CHAPTER 2

BRIGHT FIELD MICROSCOPY

2.1 INTRODUCTORY SECTION About fibre morphology

The morphology of a fibre is the sum of all its characteristics when viewed under bright field microscopy. For natural fibres, the characteristics are somewhat limited because the morphology within a subgroup of naturally occurring fibres is not that variable.

Man-made fibres, however, can be engineered to obtain favourable properties. Therefore, man-made fibres can present a wide variety of morphological characteristics. Examples of these characteristics include fibre colour, the presence, amount and distribution of delustrants, the type of dyestuffs (dyes or pigments), the cross-sectional shape, the diameter, the form of the fibre extremities, and many more. Some of these traits can either be linked to the production process or the dyeing/finishing process. Other traits are acquired during the lifetime of the textile material. For instance, after prolonged exposure to sunlight, dye components with low light fastness can degrade, which results in fading. If a textile material was exposed to a heat source, the endings of man-made fibres at the surface could melt, creating a particular morphology.

All these traits describe a morphological fibre type. The morphology of fibres can best be examined with an optical microscope at high magnifications. In the examination of textile fibres, a magnification of 400x is usually sufficient to obtain an optical resolution high enough to observe the finest internal details.

µm, the depth of field about 1.8 µm and the field of view 0.55 mm or 550 µm. When changing to a 63x/NA 0.75 objective, the total magnification is 630x. The resolving power is now 0.45 µm, the depth of field about 1.2 µm and the field of view 350 µm. The visual field brightness is reduced by about 2. When changing from the 40x objective to a 20x/NA 0.50 objective, the visual field brightness doubles in strength.

2.3 INSTRUMENTAL ASPECTS

2.3.1 Objectives

The optimal magnification for observing the internal characteristics of textile fibres is 400x. This means that for an eyepiece magnification of 10x, an objective of 40x should be used. The numerical aperture should be in the range of 0.65 to 0.75 because it makes observation easier when a larger slice of the fibre is in focus at any one time. Additional objectives can include 5x, 10x, 20x and 63x. **[Fig. 2-3]**

Modern objectives are infinity corrected (UIS, Universal Infinity corrected optical System), which is the ISO standard. This means that several optical elements (such as filters and compensators) can be inserted in the path between the objective and tube lens. High-quality objectives are corrected for most aberrations a lens system may experience, such as spherical aberration, flatness of field and chromatic aberrations. By turning the objective revolver, one changes from one objective to another. As modern objectives are adjusted to reach parfocality, the focus should only be slightly adapted when changing between objectives.

A correct choice of objectives should be based on the microscopy application. If quantitative polarization microscopy is used, stress-free POL objectives that can be centred are indispensable (see next chapter). If fluorescence microscopy is going to be used, FLUO objectives are needed (see chapter 4).

Fig. 2-3 A series of microscope objectives.

wheels of a microscope, the sample stage moves. In **[Fig. 2-7]**, a visual mnemonic for focusing with the microscope is shown.

When turning the right focussing wheels counter-clockwise, i.e. a rotation towards the observer, the stage goes down. This brings the objective further away from the sample. In other words, the working distance is increased. While the objective focal distance is always a fixed distance, the light is now focussed on the upper part of the sample.

On the other hand, when turning the right focussing wheels clockwise, i.e. a rotation away from the observer, the stage is raised. This brings the objective closer to the sample. The working distance is reduced, and the focus is now on the lower part of the sample.

Fig. 2-7 A visual aid for focusing.

> ☞ *Remember the simple rule:*
> *Stage down brings the focus up. Stage up brings the focus down.*

The main classes of synthetic fibres encountered in casework are:

- acrylics (PAN, the abbreviation for polyacrylonitrile) and modacrylics (MAC)
- polyesters (PES)
- polyamides (PA) or nylons
- aramid fibres (aromatic polyamides, such as Kevlar and Nomex)
- polyolefins: polyethylene or polyethene (PE) and polypropylene (PP)

The principal classes of regenerated fibres include:

- regenerated cellulose: viscose (called rayon in the USA), cupro, modal or high tenacity (HT) viscose and Lyocell
- cellulose esters: diacetate and triacetate
- regenerated proteins, also called azlons

2.5.2 Manufacturing

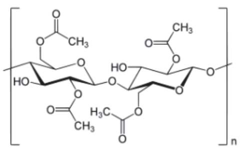
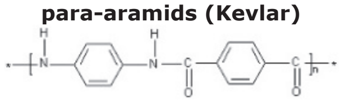
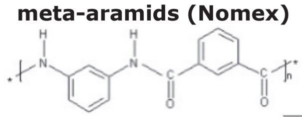
Man-made fibres are produced from a bulk polymer - the spin dope - by one of the following spinning processes, illustrated in **[Fig. 2-12]** :

- **Melt spinning**: a fused thermoplastic polymer is forced through the spinneret holes and forms filaments that harden in a cool air stream.
- **Dry-spinning**: a polymer is dissolved in a suitable organic solvent and is drawn through the spinneret holes as filaments that harden in a hot gas stream.
- **Wet-spinning**: a polymer is dissolved (in an aqueous solution or organic solvent), and, after leaving the spinneret, the filaments coagulate in a bath in which the solvent is regenerated.

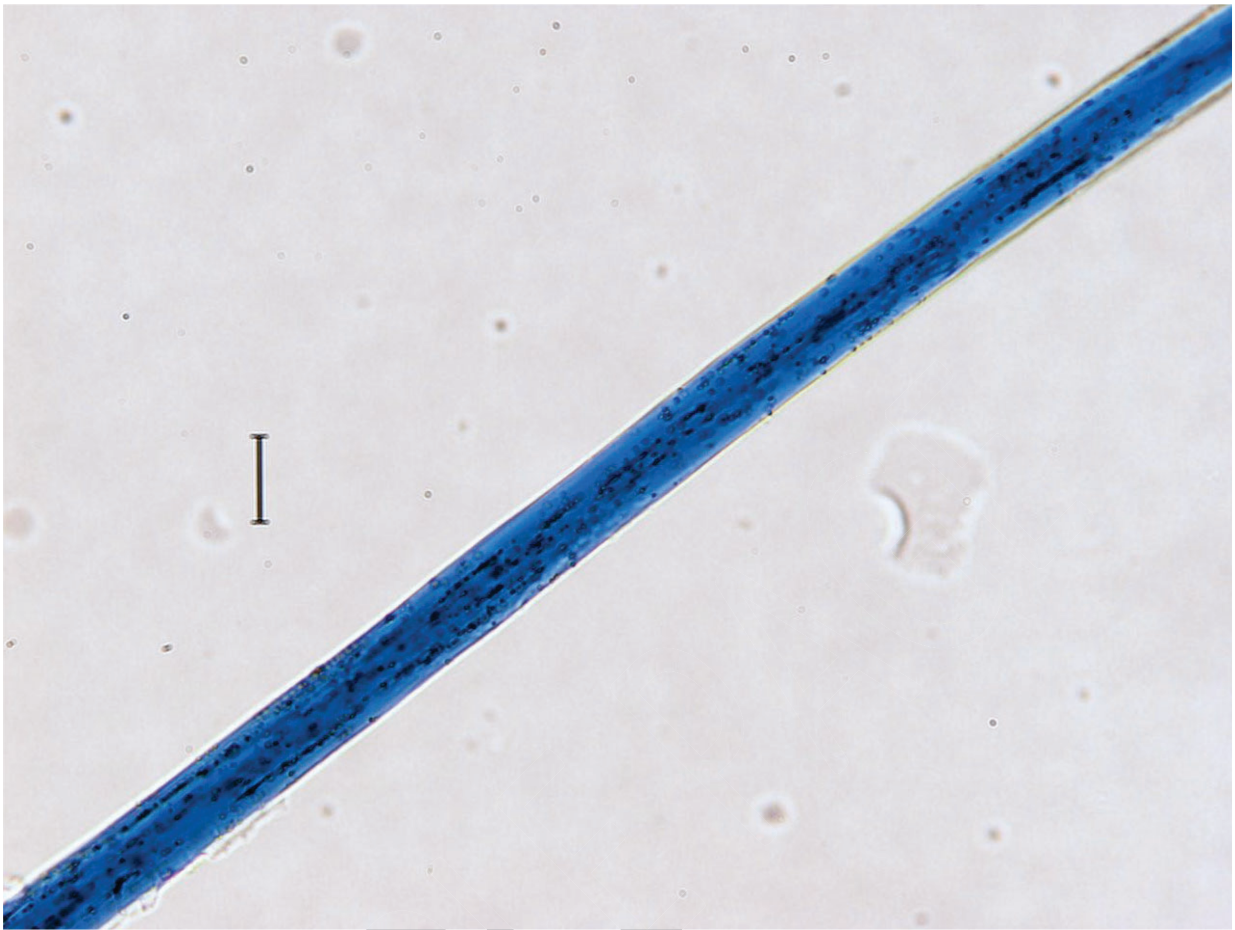
After leaving the spinning cabinet, the dry-spun filaments are washed. Furthermore, dry-spun and melt spun filaments are stretched, lubricated, texturized, wound up as filament tow or divided into smaller staple fibres by cutting or cracking.

After leaving the regeneration bath, the wet-spun filaments are washed, stretched, lubricated, dried, crimped and finally wound up as filament tow or divided into staple fibres by cutting or cracking.

The main generic fibre classes obtained by melt spinning are polyesters, polyamides and polyolefins. Dry-spinning is often applied in the production of acrylics and acetates. The main generic classes obtained by wet-spinning are cellulosic fibres and acrylics.

Modal Regenerated cellulose	as viscose, but less chain degradation; wet-spun	★ improved strength over viscose ★ silky handle Blending: as staple mixed with cotton, flax, wool, viscose, acrylics; CR: 40-50%, DP: 600–800	Garments (Wo, Kn, Un)
Cupro Regenerated cellulose	wood pulp matured in caustic soda, cuoxame formation (cuprammonium process); wet-spun	★ improved dye uptake (more porous) ★ silky handle and drape	High-quality garments Seat coverings
Lyocell Regenerated cellulose	wood pulp dissolved in NMMO solvent; wet-spun	★ excellent handle and feel (enzymatic fibrillation) ★ improved strength over viscose	Garments (soft peach-skin fabrics)
Acetates  Esterified cellulose	wood pulp in acetic acid (acetylation of cellulose); dry-spun	★ silky handle and drape ★ thermoplastic (texturizing by heat setting) ★ good dye uptake DP: 250	Garments (Wo, Li, neckties)
para-aramids (Kevlar) 	polycondensation; wet or gel spun	★ excellent tensile strength (good mechanical properties) ★ good heat resistance	Technical garments: bullet-proof jackets, cut-resistant gloves, sports Technical: high resistant tires Aviation/space travel Composites
meta-aramids (Nomex) 	polycondensation; dry or gel spun	★ excellent flame resistance ★ high chemical resistance	Technical garments: firefighter jackets industrial applications
Elastane (EL) **(segmented polyurethane)** >85% urethane bonds	(poly)glycol and diisocyanate monomer (prepolymer) followed by chain extension with diamine; dry or wet-spun	★ high elasticity (elastomeric fibres) ★ thermoplastic ★ hydrophobic ★ difficult dyeing	"skin-tight" garments such as (Un, Tr, Sp, swimwear, parts requiring elasticity)
Chlorofibres PVC : > 50% $(\text{-}CH_2\text{-}CHCl\text{-})_n$ PVDC : > 50% $(\text{-}CH_2\text{-}CCl_2\text{-})_n$	polyaddition of vinyl chloride (PVC) or vinylidene chloride (PVDC); melt or dry-spun	★ flame retardant ★ thermal insulator ★ hydrophobic ★ highly resistant to acids, alkalis and oxidizing agents ★ soluble in chlorinated and aromatic solvents	Garments (Un) Car upholstery
Fluorofibres (PTFE) $(\text{-}CF_2\text{-}CF_2\text{-})_n$	polyaddition of tetrafluoroethylene; wet-spun	★ heat resistant, not flammable ★ inert (insoluble, resistant to acids and alkalis) Very high CR	Technical (coatings, filters)
Vinylal (PVA) > 50% $(\text{-}CH_2\text{-}CHOH\text{-})_n$	hydrolysis of polyvinyl acetate; wet-spun	★ silk-like appearance ★ nice drape CR: 70%	Garments (Japanese market) Industrial applications

CR: crystallinity; DP: degree of polymerization (amount of repeating monomer units); Kn= knitware; Wo= womens clothing; Sp= sportswear or outdoor wear; Un= underwear; Tr= trousers; Ja= jackets; Li= linings; Fi= filling material

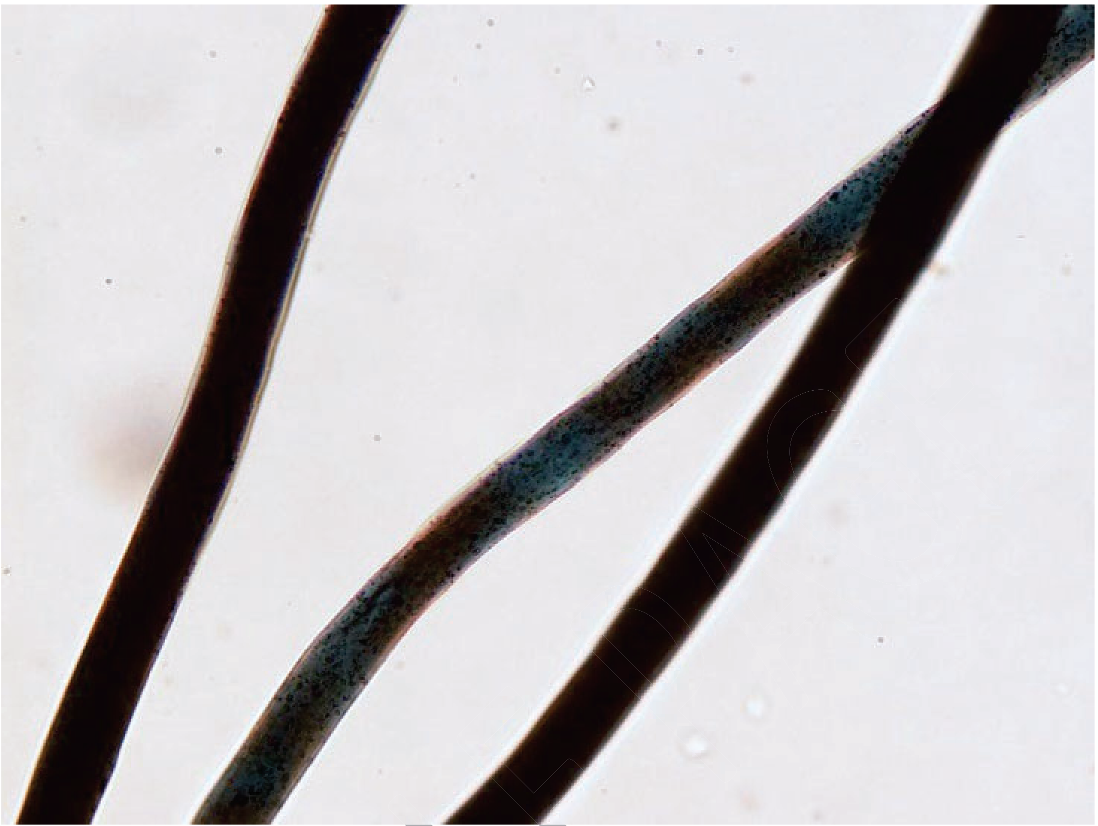


Ph. 2-4 Delustrants in streaks.

2.6.2 Fibre colour

Both dyes and pigments are dyestuffs that impart colour to the fibre. Dyes are water-soluble substances, whereas pigments exist as small grains that do not dissolve in water. In the upper image of **[Ph. 2-5]**, the dyed fibre shows a homogeneous red colour. The lower image shows a fibre with a speckled granular appearance caused by the pigment particles or granules.

The description of fibre colour is bound to vary between different examiners. Therefore, it can be useful to restrict the description of colour to one of the following categories: black (opaque), grey-black, blue-violet, brown, green, yellow, red-orange, not coloured.



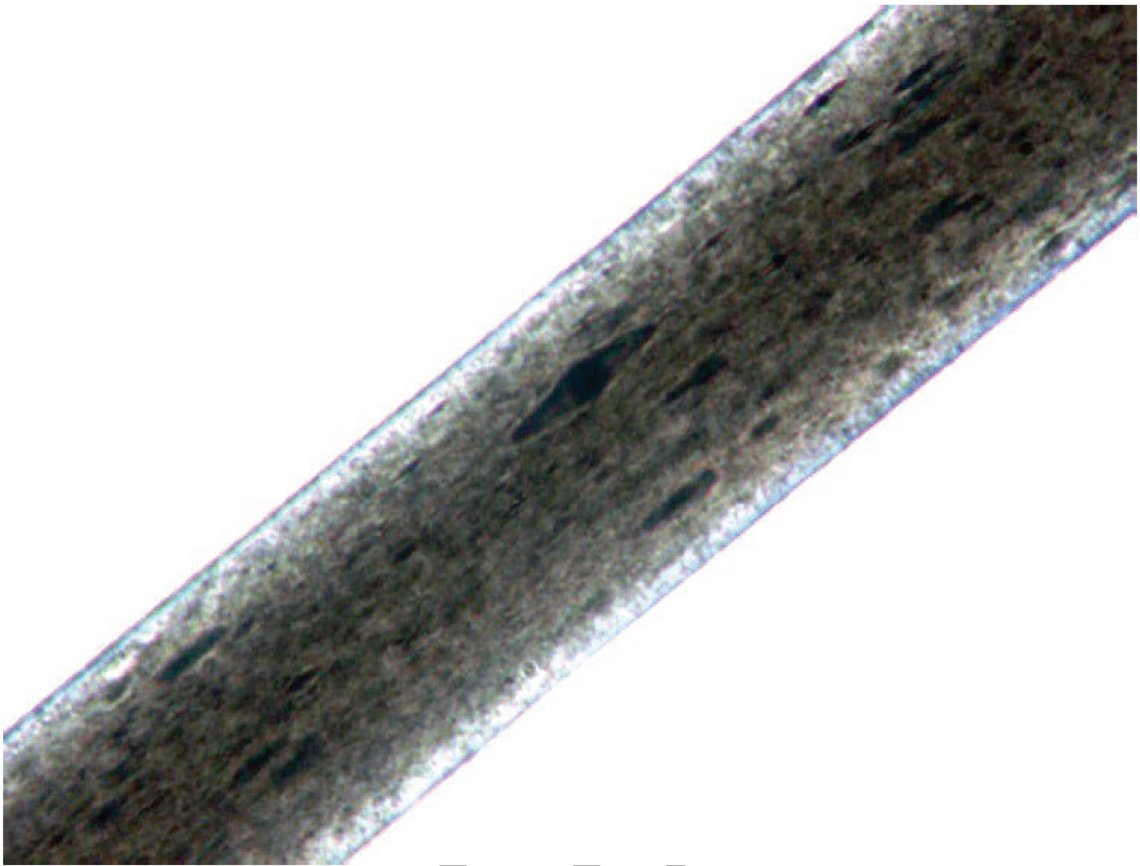
Ph. 2-9 Tiger tail acrylics.

2.6.6 Pigments

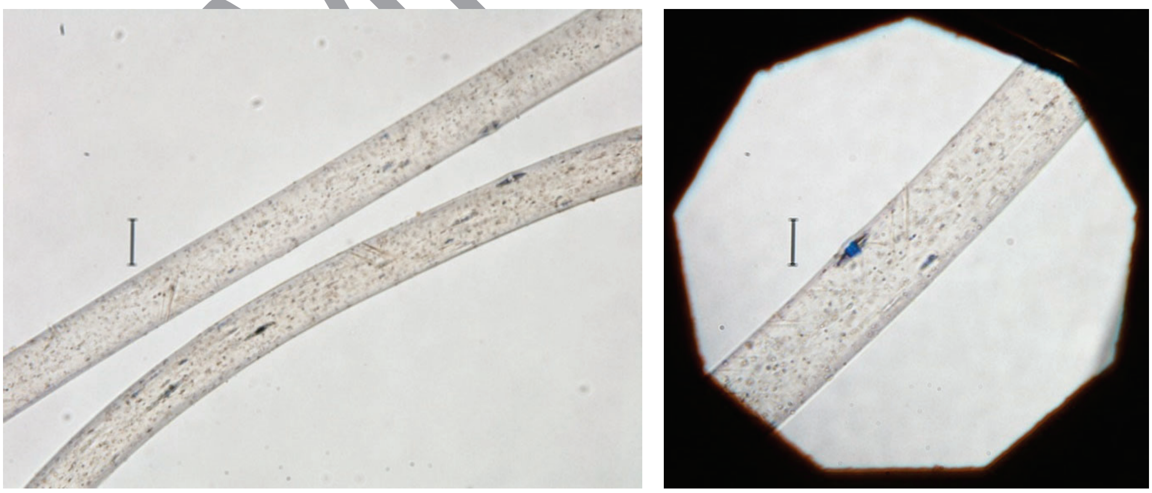
As for delustrants, pigments are added to the bulk polymer before the spinning process takes place. Adding pigments to the spin dope is sometimes called solution dyeing. The primary function of pigments is to confer colour to the fibre. Moreover, the large pigment grains are more successful than individual dye molecules in absorbing the UV light that may damage the fibre. They render lightfastness to the fibre. The pigment size and amount of pigments are important characteristics.

The colourful fibres in **[Ph. 2-10]** are different from the homogeneously coloured fibres in **[Ph. 2-6]**. Here, a huge number of coloured particles can be distinguished. These pigments are dispersed throughout the fibre matrix.

Carbon black, i.e. graphite, is almost exclusively used to obtain black pigmented fibres because of economic reasons. For obtaining bright blue and blue-green fibres, phthalocyanine pigments are often used. Other hues are obtained using a mixture of different pigments.

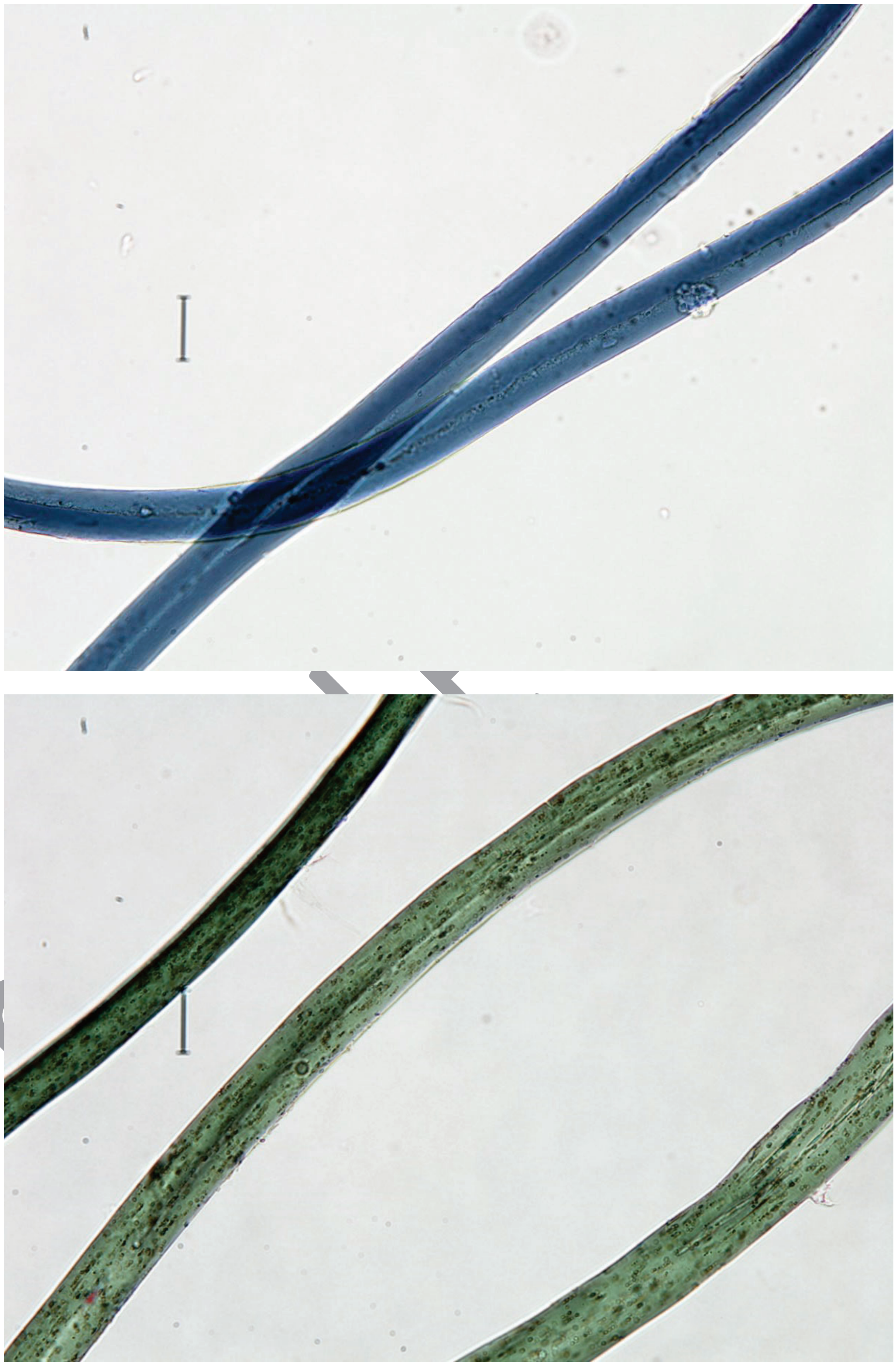


Ph. 2-13 Variation of fish eye size.
Cropped image of a black pigmented fibre, showing a considerable variation in fish eye size.

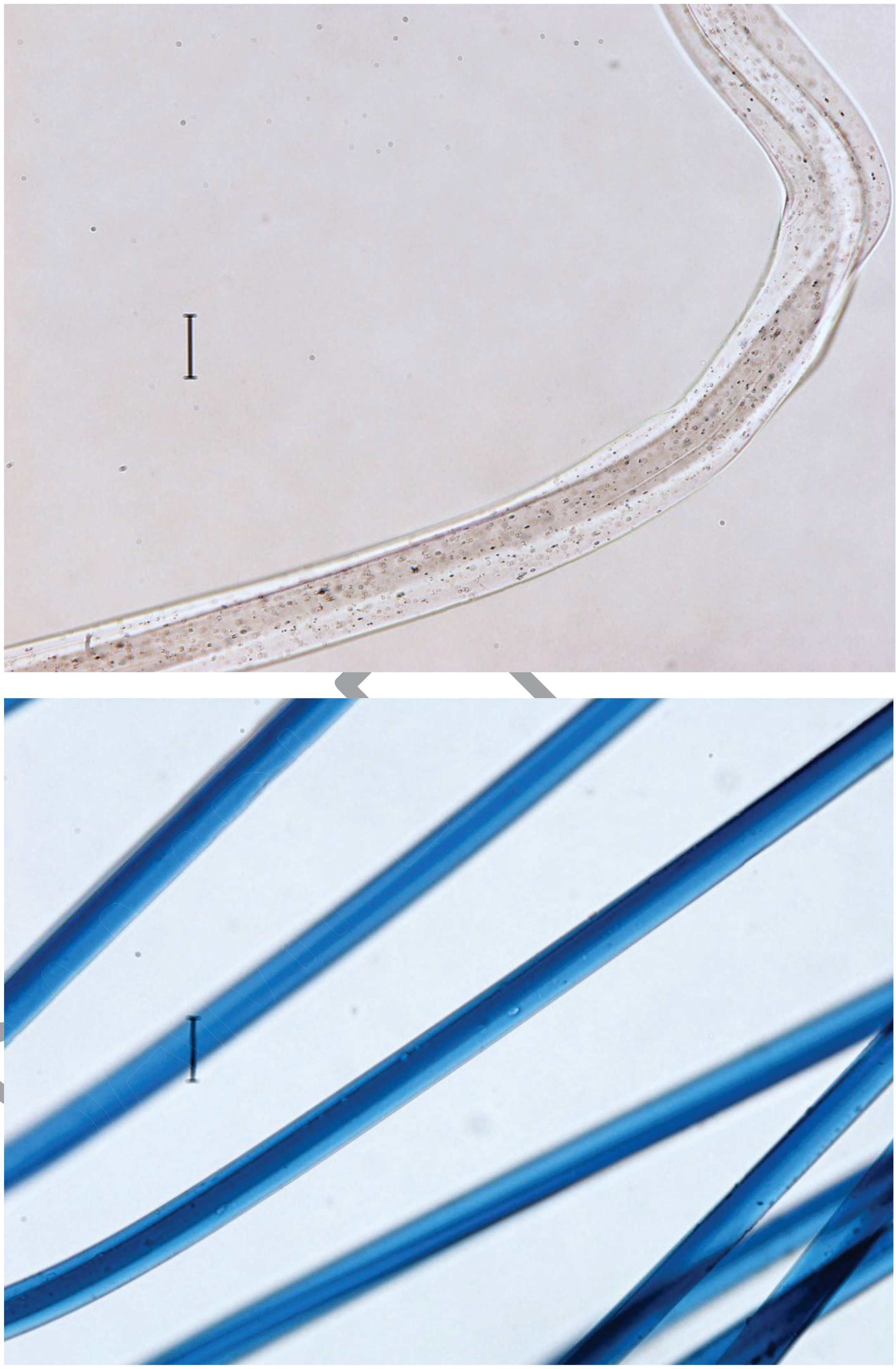


Ph. 2-14 Traces of blue pigments in a delustred polyester fibre type.
Left: fibres at 400x magnification, I = 25 µm; right: the same type at 630x magnification, I = 16 µm.

major generic fibre classes. The circular cross-section is less frequently encountered in acrylics. Some examples of acrylics with bean cross-sections are given in **[Ph. 2-19]**.



Ph. 2-19 Bean cross-section in acrylic fibres.



Ph. 2-24 Examples of fibres with a trilobal cross-section.

A bicomponent fibre of the core/sheath type is shown in **[Ph. 2-29]**. This fibre type is composed of two polyester fibre types, in which a PET fibre type enrobes the central PET fibre.

Ph. 2-29 Example of a core/sheath bicomponent fibre type.

With optical sectioning, it is possible to determine which part of the fibre contains delustrants. The strange-looking core/sheath bicomponent fibre in **[Ph. 2-30]** is composed of a delustered outer part and a bright central part. When focusing on the lower and upper section of the fibre, the central part shows delustrants in-focus. When focusing on the middle section, no delustrants are in-focus in the fibre centre, and only the side portions show sharp delustrants.

A bicomponent fibre of the mushroom type consists of two round fibres with different diameters melted together. An example of a mushroom type acrylic bicomponent fibre is shown in **[Ph. 2-31]**. Typically, the spiral crimp in this bicomponent fibre type is caused by the two different acrylic sub-types fused during spinning. The fibre straightens out with increasing moisture uptake but crimps again during drying. Remark that, due to the different fibre composition, the two parts have a different dye uptake.

2.6.25 Texturizing

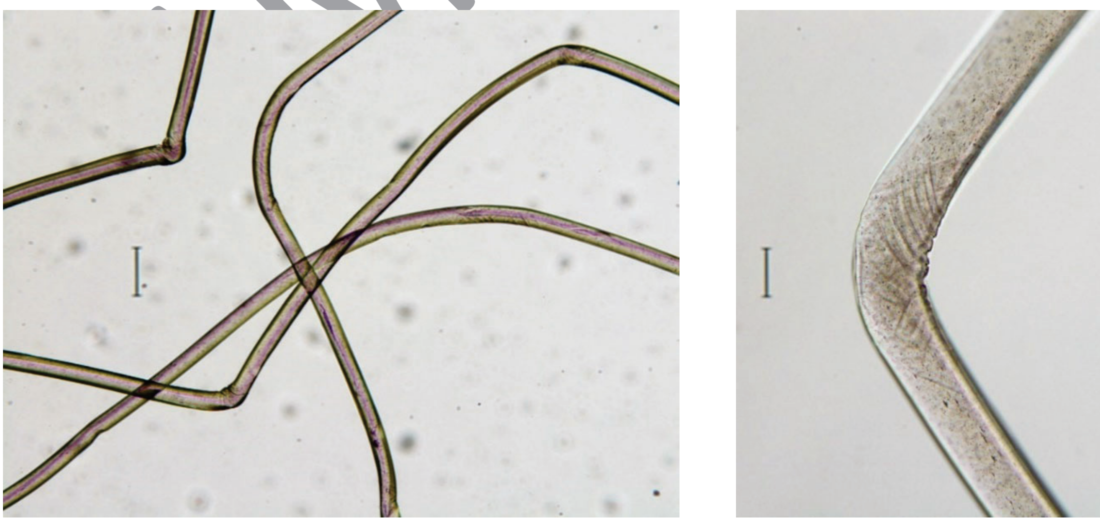
The texturizing process is a heat-setting technique in which more bulky and elastic filaments or staple fibres are obtained. This process is performed after spinning, and several texturizing methods can be used.

Texturized yarns belong to one of the following categories:

- **stretch yarns**, or **high elasticity yarns** (HEY), are texturized to obtain a fibre that can undergo an elongation of 200 to 500%. This type of yarn is frequently used in sportswear, socks and underwear.
- **set yarns** (SY) have an average elasticity and can obtain a stretch of 200%. This yarn type is typically used in upper garments, knitwear and interior fabrics.
- **bulk continuous filaments** (BCF) possess a high volume but limited stretch and are used in carpets and upholstery.

Some of these texturizing methods produce regular waves which cannot be attributed to a particular method. However, two texturizing processes induce characteristic features to the fibre.

Examples of the **false-twist texturizing** process, which produces a polygonal section, can be found in **[Ph. 2-23]**. The false-twist process is a mechanical-thermal texturizing method. The filament yarns are twisted in one direction so that a stretch is obtained. Once these are set by heat, the tension is released. The false-twist process is often used on thermoplastic fibres such as polyester and polyamide and sometimes on polypropylene. It can be used for fine filament yarns and is therefore encountered in garments. False-twist texturizing produces filaments that possess irregular waves extending in three dimensions. This kind of texturizing is comparable to the crimp of wool fibres.



Ph. 2-34 Elbows due to the stuffer-box texturizing process.
Left: magnification 50x, I = 200 µm (left); right: magnification 200x, I = 50 µm.

2.7 MORPHOLOGY OF NATURAL FIBRES

2.7.1 Classification

Usually, natural fibre types are classified according to the scheme in **[Fig. 2-15]**. According to their provenance, natural fibres fall into one of the three main categories: vegetable, animal and mineral fibres. In forensic casework, only the two first groups are often encountered as trace evidence. Mineral fibres mainly include several types of asbestos and are not of importance in forensic fibre examinations.

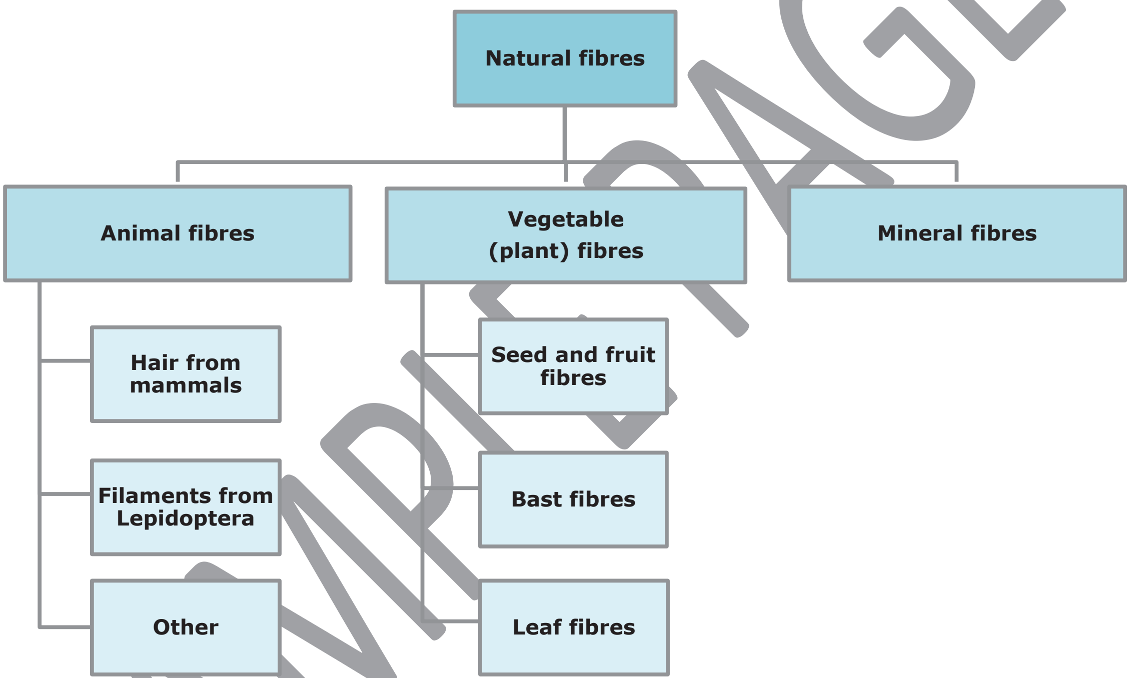


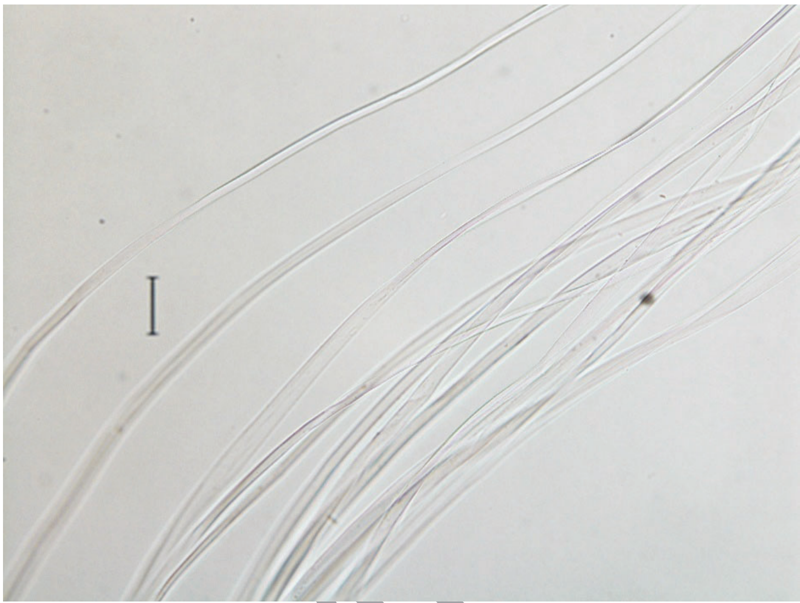
Fig. 2-15 Classification scheme of natural fibres.

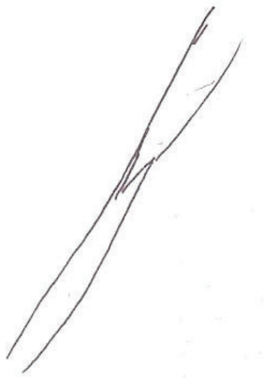
Vegetable fibres or plant fibres can be sub-divided according to the part from which they were obtained: seed and fruit fibres, bast (or stem) fibres and leaf fibres. The most common vegetable fibres in clothing are cotton and flax. These generic classes are often dyed and can be mixed with man-made fibres. Other frequently encountered vegetable fibres include hemp, jute, and sisal. Vegetable fibres are mainly composed of cellulose, which is the soft material of plants. Depending on the fibre type, the composition also includes variable amounts of lignin, a hard woody substance, and pectins acting as a natural glue.

2.7.4 Mercerised cotton

When cotton is treated with caustic soda (NaOH), the fibre swells and obtains its original **tubular shape**. This treatment renders the fibre more lustrous and makes it more accessible for dyeing. Mercerized cotton is used in sewing yarn, although nowadays it is often replaced by polyester fibres.

In bright field microscopy, mercerized cotton has a circular section but can still possess some twist. The image in **[Ph. 2-40]** shows a sample of mercerized cotton at 200x magnification with almost no convolutions.

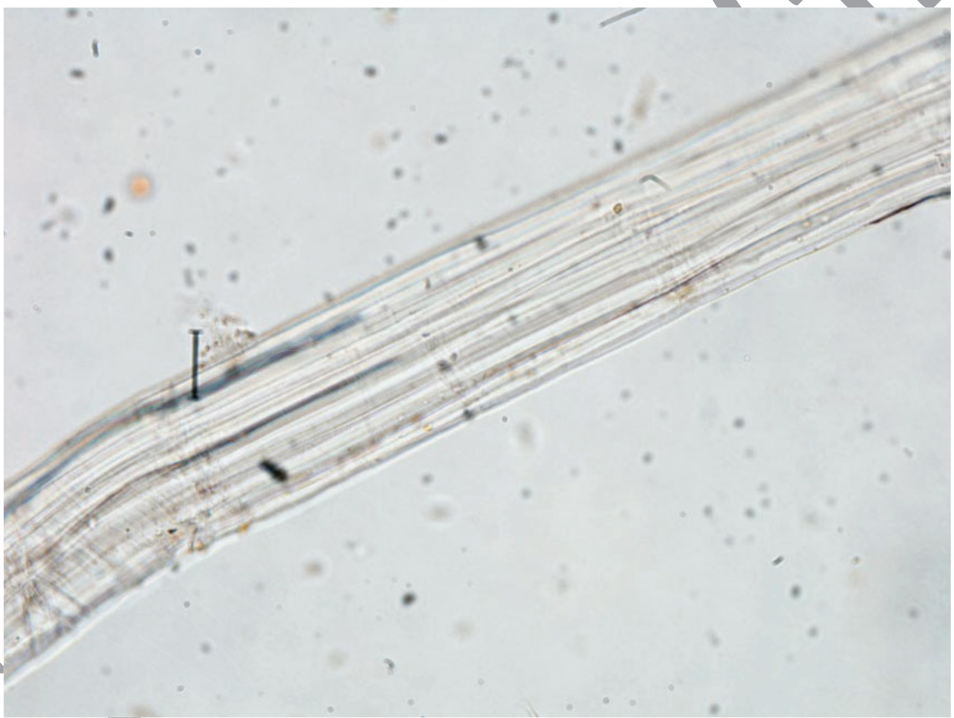




Ph. 2-40 Mercerised cotton.
200x magnification, I = 50 µm.

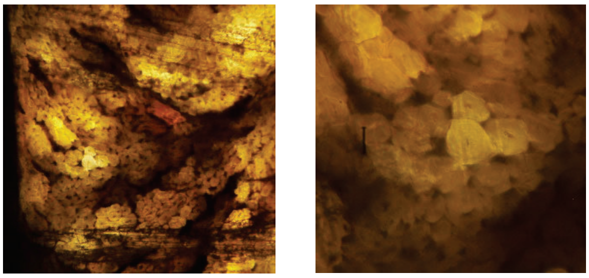
In specific parts of the world, many other bast fibres are used in textiles, but only two are of importance in forensic science. **Jute** is obtained from the stems of the herbaceous annual plant *Chorchorus*. **Kenaf**, also known as Guinea hemp or mesta, is obtained from the stems of the annual plant *Hibiscus cannabinus*. Both jute and kenaf are primarily used in the production of ropes or bags. These textile products are produced using technical fibres and have a natural brownish colour.

In bright field microscopy, jute fibres have a smooth appearance. There are no apparent nodes, and few cross marks are present, as illustrated in **[Ph. 2-45]**. The individual fibres, also called ultimates, have a diameter of 15-25 µm and are 1 to 6 mm long.

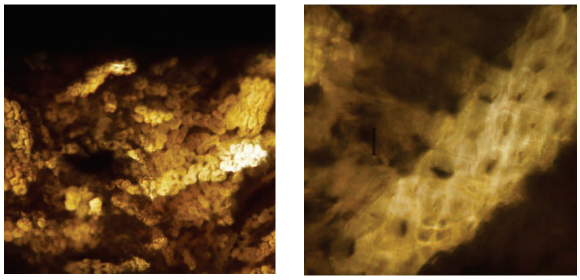


Ph. 2-45 The morphology of jute.

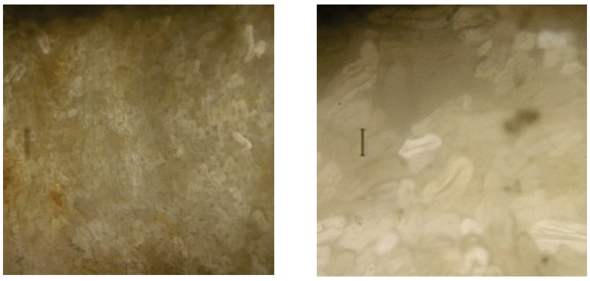
Kenaf fibres also lack the presence of nodes and cross marks. Instead, transverse and longitudinal channel-like structures are present. The morphology of kenaf is illustrated in **[Ph. 2-46]**.



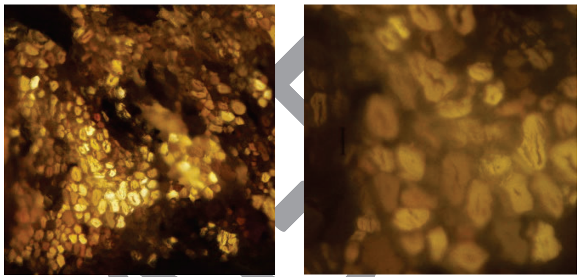
Flax



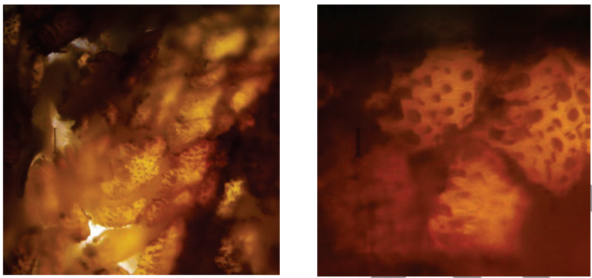
Hemp



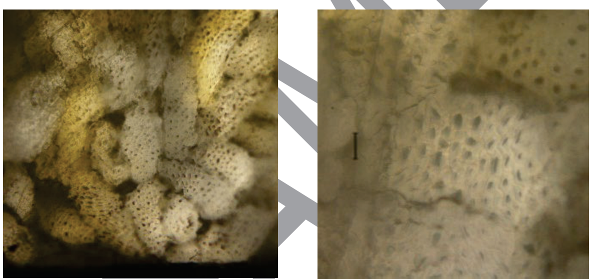
Ramie



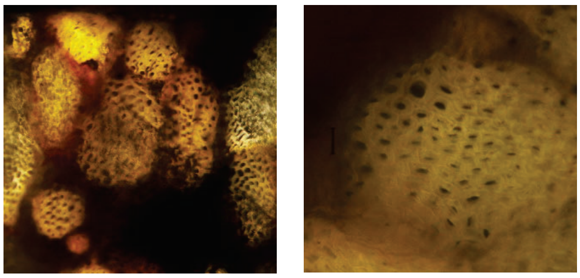
Jute



Kenaf



Sisal



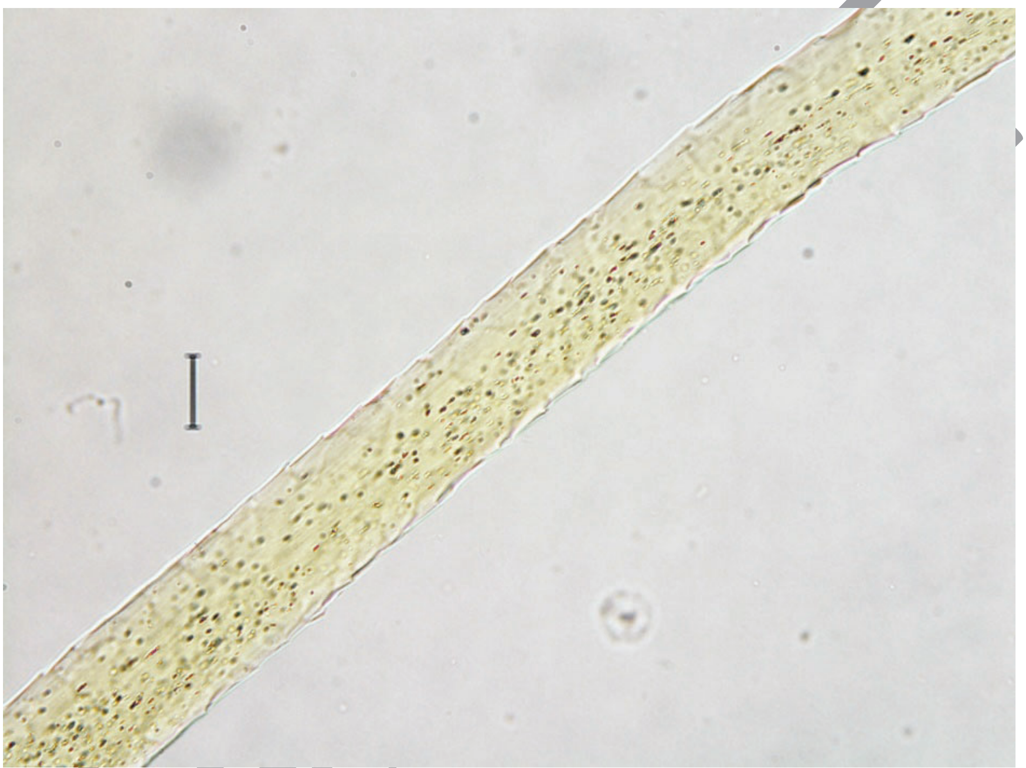
Abaca

Ph. 2-49 Cross-sections of bast and leaf fibre bundles.
Fibre bundles, cross sectioned using a Mieco QCSMS at magnifications 200x (I = 50 µm) and 630x (I = 16 µm).

> ☞ *Remember: Identification of vegetable fibres is challenging due to the natural variation within these fibre types. Therefore, it is essential to possess a reference collection of authenticated samples. In case of doubt, always compare with samples from this reference collection.*

pigments. However, some pigmented animal hair is used in textiles as it occurs naturally, without any dyeing.

Sometimes, larger egg-shaped pigment globules may be present in the cortex. These are called **ovoid bodies**. In some cases, small circular structures are observed, often close to the hair root. These are small vacuoles in the cortex and are called **cortical fusi**. Both structures are represented in **[Fig. 2-18]**. An example of fusi in a coarse wool fibre is shown in **[Ph. 2-50]**.



Ph. 2-50 Cortical fusi in a coarse wool fibre.

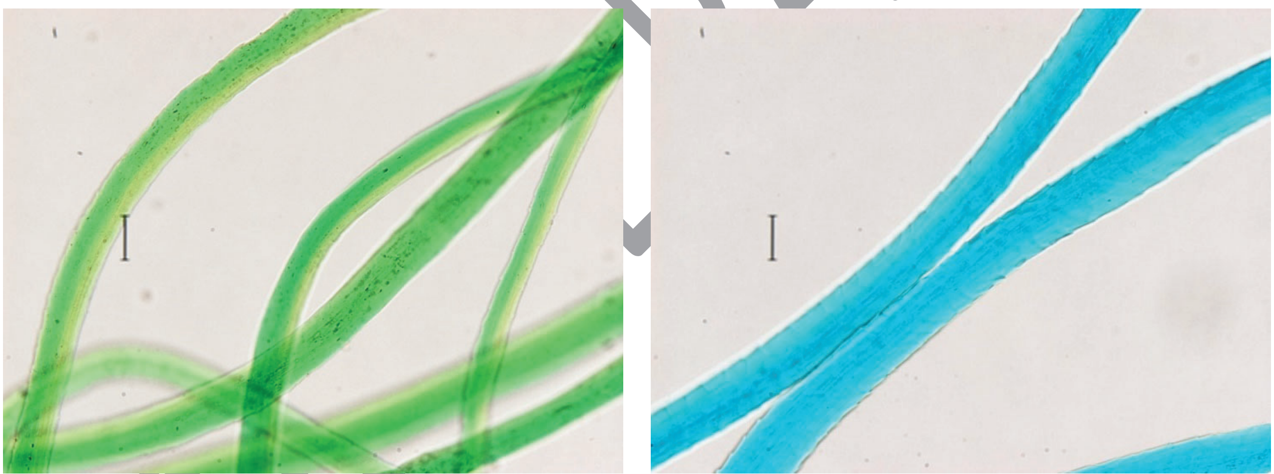
2.7.16 Scale pattern

Different species have different cuticular scale patterns. Usually, these patterns cannot be observed in bright field microscopy if the sample is mounted in a synthetic resin. Several methods are applied for visualizing the scale pattern of animal hair. One of these methods involves additional preparation of the animal hair in a mounting medium with a lower refractive index or observing the fibre as a dry mount, as shown in the images of **[Ph. 2-51]**.

2.7.21 Merino wool

Merino sheep are a breed that has been selected for their outstanding quality of wool. With an average diameter of 17,5 µm and a diameter range between 12,5 and 30 µm, it is one of the finest sheep wool varieties. The ortho-cortex and para-cortex are present as two half-cylinders that possess very distinct densities. This density difference generates a spiral crimp and causes merino wool to curl even more than regular wool. Thus, merino wool fibres are easily intertwined, which is greatly appreciated in yarn spinning.

In bright field microscopy, merino wool can be distinguished from regular wool. Merino is recognized by its smaller diameter but more apparent is the very distinct difference in dye uptake between the two halves of the cortex, as shown in the pictures of [Ph. 2-53]. The softer ortho-cortex forms the outside of the curvature. As this cortical part is more accessible for dyes, the ortho-cortex is more deeply dyed. The denser para-cortex lies on the inside of the bend and is less deeply dyed.



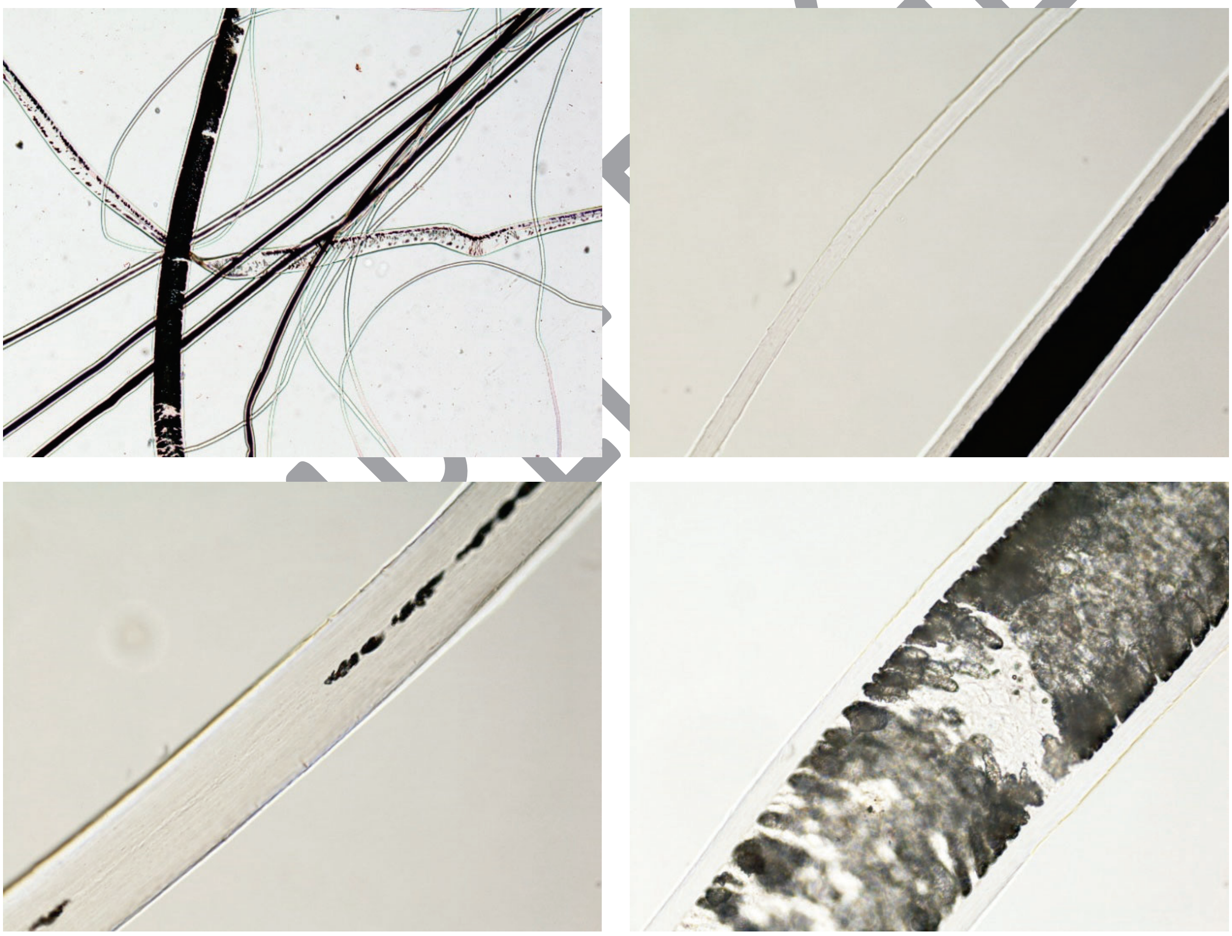
Ph. 2-53 The morphology of merino wool.

This side-by-side cortical structure of merino wool is unique. Side-by-side bicomponent fibres imitate the structure and crimp characteristics of merino wool. The two fibre parts in this type of bicomponent fibre possess two different densities, which produce a crimped fibre.

Other types of mammalian hair do not possess the crimp characteristics of wool. In these long and straighter hair types, the ortho-cortex is present as the inner cylinder enclosing the medulla, while the para-cortex forms the outer layer.

Cashmere does not present many characteristics features in bright field microscopy neither. The most apparent characteristic is its medulla type, as shown in **[Ph. 2-57]**. Fine hairs have no medullae. Medium-sized hairs have a simple medulla trace (MI~ 0,15) or medullae consisting of broad rectangles of small height with rounded sides (MI~ 0,75). The medulla borders are therefore not straight but have a scalloped appearance. The guard hairs of cashmere possess very broad medullae (MI~ 0,9) that can be translucent at places where the mounting medium has penetrated the closely packed mosaic of medullar cells.

Mohair and cashmere differ in scale protrusion, which is low for mohair and high for cashmere. Both goat hairs can possess medullae in coarse hairs. Some examples of scale casts of goat hair are shown in **[Ph. 2-62]**.



Ph. 2-57 Cashmere sample (reference collection).
Above left: sample at 50x magnification; other images taken at 400x magnification show a fine fur hair and a medium continuous medullated hair; a medium hair with fragmentary medulla; and a coarse hair with high medullar index.

The properties of mohair and cashmere are summarised in **[Tab. 2-4]**.

Tab. 2-5 Properties of hair from Old and New World camels (Camelidae).

Characteristics	 Camel	 Llama	 Alpaca
Natural colour	pale red-brown	black, brown, white	black, brown, fawn, white
Fibre length	G: 30 cm; U: 2,5 – 15 cm	8 – 25 cm	G: none; U: 60 cm
Average ∅ range	10 – 40 µm	20 – 40 µm	20 – 35 µm
Crimp	none	none	none
Medullae	F: none or fragmental; M, C: continuous fine lattice with fluctuating thickness	F: none or fragmental; M: interrupted to fragmental C: translucent or continuous simple	F: none or fragmental; M, C: fragmental to continuous fine lattice, granular
Cortex	yellow-brown, granular and streaky pigments, higher density towards centre	no, medium to dark brown pigments (varying density), fine and streaky, higher density towards borders; sometimes ovoid bodies	striated, mostly no pigments, some pigmented with higher density towards borders; sometimes ovoid bodies
Scale protrusion	low	low	low
Scale count	close to near margins	near margins	near margins
Scale margins	M: smooth to crenate		
Cross-section	circular to oval		
Properties	warm, comfortable textile		soft, lustrous and durable
Textile application	F: overcoats, dressing gowns, knitwear C: ropes, tent fabrics, blankets	carpets, rugs and hand-made clothing fabrics	dresses, linings, plushes, tropical suits

G = guard hair; U = underhair; F = fine; M = medium; C = coarse

2.7.25 Other mammalian hair

Although it is not our intention to be exhaustive about the hair fibres that can be used in textile, three other high-quality hairs are worth mentioning:

- Quiviut, the soft, downy undercoat of the Musk ox (*Ovibos moschatus*) - a bovid whose territory ranges from Alaska, the Canadian arctic, Greenland, Scandinavia and Siberia - has an average diameter of 12,5 µm and a range of 17,5 – 22,5 µm;
- the very fine down hairs of the domesticated Yak (*Bos grunniens*), another bovid, originally native to the Himalayas, have a diameter of 15 – 20 µm, comparable to the fineness of cashmere.
- Shahtoosh is the ultra-fine hair (7,5 – 10 µm) of the Tibetian antelope or chiru *(Pantholops hodgsonii)*

2.7.27 Silk fibres

Cultivated silk is the fibre secreted as filaments from the glands of the silk moth *Bombyx mori*. Sericulture is very laborious and begins with the rearing of the silk moth's caterpillar. This silkworm feeds on mulberry leaves, and this is why the fibre often is called mulberry silk. After several instar stages, the silkworm is full-grown and goes into the pupa stage. It produces fine silk filaments from its spinning glands to envelop the cocoon in which the transformation from chrysalis to adult moth occurs. As shown in **[Fig. 2-18]**, the raw silk coming from the cocoon contains two filaments composed of fibroin held together with the globular protein sericin, acting as a glue.

The silk cocoons are harvested before hatching takes place because the silk filaments would be ruptured. The cocoons are heated to kill the chrysalis. The raw silk is first reeled from the cocoons. Afterwards, the raw silk undergoes throwing, in which several raw silk filaments are combined and slightly twisted to obtain a yarn of suitable thickness. The silk fabric, obtained after weaving or knitting of these yarns, is stiff and dull. This fabric undergoes a degumming process which involves soaking and boiling in soap. In this process, the sericin is dissolved, and the individual silk filaments remain. After degumming, the silk fabric receives its delicate drape and brilliance. After a bleaching step, the fabric is ready to be dyed.

In bright field microscopy, silk fibres are not that easily recognized. Silk has a slightly twisted structure due to its **triangular cross-sectional shape**. The dyed fibre usually has subtle colour variations that suggest the natural origin of the fibre. Sometimes, thickened structures are observed, resembling the **pearl beads** of a necklace, such as those in **[Ph. 2-65]**. These result from exposure of the silk fibre to heat. **Fibrillation** of the fibroin material into fine micro-fibrils is sometimes observed as well.

2.8 SPECIFIC FIBRES

2.8.1 Microfibres

Microfibres are man-made fibres with a titer of less than 1 denier. This corresponds to a fibre diameter of less than 10 µm (for circular fibres with a density of 1,5 g/cm^3). These fibres are discussed here because initially, microfibres were developed to mimic the fine substructure of leather. A microfiber yarn typically has the same diameter as a regular textile fibre. An important aspect is that as the fibre diameter is reduced, the filaments are becoming more fragile. Upon contact, microfibre filaments are ruptured, and individual microfibers or microfiber tufts can be transferred easily.

Because of their fine structure, fabrics made of microfibre yarns are waterproof yet let through water vapour from transpiration. Microfibre fabrics have a smooth surface with an excellent drape and are very soft to the touch, a property that is described as a "good handle". Because of the increased specific surface of microfiber yarns as opposed to standard yarns, the dye uptake is better and more vivid colours can be obtained.

A standard production process of man-made leather involves brushing microfiber fabrics impregnated with polyurethanes.

Microfibres are often produced in a spinning process involving bicomponent fibres, i.e. fibres consisting of two different polymers. One of these production processes involves the spinning of an islands-in-the-sea bicomponent fibre type. In this bicomponent, the "islands" are insoluble polymers (polyester and polyamide are mainly used), and these are embedded in a matrix of soluble polymer (polystyrene). After spinning this bicomponent fibre and the production of the fabric, the "sea" is dissolved, leaving a bundle composed of microfiber filaments. Nowadays, with the advancement in technology, microfibres with much smaller diameters can be produced. The diameter of these ultra-microfibres or nanofibers has sub-micrometer dimensions.

[Ph. 2-69] shows two types of delustred microfibre filaments: red, round polyester and pink, trilobate polyamide fibres. These types were found together in the yarn of a microfibre coat.

2.9 FIBRE TYPE COMBINATIONS

2.9.1 Fibre blends

In the production of yarns, a combination of different generic fibre classes is often used. Man-made and natural fibres may be intimately mixed in yarn to improve the fabric properties. Widespread used fibre blends are:

- acrylic and wool in knitwear (jumpers, scarfs, gloves, caps);
- polyester and cotton in shirts and trousers;
- polyester and wool for suits, such as in **[Fig. 1-3]**;

The warp and the weft yarns of woven fabrics may be composed of differently dyed yarns. If the warp yarns contain black pigmented fibres, while the weft yarns are made up of white fibres, a grey woven results.

2.9.2 Morphology and fibre type

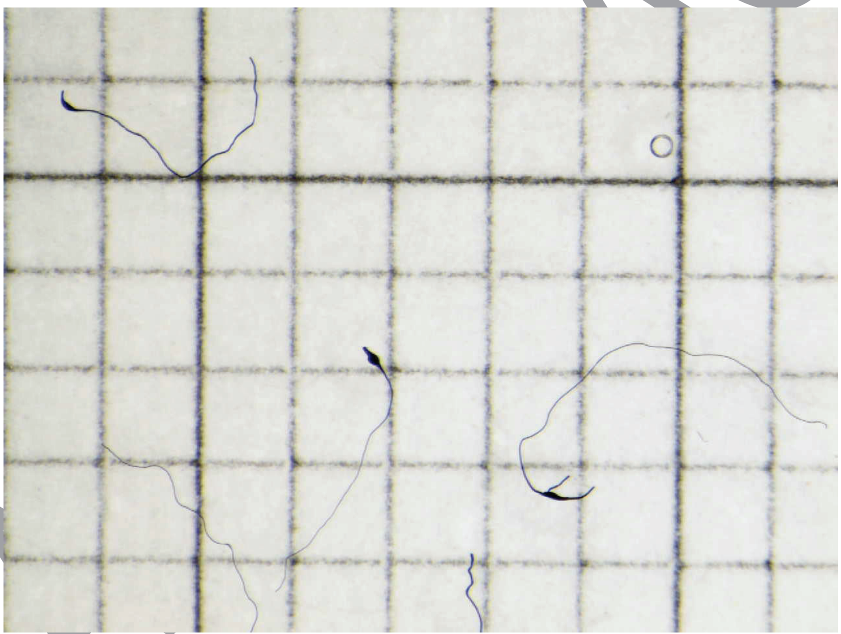
Sometimes a combination of several man-made fibre types that are morphologically very similar can be used. The author has encountered the following combinations of man-made fibres while observing reference material in casework:

- delustred and non-delustred man-made fibre types;
- fibre types having different cross-sections, e.g. round and bean-shaped section;
- man-made fibre types of different thickness;
- a combination of different characteristics, e.g. small bright and thicker delustred man-made fibre types.

With bright field microscopy, apparent differences in colour may be observed due to differences in lustre and thickness. In general, the absorption spectra of these different fibre types are very similar. This observation indicates that dyeing did not occur at the fibre level but rather at the yarn or fabric level.

exposed to temperatures well over 300°C. The morphology of these acrylic fibres corresponded with the surface fibres originating from the suspect's jumper. The suspect was employed in a garage, and the acquired characteristic was found to be due to heat exposure by frequent use of welding equipment.

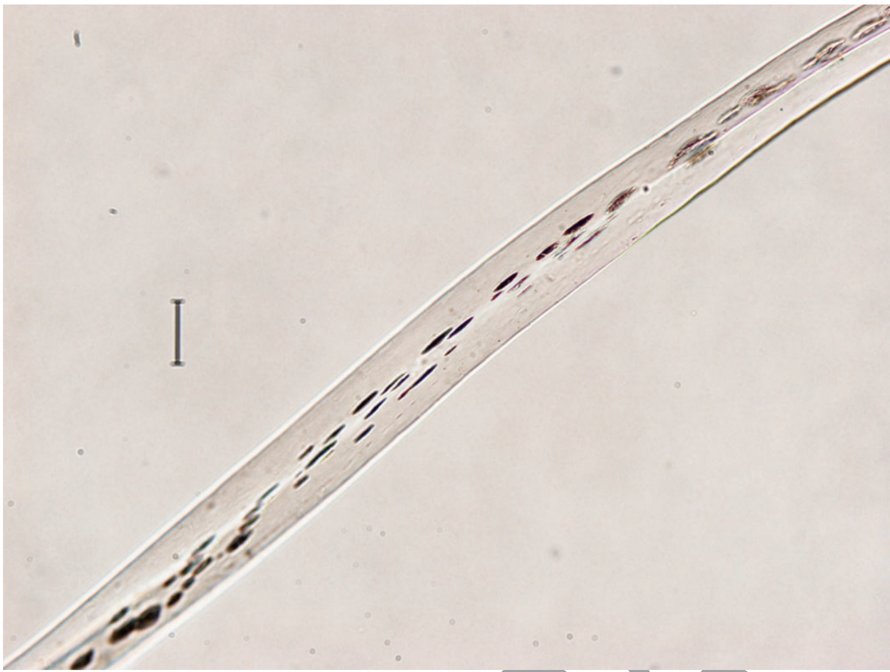
Polyester and polyamide fibres are both thermoplastic polymers, and melting caused by exposure to heat is often found. When fire weapons are used, the hot discharge of gases produces a heatwave of several hundred degrees. This is sufficient to cause a local melting or decomposition of fibres at the cuffs of the shooter's jacket. In one of our murder cases, deformed polyester fibres were found on the victim. These fibre traces were present in the neck and shoulder of the victim, the zones in which contact had taken place for firing a close contact neck shot. The morphology of the fibres corresponded to the polyester fibres originating from the cuff of the shooter's jacket. An image of these reference fibres viewed at low magnification using a stereomicroscope is shown in **[Ph. 2-73]**.



Ph. 2-73 Thermoplastic fibres deformed due to heat exposure.

2.10.3 Photodegradation

Another example of acquired fibre characteristics is the weathering of the fibre polymer due to prolonged exposure to sunlight. The UV resistance and effect of sunlight are presented in **[Tab. 2-8]**. Cellulosic fibres are more resistant to UV radiation than proteinic fibres. White cotton and also wool undergo a natural yellowing when exposed to sunlight. In man-made fibres, acrylics and polyester are the most resistant to UV radiation. Yellowing is not frequent in white viscose fibres.



Ph. 2-77 Microvacuoles.

2.10.9 Mechanical damage

Mechanical damage is provoked by the intensive use of a textile material. It gradually occurs and may be caused by frequent friction or prolonged flex of the fibres. **Fibrillation** and **splitting** are examples of mechanical fibre damage. In a fibrillated fibre, small slices are coming loose from the fibre surface. In splitting, the fibre is divided into two or more parts.

The resistance to wear and mechanical damage of different generic fibre classes is summarized in **[Tab. 2-10]**.

Natural fibres such as silk (fibroin) and leather (collagen) are composed of structural elements with sub-micron diameter. These materials are particularly prone to fibrillation.

In general, man-made fibres are more resistant to wear. Polyester is the fibre class that is most resistant to mechanical degradation. Acrylics are least resistant to mechanical wear. An exception is Kevlar: its filaments fibrillate easily due to the highly oriented polymer chains.

gain in mass when a dehydrated textile is exposed to a nearly saturated environment (relative atmospheric humidity of 95%). The values in **[Tab. 2-11]** explain the sensitivity or resistance of the main generic fibre classes to micro-biological attack.

Tab. 2-11 Microbiological resistance of the main generic fibre classes.

Fibre class	Resistance to micro-organisms	Standard moisture regain (%)	Water uptake (%)
Polyolefines	⊗	0.01 – 0.5	0
Acrylics	⊗	1.3 - 2.5	0
Polyamide	၍	3 - 6	8 - 9
Polyester	⊗	0.2 - 0.5	0.7
Viscose	၍၍	10 - 15	26.2
Cotton	၍၍	8.5 - 12	14.2
Wool	၍၍	17 - 18	25.4
Silk	၍၍	11	19.3

၍၍ poor resistance (highly sensitive); ၍ medium resitance (moderately sensitive); ⊗ good resistance

In buried victims, garments made of natural fibres may undergo bacterial or fungal attacks. Cotton textiles that have been exposed to micro-organisms can become damaged by mildew and decompose in a relatively short period. Wool is a natural fibre that resists better to biological degradation. Woollen garments in contact with the ground are attacked by mildew and bacteria but maintain their structure much longer than cotton garments. Wool is also sensitive to attack by the larvae of some moth species. The carpet beetle also feeds on wool; small pieces of fibre in the form of the insect's mandibles can be recognized if wool is attacked.

2.12 TRAINING AND QUALITY ASSURANCE

2.12.1 Training

Common terminology in the description of fibre morphology is essential in a quality system where the continuity of the work has to be assured.

In the training process of fibre examiners, the different morphological features that can be encountered should be clearly explained, and several examples of each characteristic feature should be observed with the microscope. There really is no substitute for observing the features with your own eyes. The more a particular fibre characteristic has been observed, the more it is stored in memory. The familiarisation process with morphological features does never stop. New morphological features or other ways of observing may be discovered over time.

It is good practice to save some digital photomicrographs of fibres with special features that one encountered in casework or in a fibre reference collection. These images certainly help in the training of new fibre examiners. The creation of a fibre image database is also discussed in the last chapter.

In the validation process of bright field microscopy within a fibre lab, it is important for the different examiners to have observed and described the same series of fibre samples. This allows for the detection of systematic errors that can be corrected afterwards by additional training.

In training a new fibre examiner, a first step could be the formal explanation of the most common fibre characteristics. In the next step, the trainee could observe and learn from microscopic examinations performed by an experienced fibre examiner. Important new fibre characteristics should be pointed out.

The checklist in **[Tab. 2-13]** may be useful in following the progression of the trainee.