Appendix I

Units

AI.1 Introduction

In most of physics and engineering, size and shape are specified by linear measures as three-dimensional solids, with mass (weight) added when necessary. Textiles are a mixture of solid fibres and space between and are mostly one-dimensional yarns and cords or two-dimensional fabrics. Thickness and volume depend on the methods of measurement and are ill-defined. Mass-based measures, linear or areal density, are more useful. Even for fibres, although area of cross-section and, for simple shapes, thickness, are well defined, linear density is much easier to measure.

AI.2 Fineness

The preferred unit of linear density is *tex* = g/km, which was introduced in the 1950s. The strict SI unit is kg/m = megatex, Mtex, but this is too large a unit, except for ropes. Historically, microgram/inch has been used for cotton. The silk industry used *denier* = gram per 9000 m and this was adopted in the early days of manufactured fibres. Because the numbers are close to those in denier, *decitex*, dtex = gram per 10 000 m is now widely used.

AI.3 Stress and specific stress

Unfortunately tensions and other applied forces can be normalised in a great many ways. Many different units are found in the older literature and several appear in current publications.

There is a primary distinction:

- Conventional stress, force per unit area, is normal in physics and engineering and is commonly used by researchers from an engineering or materials science background. The strict SI unit is Pa = N/m^2. GPa and MPa are convenient sizes.
- Specific stress, force per unit linear density, is more useful for fibres and is the usual mode in the textile community. The strict SI unit is N/(kg/m). N/tex and m N/tex are convenient sizes.

Numerical values of the two quantities are related by a relation, specific stress =

stress/density, which is valid without numerical factors in strict SI units, N m/kg, Pa, kg/m^3, or in the combination of N/tex, GPa, g/cm^3.

However, in both categories, many other units are found for the following reasons:

- Equivalence of quantities. Specific stress = energy per unit mass, e.g. kJ/g. Specific modulus = (wave velocity)^2, e.g. (km/s)^2. Tenacity is equivalent to breaking length (length failing under its own weight), e.g. km or strictly kmf (kilometer-force).
- Unit system. The SI system is based on metre-kilogram-second (MKS). The older CGS (centimetre-gram-second) includes dyne for force. There are former British Imperial units, which are still widely used in the United States.
- Inertial (unit mass × unit acceleration), e.g. newton, or gravitational. (unit mass × acceleration due to gravity), e.g. gram-force, gf, also called gram-weight, g wt.
- Unit of fineness, e.g. tex or denier.
- Heat units for energy, e.g. cal/g.
- Multiples and sub-multiples.
- Modes of expression, e.g. N/mm^2 or MPa.
- Abbreviations.

Table A1.1 lists units with conversion factors. It is convenient to note that nylon and polyester fibres can have strengths up to near 1 N/tex. Polymer fibres have densities between 1 and 1.5 g/cm^3, so that values in GPa are up to 33% lower than in N/tex.

Table AI.1 Unit conversions for stress and specific stress

Specific stress			Stress: density in g/cm^3 times		
1	–	N/tex, kJ/g, GPa/g cm^{-3}, (km/s)^2	1	–	GPa, J/mm^3
	–	10 c N/dtex, 10.2 gf/dtex, 11.3 gf/den		–	
	–	102 gf/tex, kmf, kg mm^{-2}/g cm^{-3}		–	102 kg/mm^2 145 ksi
		239 cal/g, 430 BTU/lb			
10^3	–	mN/tex, J/g, MPa/g cm^{-3}	10^3	–	MPa, N/mm^2
	–			–	10^4 bar, 9869 atm
	–	145 000 psi/g cm^{-3}		–	145 000 psi
					(psi = lbf/in^2)
*10^6	–	N/kg m^{-1}, J/kg, Pa/kg m^{-3}	10^6	–	7.5 × 10^6 mm Hg
	–	3.94 × 10^6 inchf, psi/(lb/cu in)	*10^9	–	Pa, N/m^2, J/m^3,
10^9	–				kg m^{-1} s^{-1}
	–	10^{10} dyn/g cm^{-1}, erg/g		–	10^{10} dyn/cm^2

*Strict SI units.
Other multiples are also used.
Gravitational units, written above as gf etc. are also found in forms such as: g, e.g. g/den, gm, or g wt; lb or lb wt; km, km wt or Rkm.

Appendix II
Fibre names

AII.1 Introduction

Apart from the oddity that flax becomes linen when made into yarns and fabrics, there is no uncertainty in assigning names to natural fibres. With manufactured fibres there are problems. Much of the early literature on the first generation of regenerated and synthetic fibres identifies them by trade names that may no longer be current. For the newer fibres, trade names are more easily recognised by many people. The alternatives are various chemical names, generic fibre names, abbreviations, etc. In this book, all the above forms are used, depending on what is most likely to be informative.

The account below, which includes names mentioned in the text, is simplified. For formal definitions, see Denton and Daniels [1]. Types that are no longer made are included in braces { }. ISO generic names and codes are underlined. The term 'manufactured fibres' is now preferred to 'man-made fibres'.

AII.2 Regenerated fibres

- **Rayon** The US generic definition covers manufactured fibres of regenerated cellulose or with less than 15% of substitutions for —OH groups. Viscose CV (cellulose xanthate route), modal CMD (high-wet-modulus viscose), cupro CUP (cuprammonium route), lyocell CLY (organic solvent route). At one time and in some countries, rayon included all manufactured cellulosic fibres, including acetate fibres. *Polynosic* was another name for a modal fibre. Trade names include *Fibro* (Courtaulds staple viscose fibre), *Tenasco* (Courtaulds high-tenacity viscose), {*Durafil*} (high-tenacity staple fibre), {*Fortisan*} (high strength, regenerated from acetste), *Tencel* (lyocell).
- **Acetate** Acetate fibre CA, cellulose ethanoate (acetate), <92% and >74% of —OH groups acetylated. Also known as *secondary acetate*; *Dicel* was a trade name. If >92%, triacetate CTA; *Tricel* was a trade name; in the United States included in acetate.
- **Alginate** Alginate ALG, fibres of metallic salts of alginic acid.
- **Regenerated proteins** {*Lanital, Fibrolane*} (milk casein), {*Ardil*} (groundnut protein), {*Vicara*} (corn zein protein).

AII.3 Synthetic fibres of linear macromolecules

- **Nylon** (introduced by Du Pont, but not a trade name) Polyamide PA, nylon, >85% amide groups attached to aliphatic groups. *Nylon* is generic in the United States. Different nylons are named by numbers of carbon atoms in repeat units. e.g, nylon 6 for $[\text{—}(CH_2)_5 \cdot CO \cdot NH\text{—}]_n$ and nylon 66 for $[\text{—}CO \cdot NH \cdot (CH_2)_6 \cdot NH \cdot CO \cdot (CH_2)_4\text{—}]_n$. Also see **Aramid**.
- **Polyester** Polyester PES, with >85% of an ester of a diol and benzene-1,4-dicarboxylic acid (terephthalic acid). The trade names *Terylene* (ICI) and *Dacron* (Du Pont) were often used in the earlier scientific literature. Common usage is polyethylene terephthalate, PET or 2GT. In the United States, and in this book, polyester is more widely used and includes: *polybutylene terephthalate*, poly-trimethylene-terephthalate, PBT or 3GT; *polyethylene naphthalate*, PEN. Note that the chemical definition of *polyester* is much broader. *Polyester resins* are cross linked polymers used in reinforced plastics.
- **Polyolefin** Polypropylene PP, isotactic $[\text{—}CH_2 \cdot CH(CH_3)\text{—}]_n$. Polyethylene PE, $[\text{—}CH_2\text{—}]_n$, see also **HMPE**.
- **Acrylic** Acrylic PAN, with >85% of cyanethene (acrylonitrile) groups. Polacryonitrile PAN is also used. Modacrylic MAC, with >35%, <85% acrylonitrile.
- **Vinyl and vinylidene** Includes: chlorofibre CLF, with >50% of chloroethene (vinyl chloride) PVC or 1,1-dichloroethene (vinylidene chloride) PVDC, >65% if rest of chain is acrylonitrile, *Vinyon* is US generic for PVC fibre; vinylal PVAL, polyethenol (polyvinyl alcohol) with differing levels of acetylation, *vinal* is US generic.
- **Fluoro** Fluorofibre PTFE, usually polytetrafluorethylene, but also other aliphatic fluorocarbons.
- **Elastomeric fibres** Elastane EL, with >85% segmented polyurethane. US generic is *spandex. Lycra* is a trade name. Elastodiene ED, natural (rubber) or synthetic polyisoprene and other diene–vinyl copolymers.
- **Thermally, chemically resistant** A number of thermally and/or chemically resitant fibres are referred to in the text.

AII.4 High-modulus, high-tenacity (HM–HT) linear polymer fibres

- **Aramid** Aramid AR with >85% amide groups attached to two aromatic groups (50% imide groups may be substituted). *Para-aramids* have benzene rings joined in opposite 1,4 positions; trade names include *Kevlar* and *Twaron. Technora* is an aramid copolymer. Meta-aramids have benzene rings joined in next nearest 1,3 positions; *Nomex* is a trade name.
- **Aromatic polyesters** *Vectran* (trade name) is a fully aromatic co-polyester fibre produced by a melt-spinning route. This type may be referred to as *liquid crystal polymer (LCP) fibres* though many other types are made by a liquid crystal route), *thermotropic liquid crystal polymer (TLCP) fibres* or *liquid crystal aromatic polyester (LCAP) fibres*.

- **PBO** *Polybenzoxazole*, poly(*p*-phenylene benzibisoxazole, fibres are commonly referred to as PBO. *Zylon* is a trade name.
- **M5** *M5* is the development name for a poly(2,6-dimidazo[4,5-b:4′,5′-e]pyridinylene-1,4-(2,5-dihydroxy)phenylene} PIPD fibre.
- **HMPE** High-modulus polyethylene, HMPE or HPPE, gel-spun, highly oriented, high molecular weight polyethylene. *Spectra* and *Dyneema* are trade names.

AII.5 Carbon fibres

- **Carbon** Carbon CF, >90% carbon by controlled pyrolysis. Fully carbonised and processed at high temperature are often referred to as graphite fibres. Also thermally resistant, partially carbonised fibres.

AII.6 Inorganic fibres

- **Glass** *Glass GF*.
- **Ceramic** Various ceramic fibres are referred to in the text.

AII.7 Reference

1. M. J. Denton and P. N. Daniels. *Textile Terms and Definitions*, 11th edition, Textile Institute, Manchester, 2002.

Appendix III

Standard test methods

The following is a selection of some relevant test methods for the study of the physical properties of fibres, particularly the dimensional and other properties that determine the assessment of fibre quality.

ISO and British Standard	ASTM	IWTO Standard (*Italics* for drafts)
COTTON HVI TESTING		
	ASTM D5867-05 Standard test methods for measurement of physical properties of cotton fibers by high volume instruments	
Sampling procedures		
ISO 1130:1975 Textile fibres – Some methods of sampling for testing BS EN 12751:1999 Textiles. Sampling of fibres, yarns and fabrics for testing		IWTO 7 Sub-sampling staples from grab Samples IWTO 38 Method of grab sampling greasy wool from bales
Fibre fineness		
ISO 2403:1972 Textiles – Cotton fibres – Determination of micronaire value	ASTM D1448-05 Standard test method for Micronaire reading of cotton fibers	IWTO 6 Method of test for the determination of the mean fibre diameter of wool fibres in combed sliver using the airflow apparatus
ISO 1136:1976 Wool – Determination of mean diameter of fibres – Air permeability method	ASTM D1282-05 Standard test method for resistance to airflow as an indication of average fiber diameter of wool top, card sliver, and scoured wool	IWTO 8 Method of determining fibre diameter distribution parameters and percentage medullated fibres in wool and other animal fibres by the projection microscope
ISO 137:1975 Wool – Determination of fibre diameter – Projection microscope method	ASTM D5867-05 Standard test methods for measurement of physical properties of cotton fibers by high volume instruments	IWTO 12 Measurement of mean & distribution of fibre diameter using the Sirolan-Laserscan fibre diameter analyser

ISO and British Standard	ASTM	IWTO Standard (*Italics* for drafts)
BS EN ISO 10306:1995 Textiles. Cotton fibres. Evaluation of maturity by the air flow method	ASTM D1282-05 Standard test method for resistance to airflow as an indication of average fiber diameter of wool top, card sliver, and scoured wool	IWTO 28 Determination by the airflow method of the mean fibre diameter of core samples of raw wool
BS 3085:1981, ISO 4912:1981 Method for evaluation of the maturity of cotton fibres (microscopic method)	ASTM D7025-04ae1 Standard test method for assessing clean flax fiber fineness	IWTO 47 Measurement of the mean & distribution of fibre diameter of wool using an Optical Fibre Diameter Analyser (OFDA)
BS 3181:1968 Method for the determination of cotton fibre fineness by the airflow method	ASTM D1577-07 Standard test methods for linear density of textile fibers	*IWTO DTM 62 Determination of fibre length, length distribution, mean fibre diameter and fibre diameter distribution of wool top and slivers by OFDA4000*
BS 2016:1973 Methods for the determination of the linear density of textile fibres: gravimetric methods	ASTM D1442-06 Standard test method for maturity of cotton fibers (sodium hydroxide swelling and polarized light procedures)	
Fibre length		
ISO 4913:1981 Textiles – Cotton fibres – Determination of length (span length) and uniformity index	ASTM D5867-05 Standard test methods for measurement of physical properties of cotton fibers by high volume instruments	*IWTO DTM 1 Method of determining barbe & hauteur of wool fibres using a comb sorter*
BS ISO 6989:1981 Textiles fibres. Determination of length and length distribution of staple fibres (by measurement of single fibres)	ASTM D1234-85(2001) Standard test method of sampling and testing staple length of grease wool	*IWTO DTM 5 Method of determining wool fibre length distribution of fibres from yarn or fabric using a single length measuring machine*
BS 6176:1981, ISO 6989-1981 Method for determination of length and length distribution of staple fibres by measurement of single fibres	ASTM D1440-07 Standard test method for length and length distribution of cotton fibers (array method)	*IWTO DTM 16 Method of test for wool fibre length using a WIRA fibre diagram machine*
BS 5182:1975, ISO 2646-1974 Method for the measurement of the length of wool fibres processed on the worsted system, using a fibre diagram machine.	ASTM D1575-90 (2001) Standard test method for fiber length of wool in scoured wool and in card sliver	IWTO 17 Determination of fibre length and distribution parameters

BS 4044:1989 Methods for determination of fibre length by comb sorter diagram	ASTM D5103-07 Standard test method for length and length distribution of manufactured staple fibers (single-fiber test)	IWTO 30 Determination of staple length and staple strength
	ASTM D519-04 Standard test method for length of fiber in wool top	*IWTO DTM 62 Determination of fibre length, length distribution, mean fibre diameter and fibre diameter distribution of wool top and slivers by OFDA4000*
Moisture absorption		
BS 4784-1:1988, ISO 6741-1:1987 Methods for determination of commercial mass of consignments of textiles. Mass determination and calculations	ASTM D1576-90 (2001) Standard test method for moisture in wool by oven-drying	IWTO 33 Method for the determination of oven-dry mass, calculated invoice mass & calculated merchandisable mass of scoured or carbonised wool
BS 1051:1992, ISO 6348:1980 Glossary of terms relating to the mass determination of textiles	ASTM D2495-07 Standard test method for moisture in cotton by oven-drying	IWTO 34 Determination of the oven-dry mass, calculated invoice mass & calculated merchandisable mass of wool tops
		IWTO 41 Determination of the invoice mass of scoured or carbonised wool tops or noils by the capacitance method
Tensile testing		
ISO 3060:1974 Textiles – Cotton fibres – Determination of breaking tenacity of flat bundles	ASTM D5867-05 Standard test methods for measurement of physical properties of cotton fibers by high volume instruments	IWTO 30 Determination of staple length and staple strength
BS EN ISO 5079:1996 Textiles. Fibres. Determination of breaking force and elongation at break of individual fibres	ASTM D2524-95 (2003) Standard test method for breaking tenacity of wool fibers, flat bundle method – 1/8-in. (3.2-mm) Gage Length	IWTO 32 Determination of the bundle strength of wool fibres
BS 4029:1978 Method of test for the determination of tensile elastic recovery of single fibres and filaments (constant-rate-of-extension machines)	ASTM D2653-07 Standard test method for tensile properties of elastomeric yarns (CRE type tensile testing machines)	
BS 3411:1971 Method for the determination of the tensile	ASTM D3217-07 Standard test methods for breaking tenacity of	

ISO and British Standard	ASTM	IWTO Standard (*Italics* for drafts)
properties of individual textile fibres	manufactured textile fibers in loop or knot configurations	
BS 5116:1974 Method of test for determination of breaking tenacity of flat bundles of cotton fibres	ASTM D3822-07 Standard test method for tensile properties of single textile fibers ASTM D1294-05 Standard test method for tensile strength and breaking tenacity of wool fiber bundles 1-in. (25.4-mm) gage length ASTM D1445-05 Standard test method for breaking strength and elongation of cotton fibers (flat bundle method)	