

FUTURE VIEW ON FIBERS AND TEXTILES

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ABSTRACT

The 21st century promises to provide an expansive new era of technical advances that will dramatically influence the world of fibres, fabrics and textiles. In this century, textiles will not only offer the best functional features of natural and synthetic fibres, but will be highly engineered systems targeted to provide complex functionalities for technical applications. Biotechnology, fibre engineering and materials science will be key technologies driving the development of these next generation textile systems. Exciting new opportunities will arise at the interfaces – integrated science - between these divergent disciplines.

In the general parts of this lecture the factors influencing future trends in the fibre and textile industry and application of fibrous structures are discussed. The core of presentation is specification of cotton and polyester fibres properties required for apparel production and expressing the selected properties changes due to variation of air humidity.

INTRODUCTION

We live in a world in which technology is advancing at such an astonishing rate that it is often difficult to comprehend its impact on our lives. The application of modern biotechnology for the cloning of adult mammals, the development of disease and pest resistant crops and miracle pharmaceuticals/nutraceuticals that promise hope for the management of selected cancers, heart disease and infectious diseases continue to dazzle us on a daily basis. The textile industry has likewise kept pace and today's technology can provide fibres that go well beyond the best that nature can offer. It is indeed narrow to consider textile technology as a rigid discipline concerned with making filament, yarn and fabric. It is certainly more diverse and is in a continual state of flux in response to technical innovations and the changing needs of society. One point is clear, however, and that is that the textile industry must become more profitable in developed nations and less sensitive to cyclic changes in the world economy. The challenge is to improve short-term financial performance in a way that accomplishes the long-term transformation necessary for sustained growth.

The inherent characteristics of new textiles underpin the functional and aesthetic qualities in varied applications beginning with apparel and extending to medicine, aerospace, construction, agriculture and home furnishings. There has been rapid growth in the polymer, material, information and biological sciences. Advances in these divergent sciences (and particularly at their interfaces) have begun to allow a new view of future textile systems.

History has shown that the earliest fibre technologies originated mainly in Asia. Cotton and silk are native to China and India, while wool was first put to practical use in Central Asia. It is widely known that the “Silk Road” arose from the strong desire of western civilization to acquire silk products originating in China. Centuries later, the era of man-made fibres began with the invention of rayon in the late 19th century. Invention of nylon in 1935 by Wallace Carothers at DuPont was closely followed by the development of acrylic and polyester fibres (Hiratzuka 1996, Militký 2009). This led to increased research to develop a variety of new materials comprised mainly of these three polymer platforms. New fibre processes suitable for these newly developed polymers were invented (O’Brien and Aneja 1999). High-performance fibres including, among others, carbon and aramid fibres were invented in the 1960’s (O’Brien 1993).

Thirty-five years after the invention of nylon, worldwide synthetic fibre production surpassed that of man-made cellulosics. Today, synthetic fibres comprise more than half of total fibres consumed worldwide.

TEXTILE INDUSTRY AND FIBROUS STRUCTURES

Textile and clothing plays an important role in the processing industry of EU countries. This sector of the economy employs about 6.2 million people (9.3% of the work force). The total turnover represents approx. 4 % of total added value in the processing industry. This is indeed a significant portion and concomitant involvement of large number of citizens. With increasing global competition and availability of commodity products made in Asia the production in Europe must focus on consumer-oriented specialty textile products. These products with so called intelligent response will be used for special clothing and technical textiles mainly. The forecast for utilization of intelligent response textiles is shown in fig. 1 (Wilson 2011).

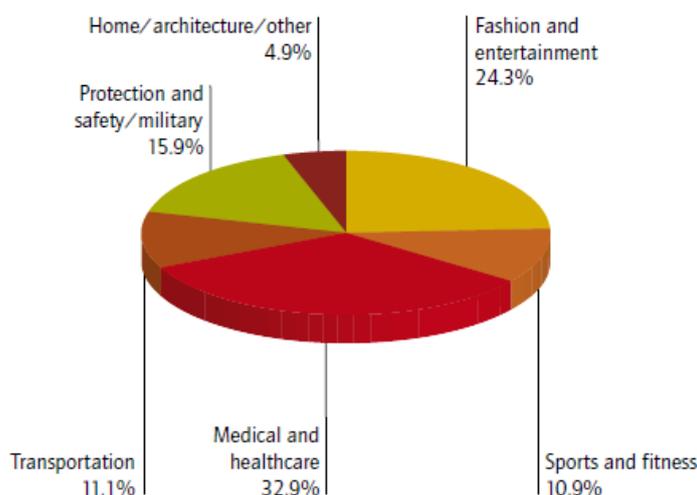


Figure 1. Forecast for use of textiles with intelligent response in 2021 (1944 mil EUR total) (Wilson 2011)

The reasons of development for the textile industry are consistent with the development of mankind. The main factors influencing the textile industry are primarily population size and increasing life span expectancy. It is expected that by 2050 the world population will increase to 8.9 billion. With average expected consumption of 20 kg of textiles per person per year a total of 178 billion tons of textiles per year will be required. In addition, by the year 2020 between 15 to 25 % of population in developed countries will be over 65 years of age. Seniors requirement for textiles have vastly different characteristics - namely higher emphasis on safety. With a longer working span in societies the requirements of textiles will change accordingly. It is strongly suggested physiological differences, physical potential and comfort of clothing when designing clothes for the demographically changing older population are to be considered.

These human factors are closely tied to the changes of trends in the availability of information, virtual availability of everything (including goods) and globalization of society. A typical feature of classical textile structures is that their utility is manifested with strong practical component in mind. A user's experience with similar products plays an important role in decision making. The prevailing classical principles of production, consumption and innovations impact productivity and the economy. The need to capture the market often leads to hasty new product introductions without a detailed analysis of real consumer benefits. In well designed advertisement campaigns and sales promotions, companies sometime use improper and often misleading information in order to attract new customers. On the other hand, a number of breakthroughs have diffused at a slow rate since potential buyers are not fully informed and prepared for adoption.

Textile industry is characterized by series of rapid cycles of innovation driven by rapidly changing consumer needs and desire for new products. To achieve a permanent sustainable development, it is necessary to incorporate emerging innovations from other scientific disciplines i.e. an integrated scientific approach. This involves flexible production technologies resulting in effective and ecologically friendly productions for care of global responsibility, using conventional and renewable material alternatives and decreasing the water and energy demand for industrial development.

The utilization of fibrous structures has been critical to the success of many industries over the millennium. It is associated directly with the development of human society. It has been influenced by many other disciplines, such as mechanical engineering, material engineering, electronics and biotechnology. Nanotechnology and nanomaterials including nano-composites have also utilized the innovation concepts emerging from the textile industry. Fibrous structures are used not only in garments for clothing and technical textile applications, but also as special material for construction and composites. New textile structures giving rise to new products should be created for clothing materials with emphasis on adaptability to the changing conditions. Special technical textiles with unique properties are required for new and emerging applications.

CURRENT CONCERNS IN FIBERS

Fibres are very specific materials with some extraordinary properties in comparison with polymers of the same chemical composition. Reason is so called fibrous structure which appears in practically all natural chemical and synthetic fibres. This structure is responsible for enhanced mechanical properties in the direction of fibrous axis and huge anisotropy of physical properties.

The quality of fibres depends critically on the aim of evaluation. For fibre producers the quality means the achievement of required technological parameters (geometrical evenness, fineness, shrinkage, mechanical and physical parameters, etc.). For textiles producers the quality means the ability to fulfil requirements of technologic operations and process ability (friction, surface properties, cohesion, selected mechanical and physical properties and evenness). For consumers is fibre quality hidden in the properties and comfort of fabrics (hand, wearing pleasance, thermal comfort, transport properties etc.).

Changes of fibres parameters responsible for their quality depend on the fibres origin. Natural fibres as **cotton, bast fibres and wool** are created by nature not for purpose being used for the textiles creation. Major changes of their properties are very difficult. In fact it is possible to use of techniques requiring long time as selection, breeding, gene manipulation, etc. The main aim of improvements is to select fibre varieties bringing the good process ability (spinning ability) and mixing. On the other hand, the chemical and synthetic fibres (**viscose, polyamides, polyesters, acrylic fibres, polyolefines**, etc.) are prepared by humans for textiles creation. Their properties can be simply changed by the by the variation of fibre spinning, drawing and heat setting conditions. It is simple to change markedly majority of properties by selection of fibres geometry (denier, cross section profile, texturing) and spinning conditions (rate of production, drawing degree, and temperature treatment). The proper chemical modification is another way to change some of properties (Militký et al. 1991).

The set of required fibres properties depends on the area of utilization. For the case of apparel textiles the 12 fibre properties and their sufficient values were specified (Horrocks 1985) - see Table 1.

Table I. Sufficient properties for “mean” fibre

Tenacity	T	0.3 N/tex
Breaking strain	BS	15 %
Initial modulus	I	5 N/tex
Work to rupture	W	40 mJ / (tex m)
Moisture regain	R	5 %
Water retention	WR	50 %
Electric conductivity	C	0.1 ^{a)}
Limiting oxygen index	OI	21
Light resistance	L	3 ^{b)} month
Alkalis resistance	ALK	2 ^{c)} hour
Acids resistance	AC	2 ^{d)} hour
Heat resistance	H	120 ^{e)} ° C

a) Reciprocal value of electric resistance logarithm.

b) Time, when tenacity on sun (Florida) is dropped to 50%

c) Time, when tenacity in 10% NaOH at 100°C is dropped to 50%.

d) Time, when tenacity in 10% HCl at 100°C is dropped to 50%.

e) Maximum temperature at which can be fibre used without time limitations.

For any fibre, an identity diagram or polygon may be constructed, which describes the behaviour of a given fibre with respect to that of an "average" fibre. Identity diagram is twelve sided polygons, where on the rays are, relative values of properties (percentage from “mean” fibre property). Approximate symmetric shape indicates balanced properties. Superimposing values of real fibres into this diagram enables to identify properties positively distorted towards those features in which real fibre is particularly well endowed. Conversely, property deficiencies are similarly identified. The strengths and weaknesses of any fibre may be then graphically observed.

Two major fibre types i.e. **cotton** and **polyesters** are currently most important for creation of apparel fabrics. The cotton fibres were dominated till the 20th century. Now they are exceeded in volume by polyester. Partly the dominance of cotton textiles was due to the economics of production, distribution and manufacture, but was also results from the combination of structure and physical properties (Gordon and Hsieh 2007).

Cotton was the best fibre for the apparel purpose and sometimes as a cheaper alternative. Now cotton needs the properties that give a market for high quality, since polyester has captured much of the cheaper end of the market, as well as providing premium types for higher quality fabrics (Gordon and Hsieh 2007).

For typical **polyester fibre** are deficient the moisture regain R and water-retention WR and for typical **cotton fibre** are deficient the breaking strain BS, work of rupture W, limiting oxygen index OI, heat-resistance H and acid-resistance AC (Horrocks 1985).

Standard characteristic of fibres is their fineness [dtex] (as product of cross section area and density) and length. Most of fibres are thousands times longer in comparison with their thickness. Cotton fibres range in dimensions from superfine Sea Island cottons with a length of 5 cm and a linear density of 1 dtex to coarse Asiatic cottons of 1.5 cm and 3 dtex (Gordon and Hsieh 2007). The fineness and length of polyesters can be varied according to the aim of application and potential mixing with natural fibres. Typical fineness of polyesters of cotton type is from 1.3 till 1.75 dtex (Militký et al. 1991). The polyester fibres are nearly round but cottons have lumen and cross section area is very far from circular shape (see fig. 2). The degree of secondary wall thickening for mature cotton fibres is usually about 0.4 -0.6 (Hequet and Wyatt 2001).

For creation of yarns and fabrics it is necessary to have sufficient fibres flexibility. Flexibility of a fibre, i.e. its ability to be bent to an arbitrary radius is one of the main attributes of a fibrous material. Many operations such as spinning weaving, braiding, winding, etc., depends on the ability of a fibre to be bent without several damages. A high degree of flexibility is really a characteristic of a material having a low modulus and a small diameter (Chawla 1998).

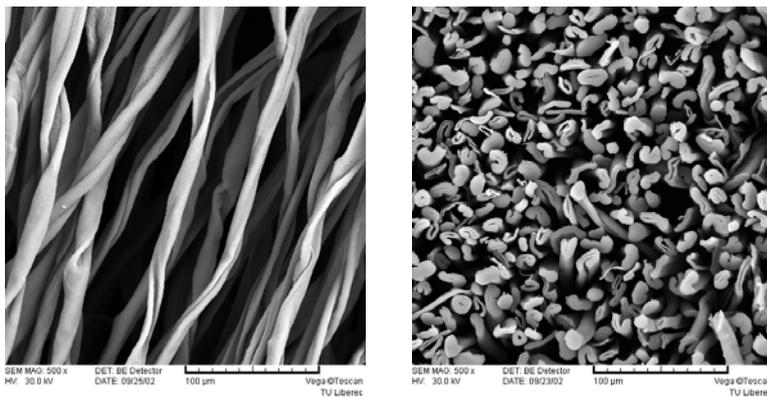


Figure 2. Longitudinal view and cross section of cotton fibres

The flexibility FL of a given fibre is a function of its stiffness or initial modulus E , and the moment of inertia of its cross-section, I . The initial modulus is quite independent on a material form or size. It is generally a material constant for a given chemical composition. For a given chemical composition and density, the flexibility of a material is determined by its shape, the size of its cross-section, and its radius of curvature, which is a function of its strength. The flexibility can be therefore defined as inverse of product which is called bending rigidity $FR = E I$. From elementary strength of materials, the following relationship for a circular rod (shape factor $s = 1$) having fineness T , initial tensile modulus E and fibre density ρ can be obtained.

$$FL = \frac{1}{FR} = \frac{4000 \pi \rho}{s E T^2}$$

For non circular cross section the proper shape factor s should be used. The shape factor for cotton (in torsion experiments) is estimated to be 0.71 (Morton and Hearle 1993). Because polyester fibres are usually finer (with $s = 1$) they are more

flexible than cotton despite on the higher initial modulus. For fibres with higher modulus E it is generally necessary to use finer fibres for obtaining sufficient flexibility.

In analogy to bending rigidity, the torsional rigidity (resistance to twisting) can be calculated as well. The finer cotton varieties show less rigidity than coarser fibre: fine Egyptian cottons are in the range 1.0–3.0 mN m²; American cottons, 4.0–6.0 mN m²; and coarse Indian cottons, 7.0–11.0 mN m² (Wakelyn et al. 2007). The ratio of shear modulus to tensile modulus is given by Morton and Hearle (1993) as 0.27. For PES fibres is shear modulus about 0.7 - 0.8 GPa (Morton and Hearle 1993) and for cotton it is 2.4 GPa.

Fibre rigidity increases with temperature and decreases with moisture content. Difficulties in fibre rigidity during spinning are thus eased by maintaining a reasonably warm and humid atmosphere (Wakelyn et al. 2007).

The more rigid fibres are not able to be optimally arranged in the fibrous structures. The yarns from more rigid fibres have then more porous structure with higher diameter. The indication of arrangements of fibres in yarns is packing density. The 95% confidence interval of packing density trace for cotton and polyester yarn with the same fineness 24 tex are shown in the fig. 3

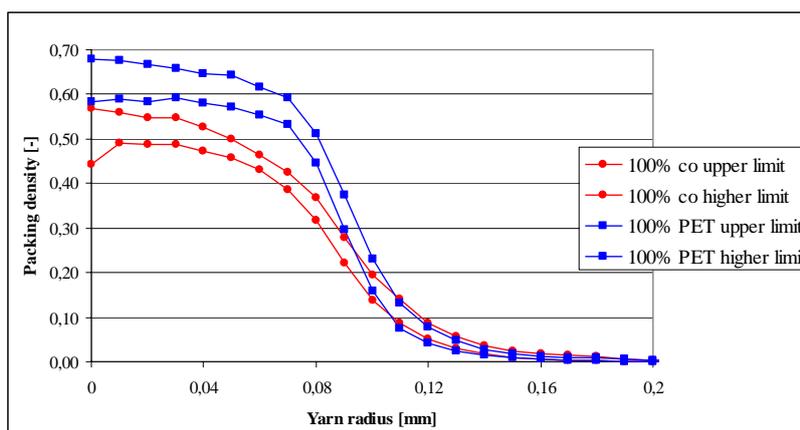


Figure 3. 95% confidence interval of packing density trace for cotton and polyester yarn

The yarn packing density is generally connected with yarn mechanical behaviour, thermal resistance, air permeability and other yarn properties which appear in end use properties of fabrics (Křemenáková Mishra Militký and Šesták 2011).

The properties of cotton and polyester fibres are summarized in the table II as combination of data from various sources (Herlinger 2008, Morton and Hearle 1993).

Table II. Selected properties of cotton and polyester fibres

Property	Cotton	PET (cotton type)
Fineness [dtex]	1- 3	1.3 – 1.7
Density [kg m ⁻³] (dry state)	1560	1390- 1410
Break elongation [%] (dry at 21°C)	6 - 9	25- 55
Tenacity [cN/dtex] (dry at 21°C)	2.5 – 4	4.5 - 6
Stress at break [GPa] (dry at 21°C)	0.35 – 0.6	1.2
Initial modulus [cN/dtex] (dry at 21°C)	39 - 74	45 - 90
Initial modulus [GPa] (dry at 21°C)	2.5 - 4	6 - 12
Rel. loop tenacity [%]	65 - 75	75 - 95
Elastic recovery (2% deformation) [%]	75	90- 98
Elastic recovery (5 % deformation) [%]	45	70 - 90
Torsion brittleness [deg]	53 – 56	42 – 48
Thermal conductivity [Wm ⁻¹ K ⁻¹]	0.25 – 0.4	0.15 – 0.25
Water absorption [%] (65% RH 21°C)	7 - 11	0.3 - 0.4
Water retention [%]	40 -50	3 - 5
Limiting oxygen index [%]	19 -20	20 -22
Spec. electrical resistance [Σ cm]	10 ⁶ -10 ⁸	10 ¹¹ -10 ¹⁴
Specific heat [J g ⁻¹ K ⁻¹]	1.22 – 1.35	1.03

Especially for cotton fibres are some properties dependent on the moisture content *MC* which is connected with surroundings air relative humidity *RH* (see fig. 4).

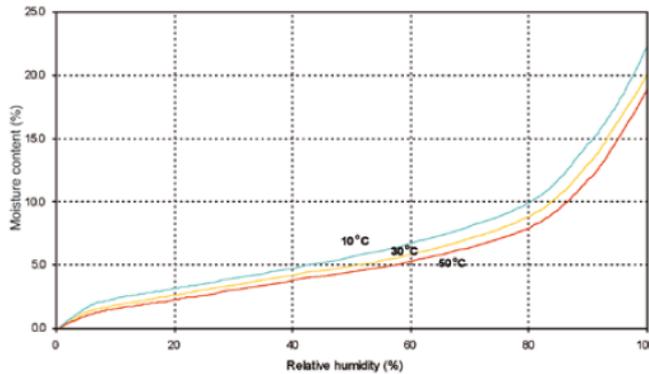


Figure 4. Relation between air relative humidity *RH* and moisture content *MC* in cotton fibres (Gordon Horne¹ and van der Sluijs 2010)

For example the cotton fibre density in wet state is calculated as harmonic mean

$$\frac{1}{\rho_w} = \frac{MC}{1000} + \frac{1-MC}{\rho_d}$$

The conductivity of wet cotton can be approximated by empiric relation (Haghi 2004)

$$K_y = 10^{-2} (44.1 + 63 (MC / 100))$$

The influence of air humidity on the polyester fibres is usually neglected. The weight of water in the fibre expressed as a percentage of the dry weight is known as the regain. For cotton, regain varies from almost zero in dry air up to a maximum of about 24% in saturated air. The saturation regain of polyester is only about 1%.

Very important characteristics of polymeric fibres is their glass transition temperature T_g i.e. the temperature characterizing discontinuity in polymer properties mechanical and physical properties. At temperatures less than the T_g the fibres will be more prone to damage, creasing, attracting penetrants molecules etc. For dry polyester is T_g about 71-80°C and for dry cotton is estimated to be 160°C. The T_g in cotton fibres varies significantly with the amount of water in the fibre MC which is directly connected with the external humidity (Gordon Horne¹ and van der Sluijs 2010). Theoretical T_g of cotton as function of moisture content is shown in the fig. 5.

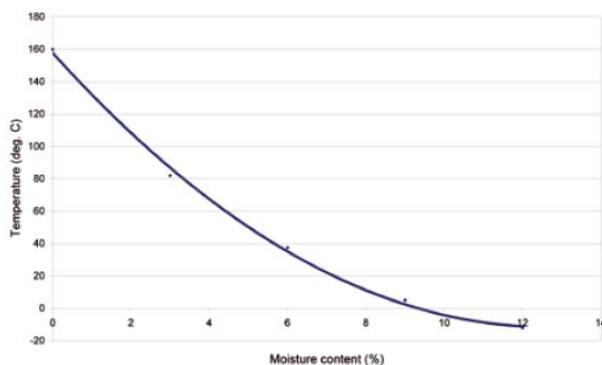


Figure 5. Theoretical T_g of cotton as function of moisture content (Gordon Horne¹ and van der Sluijs 2010)

TRENDS IN FIBRES AND CLOTHING

Over the last sixty years the textile business has enjoyed rapid growth in synthetic fibres, which has been fuelled largely by seminal discoveries in polymer and fibre science. Fibre and textile manufacturing facilities have also undergone enormous improvements in automation and simplification wherein large volume fibre production facilities today may require only tens (instead of hundreds) of personnel for their operation. Fibres, which have ease of care and natural-like aesthetics, have been major themes in recent decades with high performance and specialty fibres taking on particular significance.

Fibre and fabric tests, critical to product quality, have relied largely on destructive, off-line methods. Advances in testing and quality control promise to have a major impact on first pass product yields and product quality. The degree to which it is possible to engineer textiles today is astonishing. There is an increasing need for fabrics that can combine strength, functionality, fabric handle /tactility with enhanced mill value; and do this at a competitive price.

The standard properties of existing synthetic fibres can be heavily changed (Militký J. et al. 1991), while specialty fibres are giving valuable insight into new special properties. Fibre functionality will be improved (Table III) to yield novel applications in the future.

Table III. Functional Fibres properties

<u>Textile Functions</u>	<u>Application</u>
Thermal	High Temperature Insulation
Electrical	Grounding, Signal Transmission
Optical	UV Protection, Light Refraction, Communication
Acoustic	Sound-Absorbing
Magnetic	Magnetic Filaments
Separation-Absorption	Gas/Water Purification, Medical, Applications
Adhesion	Hot Melt Adhesion, Concrete Reinforcement Material
Anti-Bacterial	Pillows, Geriatric/Baby Clothing
Barrier Properties	Water-Proof, Water/Water-Permeable
Stretch	Comfort, Fit

Looking to the next millennium, the textile industry stands in stark contrast to its pre-eminent position of just 20 years ago. Many of the synthetic fibre products that once fuelled the rapid growth of the industry has become mature commodity products now characterized by low growth and lower profit margins. Intense global cost pressure, higher consumer expectations, and a highly diverse customer base and reduced R&D spending have all contributed to sluggish growth in current textile businesses. The challenge for the future is to revitalize the industry through technological innovations in products and manufacturing and to re-evaluate business practices in a global context.

A computer supported approach will be used as a standard during the development of new products. This system will require new programme systems combining the existing software developed for the classical construction of textiles (appearance design) with the systems predicting the properties of textiles in dependence on their construction (analogy of CAD systems in engineering). For clothing and protective clothing fabrics it will be necessary to include also a factor of comfort.

The textile treatment will utilize many particle systems of chemical elements, respectively simple compounds fixed in the substance or on the surface of the basic material. The influence of decreased particle size on the selected barrier and multifunctional effects will be subject to search in order to find their optimal size as a compromise between the price and effect. The influence of particle size on their

possible increased toxicity will be also evaluated together with related problems of dispersion stabilization, building of particles into textile materials and the stability of materials in the process of use and maintenance.

The research will be carried out to construct special membranes with controlled porosity assured in the membrane structure and also by means of special treatments with the increased protection against dust deposition, better antimicrobial protection, improved electrical conductivity and protection against electromagnetic radiation. Mainly particles in size less than 2 μm with sufficient stability in the process of maintenance and the non volatility up to 300°C will be used for the development and selection of suitable antimicrobial agents. The special technologies will be also oriented on particle systems (carbon particles, silicon based particles from the waste glass, platelets isolated from silicon clays etc.) that decelerate the speed of diffusion of combustible gases out of textiles. They have a higher thermal stability and decrease the speed of thermal energy release during burning. A combination of particle systems on the basis of metals, carbon agents, metal oxides, particles of conductive polymers with very fine metallic wires will be used for improving an electrical conductivity. For optimal use of metallic wires it will be necessary to solve the ways of their interaction with textile materials, technology of their building into the textile structures, behaviour during the use and maintenance and practical use in special applications. Materials with a high electrical conductivity including metallic wires will be used as a protection against electromagnetic fields (electro-smog) in the range of high frequencies (Militký and Křemenáková 2009).

As the interface between material/polymer science and biotechnology merge, textiles will evolve to adaptive technology-that is to those that adapt to the surrounding environment (Aneja 1994). Today's clothing is essentially passive, reacting only after body response. Lycra[®] garments stretch and move with the wearer. Coolmax[®], clothing wicks perspiration moisture away from the skin. The clothing of the 21st century is expected to recognize the surrounding environment and adapt to that environment. Instead of waiting for the wearer to become hot and perspire, the clothing will sense external temperature and adapt to make the wearer cooler.

ECOLOGICAL FACTORS

The delicate ecological balance of our planet is now comparatively well understood and grass roots organizations exist in most countries for its preservation. Heightened awareness of the harmful environmental effects of some manufacturing processes mandate that if the textile industry is to survive, it too must play a leading role in environmental conservation. Indeed, companies researching new textiles are making ecology a primary concern. Some, in fact, will defer on attractive new products unless they can be made safely and without deleterious impact to the environment. The textile industry is keenly aware that world resources are not limitless and recognizes that major changes must be implemented in manufacturing systems to assure their long term availability. Key focusing problems for the industry are:

- Waste elimination (reduce, reuse, redesign)
- Energy conservation
- Product reclamation
- Product recycle

All steps of the textile processing value chain from raw material conversion to fabric disposal must be environmentally friendly. The industry must strive to achieve a 100% recycle loop for all polymers to eliminate materials entering the landfill.

PROCESSES OF THE FUTURE

Commodity fibre technology is generally mature and broadly available to investors (capital orientation), hence competitive advantages in process technology worldwide are shrinking fast. Next generation technology will be driven by many factors, primarily to retain or regain a competitive position.

Creation of knowledge (product, process, and business) will be the deciding factor for survival and sustainable growth (Aneja Caldwell and Hietpas 2000). The industry structure will continue to be characterized by intense competition providing ultra-high quality products and highly efficient production schemes. A few large multinational companies that will consist of a diverse fibre portfolio and production capabilities and market-oriented organizations will carry out fibre production. To improve the level of control over quality, have greater speed and efficiency, and capture added value retained by them, there will be more integrated relationship within the value chain. This will yield a more collapsed structure with vertical (backward or forward) integration. The control in the value chain itself will move down stream closer to the ultimate consumer. Strong global business alliances will emerge to effectively utilize the synergy (technology, market share and channel control) of the partners at reduced risk and ease of market access. In efforts to restore profitability, adjustments will occur through the rationalization of existing firms and facilities with decentralized business structures for increased shareholder value. This will result in fewer, more efficient producers and a number of specialized companies. Market forces require that firms either adapt or close. Realistically, the compression now occurring in the industry will not tolerate mistakes. Weaker companies that are “weeded out” from textile may strategically shift resources by re-deploying to other industries – fibres to resins. The presence of e-Commerce will provide higher efficiency through rapid information exchange and perhaps higher margins through availability of consistent global pricing.

The textile sector has enjoyed the benefits of cost reductions and productivity improvements in the last decade. This has been due to processing improvements, including greater automation, increased spinning speeds, production capacity enhancements and process simplification. The production cost variance of fibre manufacturers is governed by both the investment per ton of fibre as dictated by economies of scale and the cost of basic feedstock. The investment cost for new plants is determined by raw material conversion costs and all downstream processes which include spinning, drawing and texturing.

Future fibre manufacturing technology must also accommodate mass customization in the market place. Specifically, a system of specialized product variants for small-lot production can provide high value-added products to the consumer. The challenge for the future will be the development of efficient small-scale production technology for such products (Fig. 6).

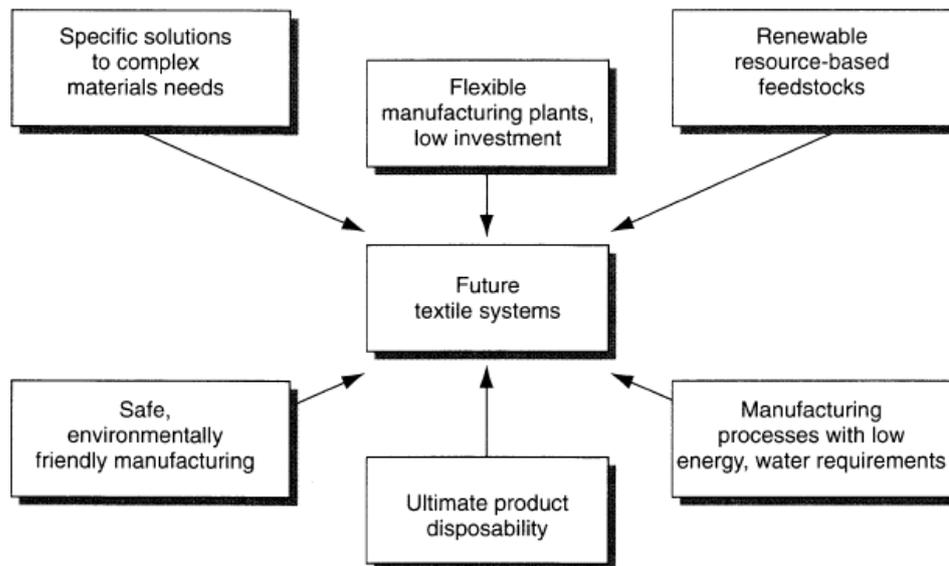


Figure 6. Factors impacting the next generation of textile

BIOTECHNOLOGY

New polymer platforms may emerge from the biological synthesis of polymeric materials, an approach which offers in some cases the precise specification and synthesis of modular building blocks for polymeric materials. The need for architectural specificity and uniform macromolecular structure has never been greater. It is expected that biosynthesis will become increasingly important for traditional chemicals. It is no longer necessary to start with a barrel of oil to produce chemicals but rather crop plants may become attractive feedstock sources. Fermentation can be used to make a fine quality ale, or for that matter synthetic polymers. Comfortable, easy-care apparel may soon be made with fibres derived from feedstock that have been fermented from sugar (Aneja Caldwell and Hietpas 2000).

In that vein DuPont is developing technology that uses genetically altered micro organisms to produce basic chemicals including some that are not readily made from petroleum. Starting with glucose it is possible to produce intermediates that can be used to make nylon and polyester. The process is expected to be less expensive and more environmentally benign than traditional chemical methods. Progress has been faster than expected in this area and if the pilot production is successful, the process could be commercialized in the near future.

With the advent of genetic engineering, it is now possible to create molecules that are difficult to synthesize by traditional methods. For example, the polymer polytrimethylene terephthalate has enhanced properties as compared to traditional

polyester in selected applications. Yet commercialization has been slow because of the high cost of one key intermediate, i.e., 1,3-propanediol (3G) for this novel polyester. Through recombinant DNA technology, DuPont and Genencor have created a single micro organism containing all the enzymes to convert cornstarch into this intermediate. Biotechnology now offers the prospect of a low cost, environmentally sound route to the production of a key feedstock for this new polyester and in quantities approaching these for traditional polyester.

After two decades of research, DuPont is looking to biotechnology to transform a number of DuPont businesses. Today, there are two classes of manmade fibres: regenerated cellulose from wood and cotton, and wholly synthetic fibres made from petrochemical sources. The future may offer new classes of fibres-including synthetic biopolymers derived from green plants, micro organisms or enzymatic processes. Thus, bio processing offers vast and emerging opportunities

Fermentation processes using genetically modified micro organisms will give rise to new routes to polymer intermediates or to directly synthesized polymers. The predominant driving force for this transformation is for products with new and improved properties. These are based on abundant, cost effective and domestically renewable feed stocks, delivering sustainable growth.

As an example, DuPont has been working to create synthetic analogy to silk. By using recombinant DNA and learning exactly how a spider makes its silk, we have created synthetic spider silk as a model for a new generation of fibrous materials. This approach includes the use of advanced computer simulation techniques that integrate all the information available about the structure of the evolutionary materials. Synthetic genes are then designed to encode information-matching aspects of the materials (see fig.7).

These genes can be cloned into an expression host to produce the silk proteins, which can subsequently be dissolved and spun into silk-like fibres. Spider silk is but one example of a sizable family of biopolymers possessing a combination of properties that synthetic materials cannot yet approach. With its unusual elastic properties, learning from silk may impact other existing materials such as Lycra® and nylon.

The new generation of advanced materials from biotechnology research has the potential to transform our lives in ways which can only be imagined.

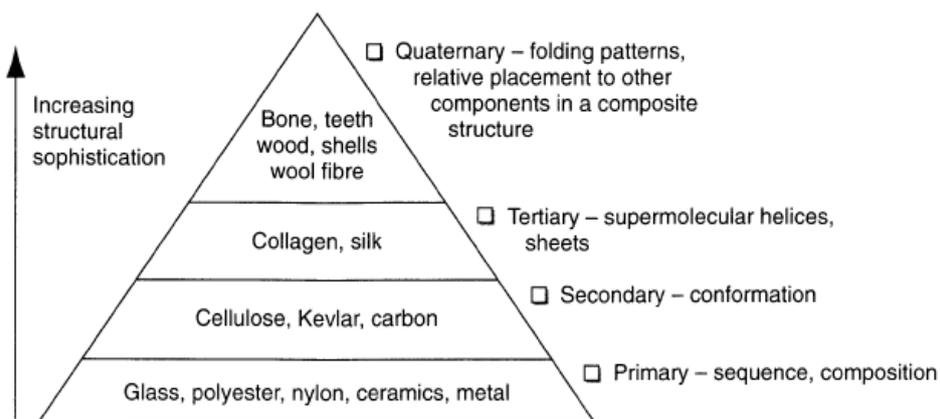


Figure 7. Architectural Hierarchy of Materials

CONCLUSION

The new millennium will demonstrate the seemingly unlimited power of the synergy of diverse disciplines as borders between material sciences; biological science and information science blur and erode. Today the breadth of complementary technologies is far greater. Next generation molecules will be designed, engineered and produced more efficiently from advances in combinatorial chemistry, robotics, nanotechnology, bioinformatics, and high throughput screening. We will continuously seek to express a desired property in a molecule or a material, whatever are the composition and the structure and develop strategies towards building precise molecules with desired properties and functions (O'Brien 1993.). This will finally result in smart textile products with attributes of selectivity, sensitivity, shape ability, self-recovery, self-repair, self-diagnosis, self-tuning and switch ability.

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