and returns, - the extra website and the infrastructure costs, - planning, designing, implementation, hosting, securing and maintaining a professional e-commerce website and also the cost regarding the support of online orders are not cheap actions, - the willingness of buyers to return to conventional methods of buying, as many consumers still prefer a physical communication with a product,- it is difficult to establish a trusted brand name, especially without a physical business from the beginning, consumers cannot bargain the price and often companies use tracking methods such as "cookies" in order to record consumer preferences and target advertising of relevant items without asking or caring about consumer's personal data and wrights.

What makes a good e-retail site?

First of all, one needs a business plan. A business plan for an online business should include the approach that will be used for financing, marketing, and advertising of the business. An easy to navigate web design with a speedy page loading and with all the appropriate info that will analyze in the nest paragraph, is a significant ingredient that will boost the customer to stay and to shop. Another major point is the setting up of the shopping cart: an e-retail without a shopping cart is like a store without a cashier. The existence of an e-retail presupposes the appropriate technological infrastructure (existence of domain name, website, hosting, existence of software connected to the warehouse system, existence of a billing system, etc. and the marketing knowledge as well as customer psychology knowledge, who until recently considered the internet market as boring. So, in order to have an e-retail you should develop:

- ICT infrastructure services - Logistics and trade facilitation as e-retail requires a reliable delivery with effective tracking systems

-A transparent legal and regulatory environment (clear procedures for e payment - taxation). The above are not the responsibility of the private company, but it has to provide all the information regarding potential extra taxation, or payments, extra delivery cost, etc. from the customer to take into consideration.

- The existence of a speedy web page, in which one must present their goods and company.

What information is required to have an e-retail in order to be completed?

- Information (terms of use), trust (security of personal and financial data), traction information (similar language and pleasant and pleasant presence as a whole), delivery and returns info
- Information about products and materials origin, as well as sizes. Today more than ever, consumers are paying attention to where products are made as well as the origin of materials. • Company financial data (a few words about its history, how it has been created, its financial data over the past five years, the company's strategy as well as its members or shareholders
- Various news or offers, frequently asked questions.
- Interaction with the customer, such as direct chatting, past customer reviews, email queries, contact info, video size guides and various innovative elements that differentiate this e-retail from the rest.

According to an article (https://www.invespcro.com/blog/shopping-cart-abandonment-rate-statistics-infographic/) the average Shopping Cart abandonment Rate of e-commerce websites is 68.81%, which means that shoppers didn’t complete the checkout process 68 times out of 100. What are the reasons for this action?

Figure 4.7.1. Shoppers leave their shopping carts

According to a research from Baymard Institute (https://www.smartinsights.com/ecommerce/ecommerce-strategy/consumers abandoning-shopping-carts-power-retargeting/) the reasons are the following: unexpected shipping charges, too complicated procedure, various website errors, complicated procedure, delay of the delivery, not clear returns policy, etc. As we can in the chart the major reasons are the unexpected cost (delivery cost - taxations cost etc.), just to browsing and better prices at another e-shop.

So e-retails try to minimize the loss of the potential buyers and they give extra motivations to their shoppers to continue and to return to their shopping carts in order to complete the shopping. The secret is to try to implement the do's to their e-retail and to boost their customers satisfaction.

Dominants of the e-Retail

According to an article to the RetailWire forum (https://www.retailwire.com) with the subject: "Online and Amazon to grow more dominant over the next decade", many eperts declare that consumers will continue to make more purchases online while cutting back on in-store purchases over the next decade. This statement is supported by a report by FTI Consulting, which forecasts total online spending in the U.S. to surpass $1 trillion by 2027 and according to the estimates online sales will grow to 22 percent over the next 10 years form the 12 percent of the total retail sales today. E-retail, which currently accounts for 34.2 percent of online sales, will see its share grow to more than 50 percent of the market by 2027, the firm estimates. In addition, according to FTI Consulting the biggest beneficiary of the U.S. customer change from stores to online store will be Amazon.com. According to Statista, "Amazon's increasingly dominant position in the e-commerce market is owed largely to the company's aggressive growth strategy." But how to measure online success? As e-retail is a business the major issue is the profit but in e-retail significant points are also the following: the numbers of viewers, the engagement of the shoppers and conversions, the way of shopping: via internet, via mobiles or other smart devices.

What do we mean "conversion"? The definition of conversion, according to the MarketingSherpa handbooks is "the point at which a recipient of a marketing message performs a desired action." So, conversion is getting someone to respond to your call-to-action, for example to fill a form to open an email of your company, etc. This means that for online success it is important how many people visit an online store, how interested they are about products, or to fill a questionnaire or a form that we have asked for, or how many of them finally click the buy button in order to complete their shopping. Much research has been conducted and the conclusion is a growth in this area.In 2017, ecommerce general was responsible for around $2.3 trillion in sales and is expected to get more than $4.5 trillion in 2021, according to a report by Aaron Orendorff. This reports declares that in the US, ecommerce represents almost 10% of retail sales and that number is expected to grow by nearly 15% for 2018. So, as a result e-retail is one of the most active area of the economy factor worldwide.

Successful examples: Amazon

Amazon launched in 1995 as book seller and expanding into other goods, with three aims:best prices, an easy to use customer interface, and quick delivery procedure. Initially, the firm's revenues doubled in size every 2.4 months and revenues for the first year of operations were $5 million. The innovation at Amazon was that customers could search for a specific book, topic or author, or they could browse their way through a book catalog featuring 40 subjects. Visitors can also read book reviews from other customers, the *New York Times,* the *Atlantic Monthly*, and Amazon's staff. At Amazon all books are discounted: regularly bestsellers are sold at a 40% discount and the rest books at a 10% discount. Amozon offers free shipping in order to encourage customers to increase their basket size since customers have to spend over a certain amount to receive free shipping.

In addition, Amazon creates online communities = group of satisfied costomers who post their own reviews, means Amazon boost customer to communicate eacn other and to create online communities. This movement of Amazon is based on the fact that there are four types of needs that electronic communities should attempt to satisfy in order to be successful (Armstrong and Hagel, 1996): transaction, interest, fantasy, and relationships. This community provides an enviable amount of positive feedback, so it gives toAmazon a huge nomber of positive reviews.

Another service that Amazon offers to its customets: is to communicate the fulfillment promise in several ways including presentation of latest inventory availability information, delivery date estimates, and options for expedited delivery, as well as one day delivery shipment notifications. Amazon states that the best marketing is when people create a word-of-mouth promotion which is effective in acquiring new customersurage repeat customer visits. And this is fact, if we think that how many friends of us talked to us or describe us or make a post and they create a movement to the market.

Successful examples: Alibaba

Launched in 1999, the Alibaba Group initially focused on operating a business to business (B2B) website for small Chinese exporting companies. Today acoording to Today according the latest data Alibaba extends to 10 businesses and has approximately 27,000 employees and more than $8 billion in revenue. Alibaba suppports Chinese companies by creating a meeting platform for international sales (for buyers and suppliers). It started to offer more infrastructure services to it's costumers (as logistics - computing plattform, etc) and then also began building Taobao Mall, a platform for established brands for Chinese consumers. In 2011 the company split to the following parts: Taobao focused on consumer-to-consumer transactions, Tmall on business-to-consumer transactions, and Etao, a new unit, on product search, in order to cover the future of e-commerce sector in China. When Alibana started operations, internet penetration in China was less than 1%,. So, Alibaba has the vision to invenst to the new innovation and this was part of the suceess story. Now Alibaba offers services: business to business (B2B), business to costumers (B2C) and customers to customers (C2C), with an operation similar to ebay. In the last decade Alibaba has expanded to all most every corner of the world. Alibaba is dominated almost the 75% of e-commerce market.

Alibaba doesn’t sell any physical products themselves, but instead offers many kinds of services. As Alibaba states on its website: "Alibaba will continue to develop the quality of products."

E-Retail in the Textile Sector

The textile sector is a industry sector with unique characteristics and as an industry should have the right product in the right place at the right time (Fernie 1994). So, retailers should deal with manufacturers and with centralised buying in ordet to finalize the prices, quality and the delivery schedules (Bruce and Moger, 1999).

Many researchers claim that e-commerce is thriving, and textile and fashion markets should take the advantage of it. In order to support this we note the fact that Indonesia’s textile sales is likely to rise 10% in 2017, compared to only 2.2% growth last year, according to CEO of Tekstile One Indonesia, Desy Natalia Soeteja, as more and more textile companies there unitlize e-commerce to penetrate the global market.

According to an article: "The State of the Ecommerce Fashion Industry: Statistics, Trends & Strategy" by Aaron Orendorff the e-commerce fashion industry revenue expected to rise from $481.2 billion in 2018 to $712.9 billion by 2022. These figures proves that fashion industry is alive and year by year are involved with the new technology as the potential customers are growning every year. As the supply chain in the textile sector is complex, with many parties being involved.

Zalando example

Zalando is Europe’s leading online fashion platform, which was established in 2008 in Berlin, to sell footwear through internet. Since then Zalando offers a variery of fashion items in more than 15 countries and represents an annual revenue of almost 3.6 billion euros in just seven years. What was this that lead to Zalando to the sucess?

The aim of Zalando is to design and build e-commerce logistics properties that would help company deliver to its customers faster with the minimum cost. With this strategic Zalando continues to offer a remarkable service to its customers. The innovation is the use of a tool for personalized online style advice which can be accessed through Zalando's online shopping website and try to create a unique online experience to the costomers with the personalized and interactive style guidance according to specific customer needs.

YOOX NET-A-PORTER GROUP (YNAP) example

YOOX NET-A-PORTER GROUP is the world's leading online luxury fashion retailer, which has established in 2015, by the merger YOOX GROUP and THE NET-A-PORTER GROUP; the two companies had revolutionized the luxury fashion industry since their birth in 2000. YNAP's websites, is an innovative website, in which all the IT operations run on an IT infrastructure from Hewlett Packard Enterprise (HPE). It delivers more than 180 countries, offering same day delivery in an increasing number of global cities. In 2016 the montly unique visitors were 29 million and combined net revenues €1.9 billion, since since then tries to to continue to provide the best experience to its customers worldwide and scale its operations efficiently as well.

Editorial content is at the significant element of the e-commerce experience which offers to the custumers and one other special feature is the existence of the included multi brand stores. At the first appearance it is looked like a fashion maazine and not an online retailer. As a conlusion we affirm that retail online is not just a shop but it hides more complex procedures (IT infrastructure, logistic infrastructure, a clear strategic plan, interoperability between the systems,etc). E-retail and shopping through the internet is a way of life nowadays and not just a shopping operation, so companies involved in this should be ready to face this challenge: the new era of e-retail and the transformation of the face to face shopping to shopping through internet with new virtual applications.

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