INTRODUCTION to NONWOVENS TECHNOLOGY

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To Professor Stanley Backer of MIT (now deceased) who introduced me (SKB) to the subject and inspired me to understand the structure, properties and the technologies that formed the foundation of an emergent industry in the 20th century.

To Professor Malcom Burnip who first taught me (BP) about nonwovens in the early 1970s at Huddersfield Polytechnic. As a teacher and mentor, and aided by a small card and a needle loom, he inspired many students.

To industrial members of the Nonwovens Cooperative Research Center and the Nonwovens Institute at North Carolina State University, as well as affiliated faculty and students, who gave meaning to the interdisciplinary education and research structure needed by the global nonwovens industry.

Introduction to Nonwovens Technology

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FOREWORD

It is a great pleasure to be invited to write a foreword for this comprehensive book on nonwovens by Subhash Batra and Behnam Pourdeyhimi, which follows in the tradition of the first major book on the subject published in 1971 by the Czech scientist, Radko Krcma, whom I first met in Prague in 1961. Although, as the authors, with their welcome appreciation of history, mention in various chapters, some nonwovens date back for centuries or more, the major developments in the field occurred in the second half of the 20th century, a period of tremendous innovation in textile machines, processes and products.

I first became involved in nonwovens towards the end of the 1950s when Professor Ray Peters secured the support of three British manufacturers to fund a research programme on bonded fibre fabrics. This resulted in a series of about 15 papers, which were published in the *Textile Research Journal*. Dr. Peters focused on the chemical aspects of the fibres, while I and my research students, Phil Stevenson and Alan Newton, worked on mechanical properties, both experimentally and theoretically. This work led to industrial applications. Formica Ltd. wanted to develop their decorative and technical laminates to make shaped products. They bought a random-lay machine, impregnated a web, partially cured the resin, and hoped to be able to press-form before the final cure. Typically, an ashtray was the form used in trials. Cracks or wrinkles always appeared in the sample product, and the project was abandoned. Others have faced similar problems. At the Second World Conference on 3D fabrics and their applications, held in South Carolina two years ago, it was fascinating to learn that Behnam Pourdeyhimi had cracked the problem by drawing the fibres in the web instead of trying to pull fibres past one another in a viscous matrix.

The authors are to be congratulated in producing a book that will be equally valuable to undergraduate and graduate students, newcomers to the industry and veterans who wish to take a wider view and discover new opportunities. In comparison with other publications, the present book covers the great diversity of nonwovens and emphasizes how new types of nonwovens can be created through the use of novel fibres. This approach integrates many aspects of fibres and textile structures that are not associated with the conventional forms of nonwovens, which were established over the last fifty years. In this sense the book summarizes existing technical knowledge and suggests ways of going beyond it.

The text opens with a discussion of what nonwovens are. It is unfortunate that the technology has been described by a word with a negative prefix. The German term, *Vliesstoffe*, better defines what we now mean by *nonwovens*, which does not include knits, braids and other products that are not woven and, in another twist, excludes paper, which shares many features with bonded nonwovens. Nonwovens now form a major part of textile technology with many applications for which one type or another will have the right functional properties. However, one challenge remains, to make nonwovens that will fold easily into double curvature, and so compete with woven and knitted fabric in the drape and handle needed for apparel fabrics. One of this book's authors has made progress in this area. In an article published in *Textile World,* Behnam Pourdeyhimi outlines a route to drapeable nonwovens through hydroentanglement of special bi-component fibres. He concludes the article by observing ". . . emerging nonwovens, however, will not be your father's nonwoven, and will be different from nonwovens in use today. The future promises to be interesting and potentially very rewarding." This remark testifies to the vision of the authors of this book, which contains a generous share of their lifelong contributions to the global nonwovens industry.

John W. S. Hearle
Emeritus Professor of Textile Technology,
University of Manchester, England
Mellor, Stockport, UK, May 2011

The textile industry has traditionally been the largest user of fibers. As such, fibers have not been seen as engineering materials. This viewpoint, with rare exceptions, has impeded the use of fibers in engineering applications, where their unique characteristics (surface area/volume ratio, slenderness ratio) can provide enhanced performance at optimal cost. The rare exceptions include fiber reinforced composites, fiber optics, space and aerospace applications. The majority of innovations in these areas have come from communities outside the textile industry.

While the Wright Brothers used tightly woven cotton fabrics as the skin for wings of their prototype planes in the early 1900s, fibers did not gain recognition as engineering materials until the latter half of the 20th century. The credit for this development goes primarily to the birth and growth of the manufactured fiber industry, first in the U.S. and Europe, followed by Japan and other Asian countries. The credit also goes to the parallel growth of the nonwovens industry. Even though the textile industry claims the nonwovens industry as one of its components, much of the nonwovens industry, just as the floor coverings industry, does not subscribe to this point of view.

Today, the medical devices industry, the hygiene industry, the civil engineering and building construction industry, the filtration industry, the automotive industry, to name a few, are making strides unimaginable a mere few decades ago. They have learned to engineer high-value products using the unique characteristics of suitable fibers.

The purpose of the Engineering with Fibers series is to elucidate the role of engineering and material science in the use of fibers as engineering materials.

BEHNAM POURDEYHIMI
MIKE JAFFE
SUBHASH K. BATRA

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We are equally indebted to Professor John Hearle, who so very kindly agreed to write the Foreword to this book.

Finally, we acknowledge the sources for photographs on the cover page (Left to right, top to bottom):

a. spider web-natural nonwoven (public-domain-image.com);
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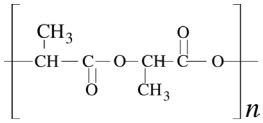
d. winged fiber for ultra high filtration media (NCRC);
e. nonwoven based irrigation (STFI, Chemnitz, DE);
f. nonwoven-based medical protective articles (USP 7013488);
g. needlepunched, molded automotive part (STFI, Chemnitz, DE).



PLA dimer

PLA, a thermoplastic, hydrolytically degradable polymer, a polyester, was first synthesized from petro-chemically produced lactic acid by Carothers in 1932. Subsequent developments[1] (increased molecular weight, copolymerization, among others) led to its use in absorbable sutures and drug delivery systems. As a hydrolytically degradable polymer[2] it gained greater importance when, during the 1980s, a far less expensive method for the commercial-scale production of lactic acid by fermenting D-glucose from corn was developed.

The FTC in the United States defines PLA fibers as: "A manufactured fiber in which the fiber-forming substance is composed of at least 85% by weight of lactic acid ester units derived from naturally occurring sugars."

[1]See http://www.nonwoven.co.uk/reports/CRWINSIGHT%202000.html

[2]Hydrolysed components are biodegradable.

The nonwoven fiberwebs made from PLA fibers are useful in hygiene and medical applications, suitable for tea/coffee bags, agricultural and horticultural use, and as geotextiles. PLA resin is used to make spunbond fiberwebs and bicomponent fibers. Electrospun PLA nanofiberwebs have been recommended for tissue engineering.

16.2.11 Polypropylene

As a resin polypropylene is tailored with different molecular weight distributions, represented by their viscosity measures, for spunbond and meltbown processes. Typically, for spunbond the polymer MFI of 18–35 is found desirable; for meltblown, MFI ~200–2000. As a resin it is also used in producing various bicomponent fibers with PE, PET as discussed in Chapters 12 and 13.

In Europe and the United States, polypropylene fiber has been found to be one of the most versatile for nonwovens.[12] It is commercially available in staple lengths of 3–100 mm and mass linear density of 1–15 dtex. Its density varies between 0.88–0.91 g/cc, making it one of the

[12]http://www.swicofil.com/pp.html#Specialities.

lightest fibers available. It can be opaque, bright, white, or pigmented (solution dyed). Depending on the source, it is also available in different cross-sectional shapes. Its refractive index is 1.49 (when clear), glass transition temperature approximately –20°C, softening temperature about 150°C, and melting temperature in the range of 160–170°C (130–150°C for metallocene fiber). Its thermal conductivity is reported to be 0.76–0.81 (Btu-in/(ft^2*h*°F)), and the coefficient of linear thermal expansion as 4 ×10^{-5} (m/m/°F). Heat of fusion for standard polypropylene fiber is estimated to be about 78 (J/g), whereas that for metallocene PP fiber is 15–20 (J/g)[13], a number that seems questionable.

Nonwovens based on polypropylene—made from staple fibers, meltblown or spunbond—have a very broad range of uses. Principally because of their excellent chemical resistance, in meltblown or needlepunched form, they are used for filtration of water, beer, petrochemicals, pharmaceuticals, coatings. Needlepunched and spunbond fabrics are used in a variety of geotextiles applications where fiber or fabric strength, permeability, chemical and biologic resistance are vital. Strength, lightweight and chemical/biologic resistance of PP spunbonds are utilized in their use as substrate fabric for luggage, wall coverings, tarpaulins, backing for visual fabrics in furniture, table cloths, and automotive applications. Lightweight thermally bonded spunbonds are also used as disposable medical/surgical fabrics (low cost, sterilizability), as agricultural crop covers and weed control fabrics, packaging fabrics, carpet backings, and industrial clothing. Meltblown PP webs are used as oil spill clean-up material (oleophilicity, high surface area/mass ratio, cost), thermal/acoustic insulation, medical devices plus protective packaging, sometimes in conjunction with spunbonds. Needlepunched fabrics are used as indoor/outdoor carpets where they utilize moisture/mildew resistance, UV resistance (with additives) of the fiber.

16.2.12 Rayon

An excellent account of the many different forms of regenerated cellulose fibers developed and commercialized since the late 1800s is given by Woodings,[14] among others. Names of such fibers often were tied to the process technology (and chemistry) used to produce them.

The regular viscose rayon for use in nonwovens can be obtained in fineness 0.9 dtex and higher, in lengths of 30 mm and higher, and in luster from dull to bright. The fibers typically have a density of 1.51 g/cc, which decreases with increasing humidity. Typically the fiber has a

[13] *Handbook of Fiber Chemistry.* Editor: Menachem Lewin, Francis and Taylor 2007.
[14] *Regenerated Cellulose Fibres.* Editor: Calvin Woodings, CRC Press, 2000.

Polyethylene Polyporopylene

As a polymer, polypropylene belongs to the olefin family, which includes polyethylene. Its chemical structure is shown above. It is commercially available as a staple fiber, continuous filament yarn, and as resin. The FTC in the United States defines polypropylene fiber as a long-chain synthetic polymer composed of at least 85% by weight of propylene [http://www.fibersource.com/f-tutor/olefin.htm].

round cross-section with serrated periphery, but other cross-sectional shapes can be available. The clear fiber will show birefringence with refractive indices of 1.52 $\perp$ and 1.542 $\parallel$. As a cellulosic fiber, rayon is hydrophilic/hygroscopic in nature. Its moisture regain at 65% rh is estimated to be of the order of 11–12%. It can imbibe water equal to its own weight, and the water imbibation capacity can be doubled if suitable chemicals (~20%) are blended with the dope before spinning the fiber. Its specific heat under dry conditions is estimated to be 1.26 J/g/°C, which increases at the rate of 0.8J/g/°C for every 1% increase in rh—a consequence of its hygroscopicity.[15] The fiber is stable at temperatures below 150°C, but decomposes at 175–200°C. Its heat of fusion is estimated at 17kJ/g. Without suitable fire-retarding agents blended (~20%) in the dope before fiber spinning, the fiber is flammable (oxygen index 17–19%); a small bead at the end of the burnt fiber end offers evidence of melting.

Under standard conditions of 65% rh and 20°C, the fiber tenacity is on the order of 1.77 cN/dtex, the initial specific modulus on the order of 88.5 cN/dtex, the work of rupture on the order of 0.25 cN/dtex and breaking elongation on the order of 17%. Under wet conditions, the tenacity drops to about 0.8 cN/dtex, the initial specific modulus to 4.42cN/dtex, the work of rupture to 0.19 cN/dtex, but the breaking elongation goes up to about 40%. Its stress-strain curve at standard conditions is bi-linear, with the transition from higher initial modulus to lower subsequent modulus occurring in the neighborhood of 2–3% strain. As a result, its recovery from strains beyond 2% diminishes; measurements of 32% recovery from 5% strain have been reported. On the other hand, its abrasion resistance is rated as good.

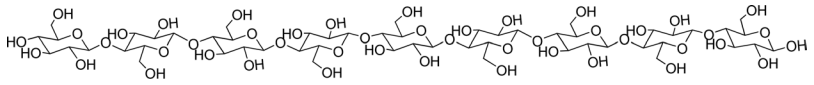
Its resistance to alkalis is rated as good, but to hot dilute acids, con-

[15]Woodings, page 231.

centrated bleach and strong oxidizing agents as poor. Its resistance to biological agents is moderate, and the fiber loses strength under prolonged exposure to sunlight or UV. Electrical properties (conductor or insulator) of the fiber are defined by its measurable capacitance. The capacitance measures of rayon fiber in the frequency range of 0.1–100 kHz in the dry state are reported to be 2.1–2.0, whereas at rh of 65% the values go from 8 to 3.5. Inasmuch as the resistance of the fiber is related to is capacitance, the specific resistivity drops from 10^{13} Ω·m (dry) to 10^{07} Ω·m (90% rh), which accounts for the lack of static charge build-up on the fiber in a humid atmosphere.

Rayon, alone or in blends, is used in nonwovens for hygiene products, medical/surgical applications, food service wipes, consumer and industrial wipes, sausage casings, tea/coffee bags, filter media, and other similar applications.

The Lyocell fiber is available in various lengths with a typical mass linear density of 1.7 dtex. The fiber has a density, typically, of 1.53 g/cc, has very low shrinkage in laundering, and a decomposition temperature of 300–420°C is a good deal higher than that of viscose-based rayon.



9-mer cellulose molecule (Courtesy of Dr. Nozar Sachinwala)

Rayon is the first known manufactured fiber. While early development of the concept of regenerated cellulose occurred in Switzerland and England during the mid-1800s, the first commercial production of the fiber is credited to French chemist Count Hilaire de Chardonnet, in France in the late 1880s. It involved cellulosic material from nature (tree bark, wood), modified chemically to purify it, then regenerated as pure cellulose in fiber form.

The FTC, in the United States, defines rayon as: "A manufactured fiber composed of regenerated cellulose, as well as manufactured fibers composed of regenerated cellulose in which substituents have replaced not more than 15 percent of the hydrogens of the hydroxyl groups."

The terms "regular" and "high tenacity" rayons refer to fibers produced by the viscose process.

In addition, "where the fiber is composed of cellulose precipitated from an organic solution in which no substitution of the hydroxyl groups takes place and no chemical intermediates are formed, the term *lyocell* may be used as a generic description of the fiber."

While it ignites at 420°C, the recommended temperature for continuous operation is below 150°C. The fiber can be engineered to yield tenacities up to 4.4 cN/dtex, with the ability to retain 80% of its tenacity in the wet state. Thus it is stronger than viscose-derived rayon both in the dry and wet states. In the same vein, its initial specific modulus is 113 cN/dtex, versus 88.5 for viscose rayon in the dry state (standard conditions of 65% rh and 20°C) and in the wet state 26.5, versus 4.2 for viscose rayon. Its breaking elongation is about 18%, and its stress-strain curve is concave down (decreasing modulus with increasing strain).

In the dry state it has fair abrasion resistance, which can be improved if blended with nylon, or if a suitable surface finish is applied. But in the wet state, the fiber fibrillates, which can be a boon or a bane. The boon is the possibility of obtaining microfibers, which can be utilized very effectively in fine particle filtration; the bane is the weakness of fibrils, leading to failure of the structure if subjected to abrasive mechanical stresses.

The fiber degrades, hydrolytically, when exposed to hot dilute and strong acids; when exposed to dilute alkali, it first swells and then degrades—maximum degradation at 9% solution of NaOH. Even so, its chemical resistance is said to be better than that of cotton or regular viscose. While it is biodegradable, its resistance to sunlight/UV is better than that of viscose.

Nonwovens containing lyocell, alone or in blends, can be used in absorbent products, comforters, pillows, dust ruffles, dry/wet wipes, medical swabs and dressings, filters, and battery separators.

16.2.13 Elastomeric Resins

Many applications of nonwovens during the past several decades have required rubber-like elastic performance (>100% recoverable stretch). In addition to new or modified technologies, this motivated the search for suitable polymers which can be melt-extruded to yield elastomeric webs.[16] The earliest elastomeric fibers were thermoplastic urethanes (TPU), developed during the 1930s by I. G. Farbenindsutrie (now Bayer A. G.), DuPont and ICI.[17] Since then, a number of other thermoplastic polymers or copolymer elsatomers (TPE), have been developed for engineering applications including fiber melt-extrusion technologies (spunbond, meltblown) and electrospinning. These developments have been well reported in a vast body of literature, including several handbooks.

[16]UK Patent 1,575,830, USP 4,426,420, USP 4,100,324, USP 4,657,802, USP 4,663,220, USP 4,724,184, USP 4,879,170, USP 5,324,576, etc.

[17]Drobny, Jiri George, *Handbook of Thermoplastic Elastomers,* William Andrew Publishing/Plastics Design Library (2007).

Hardness Scales for Elastomers

Albert F. Shore developed the "durometer" test to measure the depth of penetration of a conical indenter into a 6.4 mm-thick sheet of the material. The durometer hardness scale for a specific applied force is 0–100; 0 for a depth of penetration of 2.5 mm or more and 100 for no penetration. An indenter made up of a hardened steel rod (1.1–1.4 mm diameter) with 35° truncated cone (tip diameter 0.79 mm) and with applied force of 8.064N, yields hardness (durometer) values in the Shore A scale. A truncated cone with an angle of 30°, a tip diameter of 0.1 mm with applied force of 44.64 N, yields hardness values in the Shore D. scale.

Generally, TPEs, including TPUs, are block copolymers, in which blocks (or segments) of two or three homopolymers are attached to each other (copolymerized) in a predictable fashion. At least one of the blocks is an amorphous or soft polymer, while at least one of the other blocks is a crystallizing or hard polymer. At room temperature the bulk material separates into two phases: the crystal or hard phase is regularly and uniformly dispersed in a matrix of easily deformable amorphous, soft phase.

Thus,[18] TPEs exhibit recoverable stretch and do not creep under sustained loading at room temperature, but melt and flow when heated to the melting point of the hard segment (always greater than that of the soft segments). Based on their chemistry, they are classified as polyolefin blends, styrenic block copolymers, polymer blends/mixtures, thermoplastic polyurethanes, thermoplastic copolyesters and polyether block amides. Based on the choice of soft and hard blocks, and the process of polymerization, their properties can be tailored over a broad range (different for each class) of hardness values; this makes it difficult to report specific property values. Used by themselves, or in conjunction with conventional polymers, they offer enhanced properties (sometimes unique) to fiberwebs. In particular, good elasticity (a high degree of recovery from a stretch of 50% or more), adequate strength under high elongations, non-stickiness to human skin as well as to each other during storage (even at somewhat elevated temperatures), and low cost.

16.2.13.1 Polyolefin Blends

In considerable detail, USP 6,080,818 describes the formulation of blends of atactic flexible polyolefin polymer of Mw of 100,000 or more,

[18] http://en.wikipedia.org/wiki/Thermoplastic_elastomer.

and a heat of fusion in the range of 15–60 J/g, with isotactic polypropylene—which can be used for various applications, melt-extruded nonwovens among them. The predominance of the flexible component can impart an extension-to-break greater than 300%, while yielding adequate strength, reduced stickiness, improved hysteresis, reduced stress decay, and improved creep properties. In general, the chemistry of the formulation and the specifics of the copolymerization process determine the ultimate product properties.

Similarly, USP 5,324,576 describes the use of cross-linked ethylene/alfa-olefin copolymer to produce elastomeric webs (> 400 % stretch) through a meltblowing process. The cross-linking, and therefore the final properties, are achieved by treating the meltblown web with an electron beam radiation, dosage of 5 megarads or more.

Such polymers are available commercially. The characteristic properties of one manifestation,[19] is shown in Table 16.3. Spunbond and meltblown fabrics made from this polymer show far greater stretch and elastic recovery, as well as lower hysteresis loss, when compared to comparable fabric made from standard PP. Significantly lower crystallinity of these polymers, relative to standard PP, is credited with the recoverable elasticity of the fiber/fabric.

An excellent account of the polymerization and product characteristics of this class of copolymers and their implications for the physical/mechanical properties of fibers made from them is given by Casey *et al.*[20] The handbook edited by Drobney, previously cited, is also a good source of information.

TABLE 16.3. Polyolefin Blend Polymer Characteristics and Property Ranges.

Density (g/cm^3)	0.86–0.89
MI (g/10 min)	0.5–12
MFR	1–25
Mooney Viscosity (ML)	10–30
M_w	150–250 k
M_w/M_n	~ 2.0
T_g (°C)	–10 to –35
T_m (°C)	40–160
Hardness (Shore A)	50–90
Tensile Str. (psi)	1,200–3,500
Elongation (%)	100–1,500
Elastic Recovery	80–97%

Source: www.exxonmobilchemical.com/Public.../Elastic_Nonwoven_Fabrics.pdf.

[19]www.exxonmobilchemical.com/Public.../Elastic_Nonwoven_Fabrics.pdf.

[20]Paul Casey *et al.,* "Polyolefin Based Crosslinked Elastic Fiber: A Technical Review of DOW XLA™ Elastic Fiber Technology," *Polymer Reviews,* 48(2): 302–316.

16.2.13.2 Styrenic Block Polymers

Styrenic block copolymers: consist typically[21] of styrene (or a derivative) as one block and conjugate diene (such as 1,3-butadiene, isoprene, 1,3-pentadiene) as the other blocks, the latter contributing 80% or more of the double bonds. Specific examples include styrene-ethylenebutylene-styrene (SEBS), styrene-ethylenepropylene-styrene (SEPS), and styrene-ethylenebutylene-olefin block copolymers, which are all commercially available. The properties of one manifestation, SEBS, are shown in Table 16.4. Styrenic copolymers resist UV and sterilization radiation. SEBS can withstand high processing temperatures.

Styrenic block copolymers are commercially available for melt-blown applications. More often than not, they are blended with other polymers, including elastomers, fillers, plasticizers (oils), processing aids, colorants. The end products can range in hardness values from 5 Shore A to 55 Shore D, with corresponding variation in other properties.

Block copolymer poly(styrene-b-dimethylsiloxane) fibers with submicron diameters (150–400 nm) have been produced by electrospinning. Contact angle measurements indicate that the nonwoven fibrous mats are superhydrophobic.[22]

16.2.13.3 Polymer Blends/Mixtures

A United States patent application (20090143536) describes in detail blends or mixtures of two types of polypropylenes which yield elastomeric webs via the spunbond process. The blend is defined as a homogenous "solid solution," whereas a mixture is heterogenous. In either case, additives may be used to yield enhanced functional properties.

TABLE 16.4. Typical Properties of SEBS Copolymer.

Hardness	65 Shore A
300% Modulus	935 psi
Tensile strength	> 5000 psi
Elong. at break	660 %
MI 260°C, 5kg	7g/10min.
Polystyrene cont.	42%

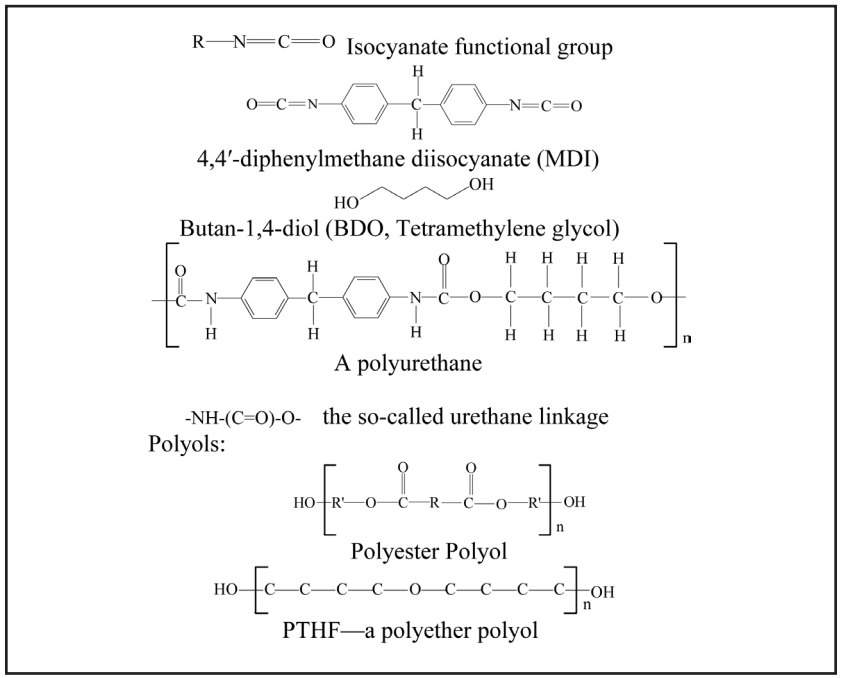
[21]USP 7,700,504.

[22]Minglin Ma et al., "Electrospun Poly(Styrene-*block*-dimethylsiloxane) Block Copolymer Fibers Exhibiting Superhydrophobicity," *Langmuir,* 2005, 21 (12), pp 5549–5554, DOI: 10.1021/la047064y.

16.2.13.4 Thermoplastic Polyurethanes

Thermoplastic polyurethanes represent a broad class of copolymers developed since the 1930s. First, a polyurethane (PUR, PU) is any polymer consisting of a chain of organic units joined by urethane links.[23] The side bar illustrates the formation of a polyurethane, with the characteristic urethane linkage, synthesized from a diisocyanate and a glycol. The glycol component in this case is called the chain extender. In a thermoplastic copolymer, units of a monomer (dimer, trimers, . . .) constitute the hard segments, which are polymerized with polyols (polyether or polyester based diols), which constitute the soft segment.

The sequencing and the proportionality of the soft and hard segments determines the processability of the resin and the properties of the resulting fibers. When fully cured, the soft and hard segments segregate to yield the two phase morphology. The hard segment aggregates apparently are arranged periodically and uniformly in a matrix of soft material—an arrangement that results in elastomeric performance of the fibers, and therefore the fabric. At high enough temperatures the two-phase morphology is destroyed and the polymer melts into a viscous, homogeneous fluid.



[23]http://en.wikipedia.org/wiki/Polyurethane.

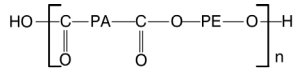
During melt-extrusion of TPU resin, a broad range of additives are used to enhance the final product performance in regard to UV and flame resistance, surface and anti-blocking characteristics, thermal stability, and color.

In general, the hardness of TPU can range between 50 Shore A to 75 Shore D, its Young modulus can from < 10 to >1000 MPa. In addition, the polymer has excellent abrasion resistance, high tear strength, excellent compressive characteristics (high strength, low set), excellent low temperature characteristics (flexibility, impact resistance), and good resistance to fuels and oils.

16.2.13.5 Polyether Block Amide (PEBA)

The chemistry, properties and development history of PEBA has been described well.[24] It is a block copolymer in which blocks of polyether (Pe) are linked to polyamide (PA) groups by an ester linkage. The PA blocks can be PA 6, 66, 11 or 12. The PE blocks can be poly(ethylene oxide) (PEO), poly(propylene oxide) (PPO), or poly(tetramethylene oxide) (PTMO). Based on the polymer block structure, the polymer can be tailored for a range of properties (see Table 16.5). In addition, PA 6, PA 66, and PEO blocks add hydrophilicity, whereas the others add hydrophobicity. These polymers have very high impact resistance (even at

TABLE 16.5. Structure & Physical Properties of Polyether Block Amide (PEBA).



Melting Point (°C)	134–174
Density (g/cc)	1
Water absorption at equilibrium (%) (23 °C, 50% RH)	0.4–0.7
Water absorption at saturation (%) (23 °C, 24H in water)	0.9–1.2
Shore Hardness (D)	25–72
Flexural modulus (MPa)	12–513
Tensile str. at break (MPa)	32–56
Elongation at break (%)	300–750
Impact resistance (Charpy, notched) (kJ/m^2)	No break
Abrasion resistance (10 N/40 m) (mm^3)	55–130
Surface resistivity (Ω)	109–1013
Volume resistivity (Ω·cm)	109–1013

Source: Wikipedia. For more detailed properties, see cited reference (Fakirov).

[24]Handbook of Condensation Thermoplastic Elastomers, Ed: Stoyko Fakirov, Wiley-VCH (2005).

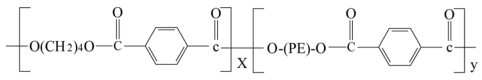
very low temperatures), as well as high tear, flex and fatigue resistance. The hydrophilic polymers using polyethylene glycol (ether) are permeable to moisture, O_2, N_2, CO_2, C_2H_4 even as they are water-proof.

Finally, PEBA is a member of the polyamide based thermoplastic elastomers, which also include polyesteramides (PEAs), polyetheresteramides (PEEAs), polycarbonateesteramides (PCEAs).

16.2.13.6 Thermoplastic Copolyesters (COPE)

COPE are a class of multi-block copolymers, described as copolyether esters with alternating, random-length sequences of oxyalkalene glycols connected by ester linkages. They contain hard blocks (for example, multiple short-chain ester units such as tetramethylene terephtalate, crystallizable) that melt at relatively high temperatures, and soft blocks (derived from aliphatic polyether and polyester glycols) that have very low glass transition temperatures. Such polymers have been available since the 1970s.

Example of a COPE structure



Hard segment Soft segment

The technology and properties of the fabrics produced using copolyester elastomers is described in several patents, USP 4,741,949 among them. The COPE polymers are reported to perform well over a wide range of temperatures (–40°C to 120°C), and offer good impact, flex, and tear resistance. They "also offer excellent chemical resistance to common solvents, fuels, oils and greases, dilute acids and bases."[25]

16.3 PROBLEMS/EXERCISES

1. Tabulate the tenacity (both dry and wet) of fibers discussed in this chapter. What role does fiber tenacity play in the properties of the nonwoven fabric?

2. Tabulate hydrophobic and hydrophilic fibers discussed in this chapter. List potential applications that exploit these characteristics.

[25]tools.ticona.com/tools/documents/.../RiteflexBrochure_en_rev.pdf.

3. Rank hydrophilic fibers by increasing values of moisture regain and water absorptive capacity.

4. Rank fibers discussed in this chapter by their melting point.

5. Caclulate the number of square meters of fabric per kg of polymer made by using PP, PET and PA6, if the fabric weighs 100 g/m^2.

6. When fabrics are shipped in containers, they tend to absorb moisture. Assuming that the fabrics were completely dry when packaged into 1,000 kg containers, discuss the final weight of the package for PP, PA6, cotton and rayon when the package is delivered at the dock.

7. Discuss how elastomers can be used to develop "stretchy" nonwovens.

8. The adhesive bandages developed and marketed by 3M are based on elastomers. Can you discuss which elastomers would be suitable for such applications and the type of process used?

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