Photo: Cotton field by David Nance / Wikipedia, Public Domain

1.1 / 1 Definition,Classification and Properties of Textile Fibres

This open educational resource has been developed by:

Outi Tuohino
Marja Amgwerd

SusTexEdu

Funded by the Erasmus+ Programme of the European Union

SusTexEdu

SusTexEdu | Erasmus+

This learning material was developed in the Erasmus+ funded project Education Partnership of Textile and Clothing Sector Materials & Sustainability (SusTexEdu)

The goal of the project is to research and develop education in the textile and clothing sector related to textile materials, sustainability and circular economy.

The learning material has been prepared for piloting, and students will be asked for voluntary feedback after the course for the further development of the material.

Project coordinator: Metropolia UAS

Partners: Hogent (BE), Mome (HU), Omnia (FI), TTHK (EE), TTK UAS (EE), University of Borås (SE)

Funding: Erasmus+

Project period: 2022-2024

About this learning unit

CONTENT DESCRIPTION

- Basic knowledge about definition and classification of fibres
- The structures and properties of different fibres
- The areas of use of different textile fibres

LEARNING OUTCOMES

Student will be able to:

- classificate different textile fibres by origin and chemical structure
- manage the general terms regarding the characteristics and properties of textile fibres
- identify the structures, properties of different textile fibres
- know different ways how to use textile fibres for different products

STUDENT WORKLOAD

2 ECTS, which is equal to 50-60 hours of work:
for example

- Lectures 26-30 h
- Group activities 6-10 h
- Independent study 10-28 h

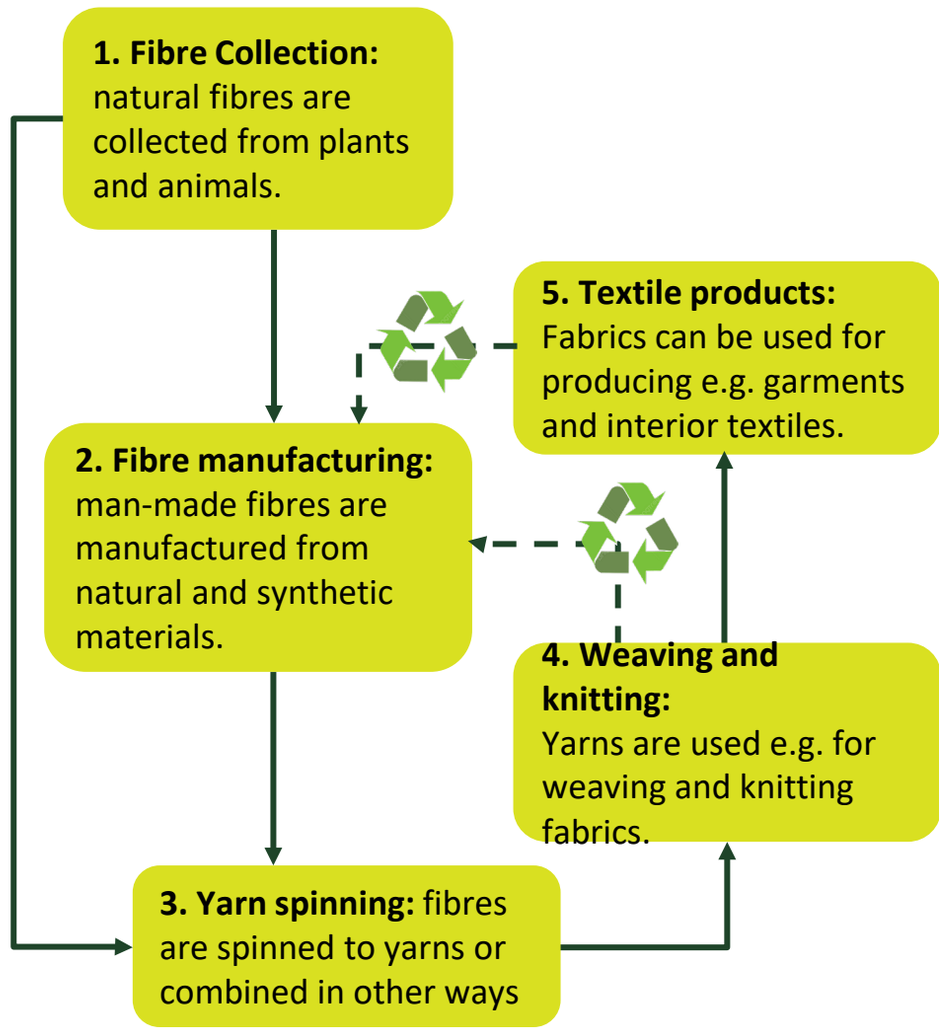
SusTexEdu

Contents

SusTexEdu

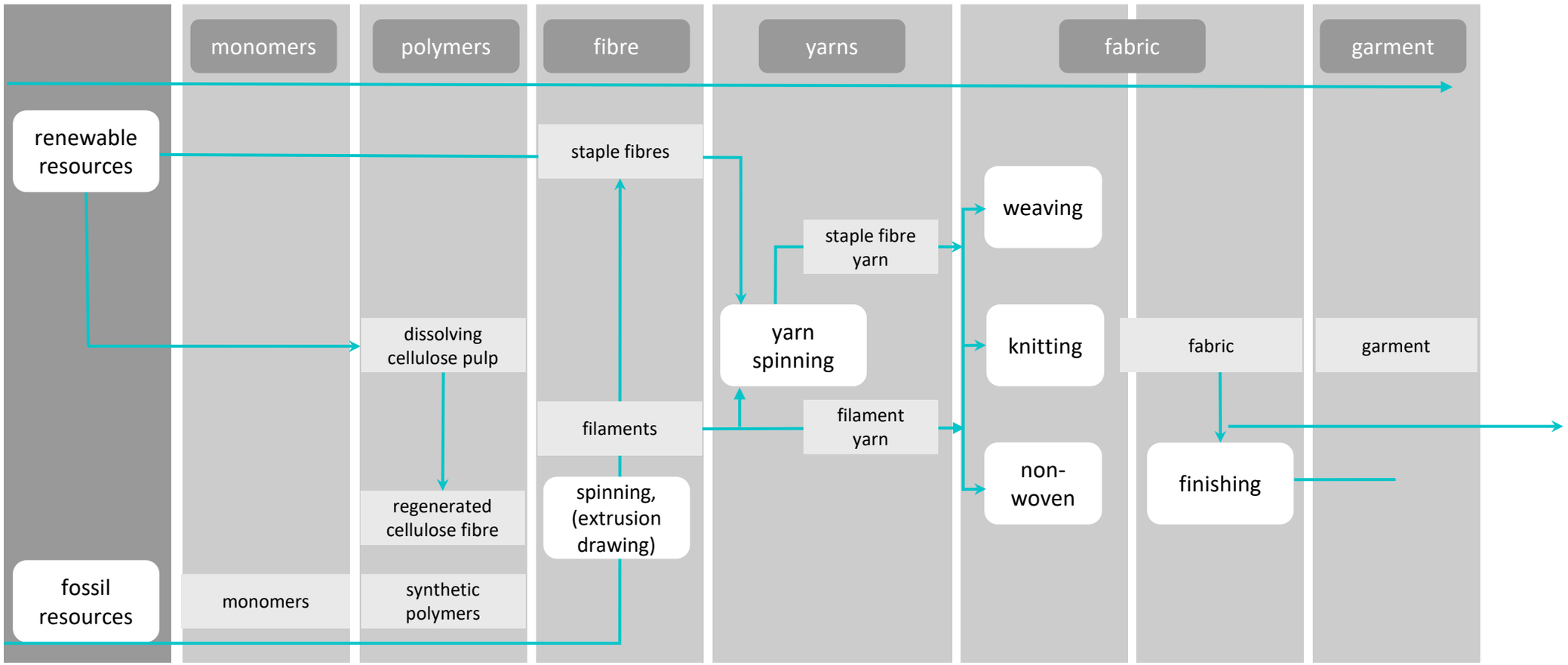
Overview to the use of textile fibres

- Fibre is the smallest visible component of textile material.
- Since from the past, there are many types of textile fibres that have been developed and used for textile products such as apparel, household textiles, technical textiles etc.
- We still use fibres used already thousands of years, as cotton, linen and wool. Developing man-made textile fibres started only about 150 years ago.
- Lack of natural resources and the climate change, partly due to over consumption, has forced the industry to create new ecological fibres, that are needed for turning world economy green.



SusTexEdu

… overview to use of textile fibres



SusTexEdu

Image: Textile production chain (Textiles for circular fashion Part 2)

Definition of textile fibre

Fibre has a hair-like appearance. Any substance, natural or manufactured will be considered as a textile fibre, if it posses the following parameters:

- High length to width ratio, at least 500 times longer than it's lateral dimension i.e, L (Length) /d (Diameter of fiber) > 500 (called slenderness ratio)
- Flexibility / stiffness (can give any shape)
- Good strength and elongation (elastic, i.e, not rigid)
- Dyeability

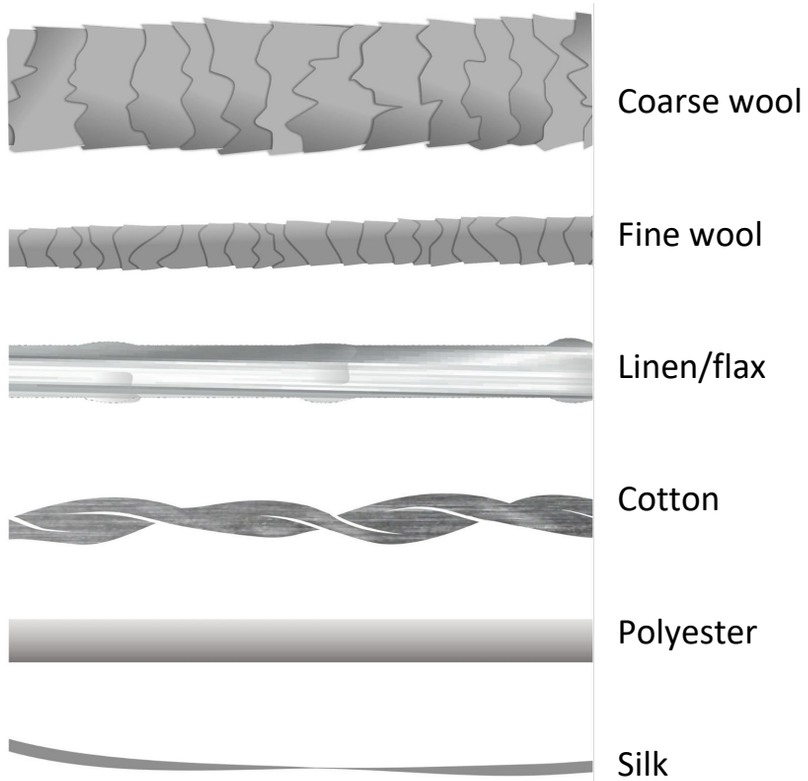
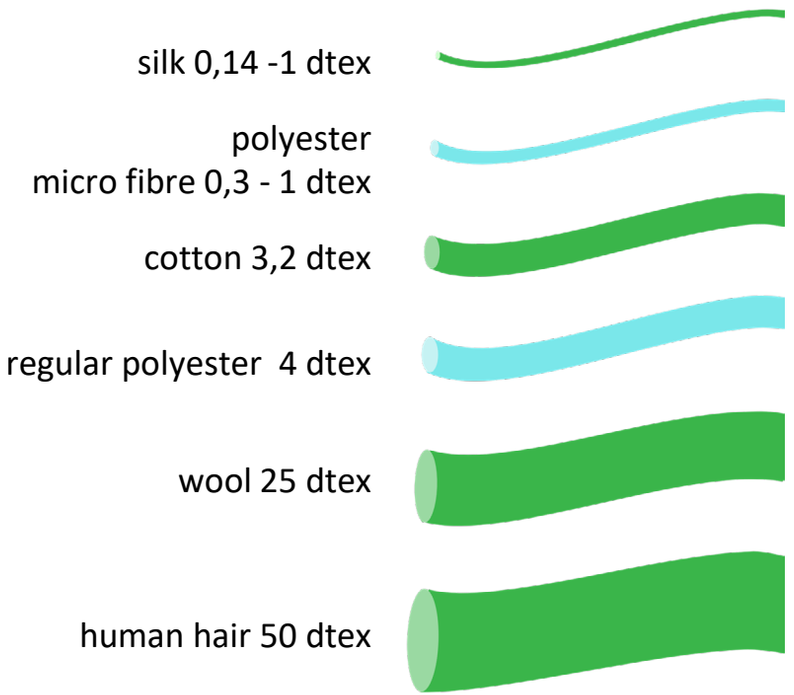


Image by authors

Physical properties of fibres. CMDgroup.in

Density of textile fibres

- Textile fibre is measured in terms of linear mass density, the weight of a given length of fibre, commonly by using units denier or tex.
  1 tex = 1g / 1000 m, 1 dtex (decitex) = 0.1 tex
- Microfibres are produced in the range of 0.3–1.0 dtex (diameters of about 5–10 µm). Microfibres are many times finer than a human hair, about as silk.
- Microfibres have opened up a new field of applications and expanded the expression potential of fibric materials.



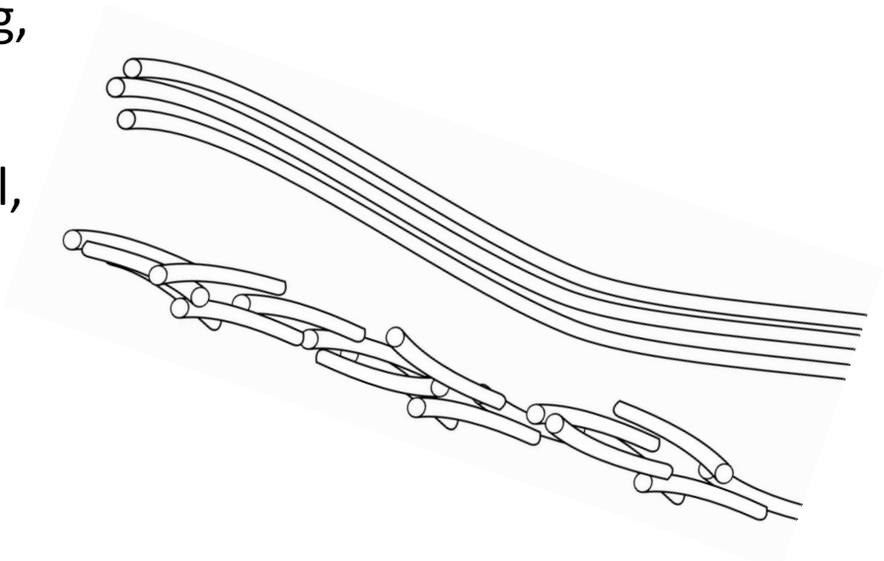
Examples of density of different fibres
Image by authors

SusTexEdu

Definitions of fiber, yarn, thread. Me-systeme.de
Manufacturing methods of microfibres. Textilelearner.net

Filament and staple fibres

- Filament fibre is a fibre of indefinite length or extremely long, such as natural silk.
- Staple fibre is either naturally short, such as cotton and wool, or a fibre from a couple of centimeters to ten centimeters long that is cut during the manufacturing process.
- Man-made fibres are produced by extrusion, either directly into filament yarn or grouped into a bundle referred to as a tow and then cut into the desired staple length.
- As staple fibre, man-made fibres may get characteristics of natural fibres, such as softness.

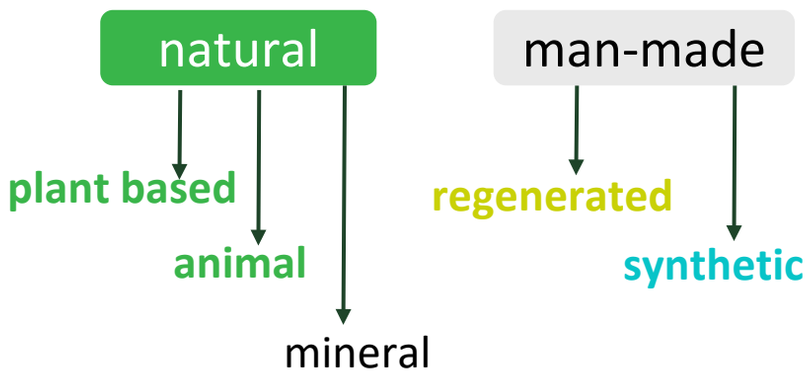


Images by authors

SusTexEdu

Classification of textile fibres by origin

- Plant based natural fibres are seed fibres as cotton, bast fibres as linen, leaf fibres as sisal and fruit fibres as coir.
- Animal based natural fibres are obtained from hairs of different animals as wool from sheep and threads made by certain insects as silk maggot.
- Regenerated fibres are manufactured from nature based materials as wood cellulose, e.g. viscose and protein e.g. azlon.
- Synthetic polymers are manufactured from petrochemical waste. The most common synthetic textile fibres are polyester and polyamide.



SusTexEdu

Classification of Textile fibers by chemical structure

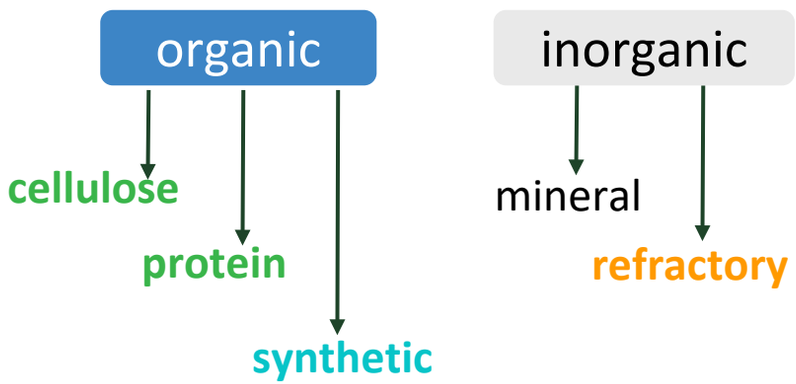
The textile fibres are also classified according their molecular structure, which effects on their reactions when e.g. dying, finishing, washing and ironing them.

- **Organic man-made fibres**

are generally manufactured from natural resources containing carbon chains as their main material.

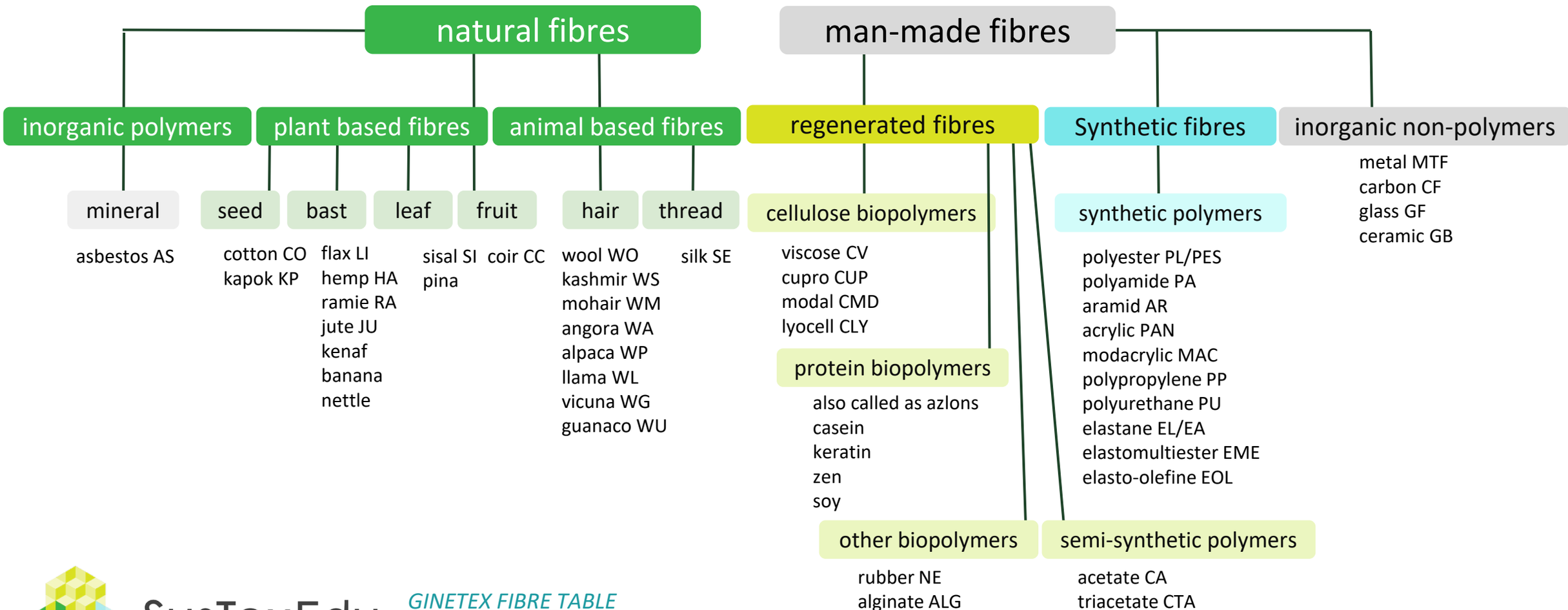
- **Inorganic man-made fibres**

are made from different synthetic materials, which are not carbon based.



SusTexEdu

Classification of textile fibres

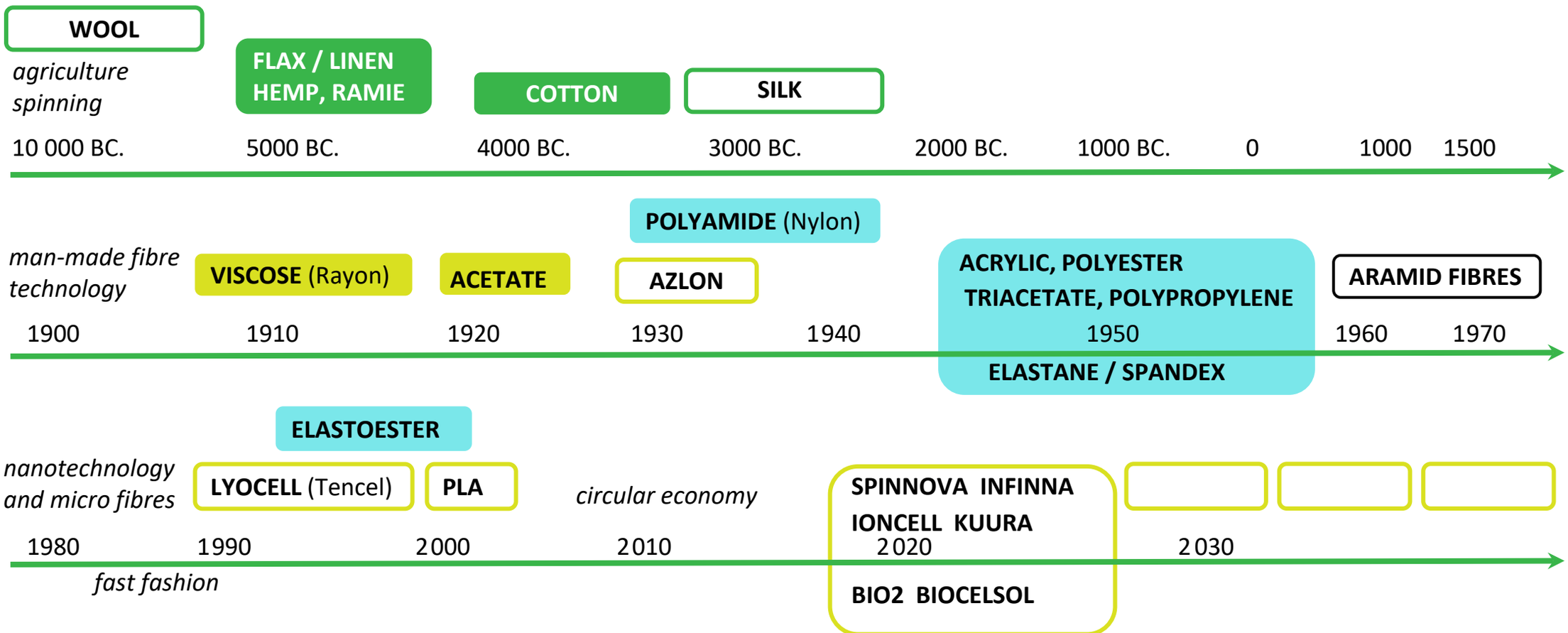


SusTexEdu

GINETEX FIBRE TABLE

International textile fiber abbreviations

Timeline of textile fibres



SusTexEdu

https://www.fabriclink.com/University/History.cfm
https://iwto.org/wool-supply-chain/history-of-wool/
https://heritagecrafts.org.uk/spinning/

Textile fibre world markets

- Global fibre production has increased at an accelerating rate total and also per person.
- The growth in fibre production has significant impacts on people and the planet. Awareness of the urgent need for more responsible use of resources and decoupling growth from resource consumption is growing; however, change is not yet happening at the scale and speed required.
- Polyester is the most used textile fibre in the world and cotton comes as second.
- The current situation of the textile fibre production you can follow on statistics which are yearly published:
  - *Preferred Fiber & Materials Market Report* https://textileexchange.org
  - *An overview on global fiber and yarn market* https://www.textiletoday.com

SusTexEdu

Natural raw materials of textile fibres: Cellulose and protein

- As natural and organic materials, cellulose and protein both are biodegradable.
- They are biodegradable by many micro-organisms. This makes them excellent alternative when developing new, fully biodegradable materials and avoiding microplastics.
- Their lifeloop depends on the use and treatments made to them.
- Cellulose is a molecular compound containing only carbon and hydrogen.
- Proteins are very large molecules (macromolecules) composed of many peptide-bonded amino acids.

Photos from Wikipedia:
Birch trees in Finland by SeppVei, C0 1.0 Universal
A cow taking rest by Kim Hansen, CC BY-SA 3.0

SusTexEdu

Raw material of synthetic fibres: Petroleum

- Petroleum is an organic nonrenewable source of energy. It took millions of years for it to form.
- Petroleum is a molecular compound containing only carbon and hydrogen. Materials made from petroleum are called petrochemicals.
- Petrochemicals are used for manufacturing synthetic fibres.
- Whether made from recycled or virgin feedstocks, petroleum-based fibres will not biodegrade.

Photos from Wikipedia:
Oil Rigs, photo by Aaron Logan (Lightmatter), CC BY 2.0 DEED
Fuel barrels, photo by Trevor MacInnis, CC BY-SA 2.5 DEED

Environmentally Advantaged Fibres

- Another short-term development on the fibre future are environmentally advantaged fibres.
- The term “green” fibre can mean avoiding or/and reducing environmental critical factors, as:
  - agricultural land use
  - carbon dioxide emissions (carbon footprint)
  - microplastic emissions
  - unethical labor treatment
  - unethical treatment of animals
  - use of harmful chemicals
  - use of water resources (water footprint)

- As one solution there are new fibres being developed e.g. new biobased polymers.

Textile laboratory in Hogent, photo by authors

Cellulose Fibre Innovation Of The Year 2021.
Textileworld com

Molecular structure of textile fibres

- Textile fibres consist of molecules (group of atoms) organized in chains, which in organic fibres mainly consist of Carbon (C), Hydrogen (H) and Oxygen (O), and often also Nitrogen (N).
- A monomer is a small molecule.
- A polymer is a long-chain molecule of repeated pattern of small molecules, i.e. monomers, which are connected to each other by chemical bonds.

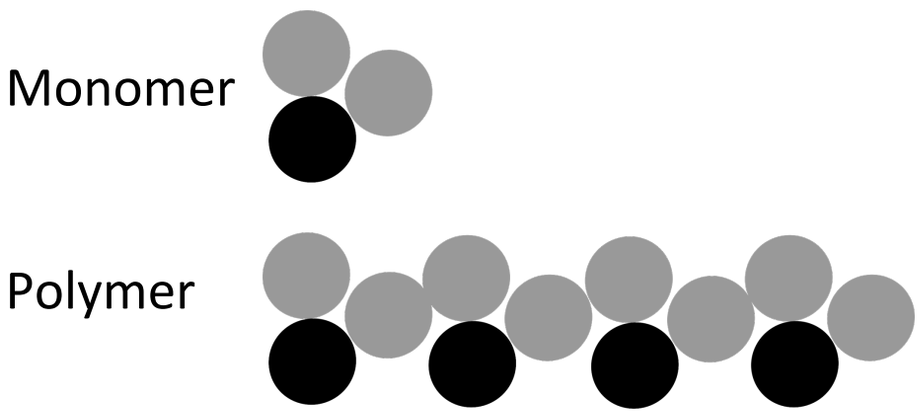


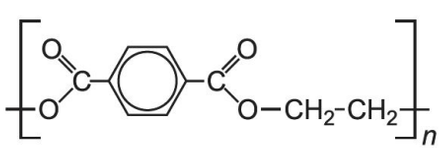
Image by authors

SusTexEdu

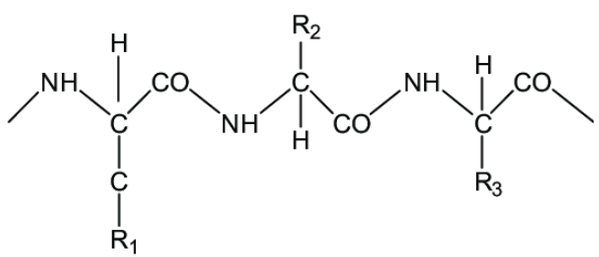
Chemical composition of textile fibres

- The chemical structure of man-made fibres is quite unambiguous and its shown as molecule pattern.
- The most common elements in man-made fibres are Carbon (C), Oxygen (O), Nitrogen (N) and Hydrogen (H).

polyester:



wool:

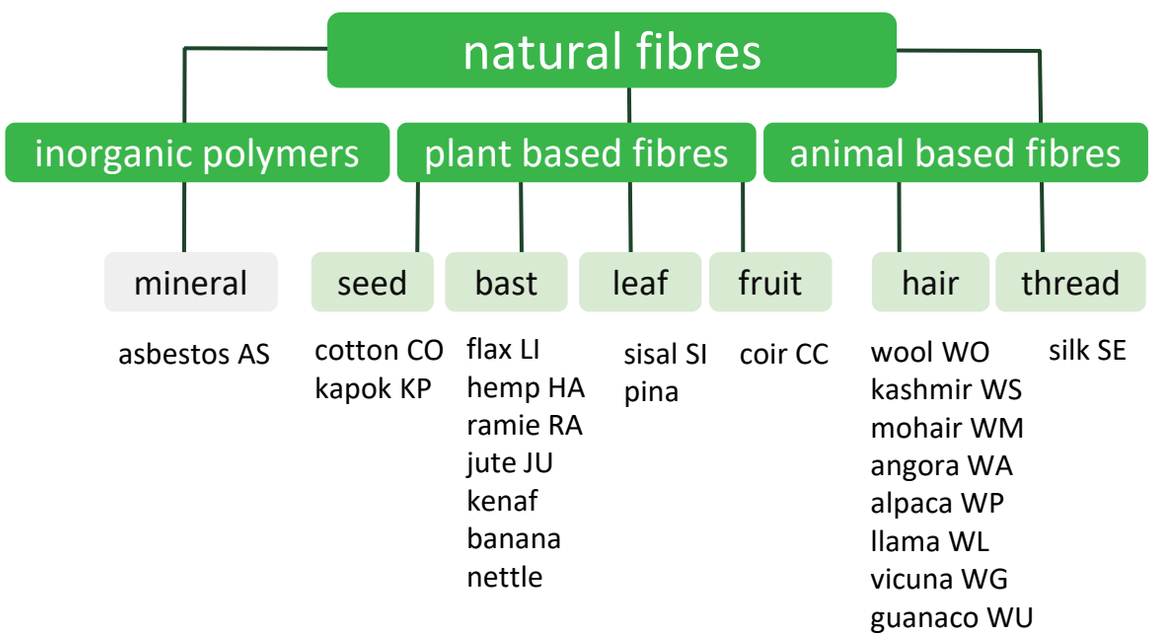


- Natural fibres consist several different chemical substances and their structure is told as average percentage shares of the weight of the fibre.
- The main constituents of vegetable fibres are hydrocarbon compounds as cellulose, hemicelluloses, lignin, pectin, and wax. Animal fibre compounds consist beside C, H and O, also Nitrogen (H).

Chemical Composition of Natural Fibers and its Influence on their Mechanical Properties. adsabs.harvard.edu

Natural fibres

- Plant based natural fibres are seed fibres as cotton, bast fibres as linen, leaf fibres as sisal and fruit fibres as coir.
- Animal based natural fibres are obtained from hairs of different animals as wool from sheep and threads made by certain insects as silk maggot.



SusTexEdu

Plant based natural fibres

- Although there is no profound relationship between the origin of fibres and their mechanical properties, bast fibres possess the lowest microfibril angle and, on average, best mechanical properties.
- Physical and mechanical properties of plant fibres differ from one type to another leading to differences in end use performance. There is a strong relationship between the fine structure of plant fibres and their mechanical properties.

- Plant fibres are an alternative resource to synthetic fibres as reinforcement for polymeric materials for the manufacture of cheap, renewable and environmentally friendly composites.
- With the increase of environmental awareness, e.g. the use of hemp and ramie as such for clothing and interior textiles has increased.

Review of the history, properties and application of plant fibres. Leonard Y. Mwaikambo 2006

Cotton (CO)

- Cotton is a soft, staple fiber that grows in a boll around the seeds of cotton plant.
- Cotton is the most produced natural fiber, over 80% of the entire natural fibre production.
- Cotton has been used already 7000 years ago and it is still a part of our daily lives. We dry our faces on a soft cotton towel in the morning until we slide between fresh cotton sheets at night. It has hundreds of uses, from blue jeans to shoe strings.
- The main producing countries of cotton are China, India, the United States and Pakistan

Cotton field, photo by David Nance on Wikipedia, Public Domain

SusTexEdu

Story of Cotton. Cotton.org

TASK 8

Cotton fibre

- Cotton mainly consists of cellulose (88-96%). In addition cotton contains pectins, proteins, wax and other by-products, such as color pigment residues.
- Waxes improve the spinnability of the fibre. The waxes are removed before the cotton is bleached and dyed to allow water to penetrate the fibre. Bleached cotton contains about 99% cellulose.

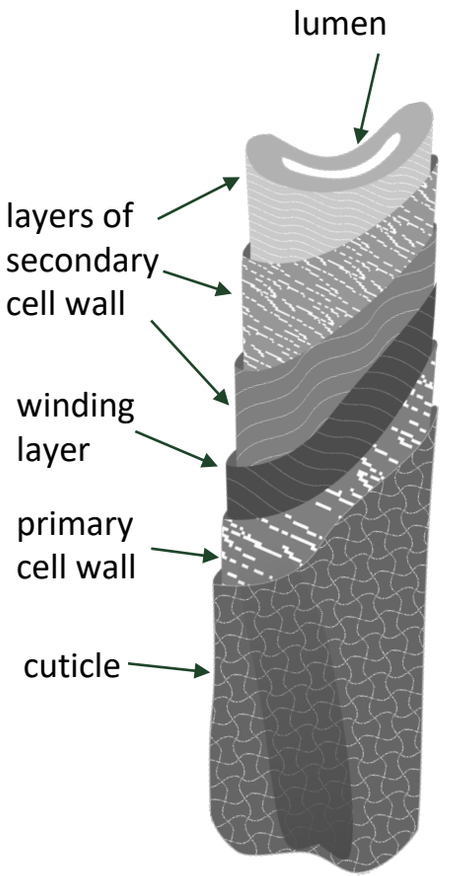
Cotton fibre, A unripe, B ripe, C mercerized / Images by authors

SusTexEdu

… cotton fibre

Physical structure of cotton comprises of several cell walls:

- The outer protective layer called cuticula mainly consists of waxes and pectin. The primary wall is the original thin cell wall consisting of crossed cellulose crystalline fibrils.
- Winding or transition layer is between the primary and secondary wall. Its fibrils are more wider angle and in this region the fibrils periodically reverse the direction of the spiral. The secondary wall has several layers of spiraling fibres, which make up most of the weight of the cotton fibre.
- The lumen, located within the secondary wall, is a hollow canal in which the fibrilles carry nutrients of the cotton during growth.



Structure of cotton fibre, image by authors

Physical structure of cotton. BdTextileblog 2012

Properties of Cotton

- With the best cotton qualities the ratio of fibre length to thickness is about 5000. The ratio of the worse qualities can be 1000.
- Long-fibre cottons are usually fine and short-fibre cottons are thicker varying between 1 dtex and 4 dtex.
- Cotton is a fairly strong fibre, which varies depending on the species. It is stronger as wet. The dry strength is 18 – 52 cN/tex (cN=centi Newton).
- The elongation at break is 3 – 7% and the elastic recovery is small. This is why cotton products tend to wrinkle.
- The bending strength and abrasion resistance of cotton are quite good. The cotton product does not pill easily.
- Cotton's weather and light resistance is moderate, it yellows and loses strength in sunlight.
- Cotton is cool and soft to touch. As wet it feels cooler, e.g. as underwear it looses the warming properties when the user is sweating.

Characteristic values of cotton. Textileschool.com 2018

Biological properties of Cotton

- Micro-organisms such as mold and fungi can damage cotton at the right temperature and humidity.
- Impurities and dirt increase the destruction caused by molds and fungi. Because of this, raw cotton is more susceptible to mold damage than bleached cotton.
- The UV rays of sunlight weaken cotton, suitable humidity and temperature can further enhance the deterioration.
- Long-term storage at high temperatures yellows and embrittles cotton.
- As cellulose fibre, cotton withstands heat relatively well and it does not melt like synthetic fibres. Cotton can be ironed with a hot iron (220°C), however, depending the finish of the product.

TASK 10

Sustainability of cotton

- The biggest environmental harms caused by cotton cultivation are artificial irrigation*, fertilizers and chemicals used to control pests and plant diseases.
- Cotton is mainly picked by machine, but still also by hand, which involves health problems.
- Intensive cotton cultivation impoverishes the soil and takes farmland away from food production.
- The aim is to guide cotton farmers to more sustainable production with various certificates and programs.

- Cotton can be called organic if it has been grown using organic methods.
- Currently, the most widely used certification system for organic cotton is the Global Organic Textile Standard (GOTS).
- In the production of Fair Trade Cotton, special attention has been paid to the rights of farmers and the realization of ethical perspectives.
- Better Cotton Initiative (BCI) cotton aims to raise awareness among cotton farmers about environmentally friendly farming methods and help them transition to more sustainable farming methods.

Cotton. Worldwildlife.org
Cotton is a popular fiber choice for both brands and consumers. Textile Exchange

The use of Cotton

- Cotton fibre is a natural hollow fibre. It is soft, cool, known as breathable and absorbent fiber, so products made of cotton are pleasant to wear.
- Depending on the species and the fineness of the fibre, cotton is mainly used for apparel as well as for home and furnishing textiles and also in technical textiles. It is used as fibre, as yarn,as sewing thread, as fabric and as knitwear.
- Cotton can be blended with other fibres; eg. with linen, wool, polyester and viscose to achieve the best properties of each fibre.

SusTexEdu

Photos from Wikipedia:
Texture of warn denim, photo by Nikodem Nijaki, CC BY-SA 3.0 DEED
Blue T-shirt, photo by Camisetas, CC BY-SA 3.0 DEED

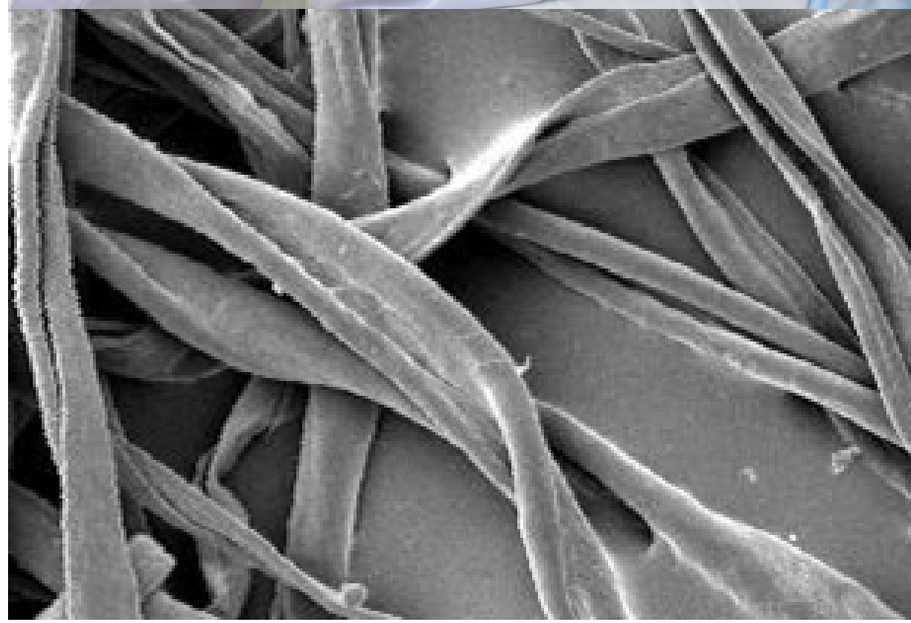
Identification of Cotton

Identification of many natural fibres is possible using the microscope:

- Longitudinal view of cotton: mature cotton looks like a flat, twisted, ribbon or a collapsed twisted tube.
- Cross section of cotton fibre is referred to as being kidney-shaped.

Other ways of identification:

- Cotton is similar to paper in its fire behavior. It burns like paper, the burn residue is gray ash and it smells like burned paper.



Photos:
A Microscope by Yakuzakorat / Wikipedia CC BY 4.0 DEED
Cotton fibres by Featheredtar / Wikipedia CC BY 3.0 DEED

SusTexEdu

Linen / Flax (LI)

- Flax is a bast fibre which means it comes from the stem of a plant.
- Linen textiles history goes back many thousands of years. Dyed flax fibres found in a cave in Southeastern Europe suggest the use of woven linen fabrics from wild flax may date back over 30 000 years. Linen was used in ancient civilizations including Mesopotamia and ancient Egypt.
- Linen is produced today mainly in Europe.

Linen field in August, photo by Markus Hagenlocher on Wikipedia CC BY-SA 3.0 DEED

SusTexEdu

Differences between flax and hemp
J.Wiener, V.Kovacic, P. Devloja
Will linen replace cotton?
Premierevision 2022: Today's eco-question

Flax fibre

- Flax is a bast fibre. Flax fibres vary in length from about 25 to 150 mm and average 12–16 micrometer in diameter. There are two varieties: shorter tow fibres used for coarser fabrics and longer line fibres used for finer fabrics.
- Flax fibres can usually be identified by their “nodes” which add to the flexibility and texture of the fabric.
- The amount of cellulose in flax fibres varies from 70% to 85%, 11-20% hemicelluloses and the rest are pectins, lignins, fat and wax.

Microscope image of flax fibre by Ian Richardson on Wikipedia CC BY-SA 4.0 DEED

Properties of Linen

- As all bast fibres linen has a good tensile strength which increases when wet.
- Flax fibre is absorbent, and dries faster than cotton.
- Linen resists dirt and stains relatively well.
- Linen has no lint or pilling tendency.
- Linen can be dry-cleaned, machine-washed, or steamed. It can withstand high temperatures, but it shrinks in the first washes.
- Linen wrinkles easily

Linen fabric, photo by authors

SusTexEdu

The use of Linen

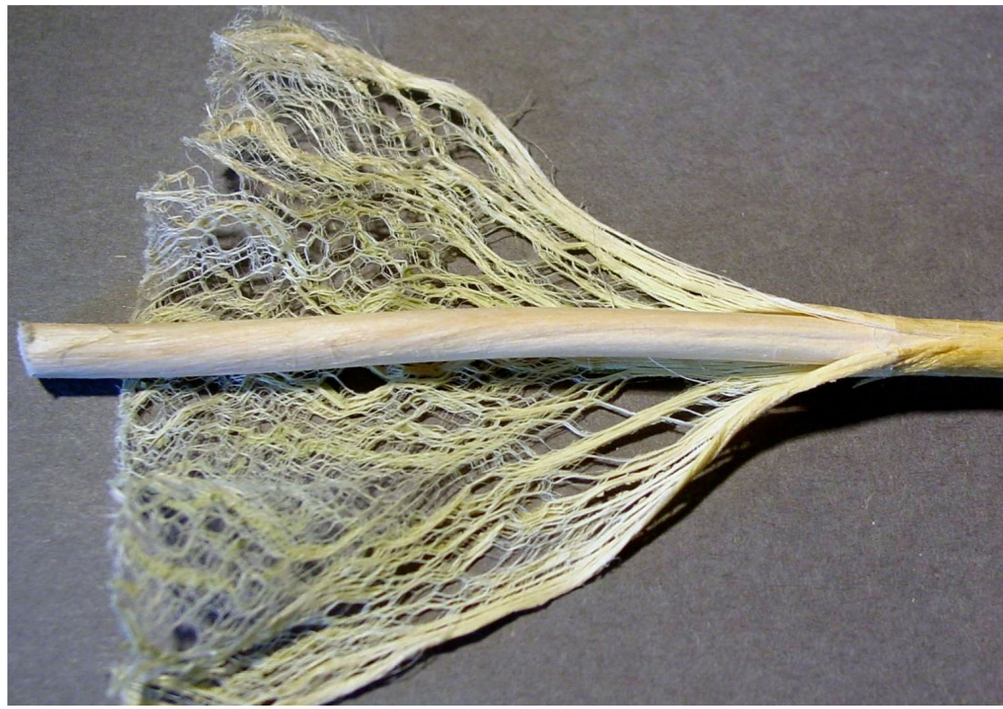
- Linen can be up to three times stronger than cotton. This is because the cellulose fibres in linen yarn are slightly longer and wrapped tighter than those found in cotton yarn.
- The great durability allows linen products to be long-lasting. For that it is usable for interior textiles as tablecloths, sheets and towels. It is also been earlier used for sails.
- Linen is comfortable to wear in hot weather and is valued for use in garments as shirts, dresses and pants.

Linen shirt, photo by authors

SusTexEdu

Hemp (HA)

- Hemp fibre is obtained from the fibre bundles of the stem of the Cannabis Sativa plant. Fibre hemp is long-stemmed, up to 4.5m high.
- The first woven fabrics were hemp, dated back to 7000- 8000 BC. The Chinese used hemp both as a medicinal plant and for fibres. Hemp was the first cultivated fibre plant in Central Asia.
- Today hemp is produced in France, Germany and Netherlands. It is also cultivated in China and North-Korea



Hemp stalk, photo by Natrij on Wikipedia, public domain

SusTexEdu

Hemp production in the EU agriculture. ec.europe.eu

A sustainable and economical alternative to cotton. Schumacher, Pequito, Pazour 2020

Hemp fibre

- Hemp fibre is very similar with its structure as linen fibre.
- Length and diameter of hemp fibres are 1-5 meters and 16-50 microns respectively.
- The distribution of chemical constituents of hemp stems varies remarkably between the outer bast and the woody core. Chemical composition of outer bast has 60-70% cellulose, 15-20% hemi-cellulose and rest is lignins, pectins, fat and wax.

Cannabis Sativa plant, photo by Barbetorte on Wikiwand CC BY-SA 3.0

SusTexEdu

Differences between flax and hemp
Wiener, Kovacic, Dejlova 2003

Properties of Hemp

- Hemp fibres are long, strong and durable and they resemble linen in feel and appearance.
- However, compared to linen, hemp's light resistance is worse, and it is also rougher and less flexible.
- Hemp fibres have the best UV protection of natural fibers.
- Hemp is also an antibacterial, antimicrobial and hypoallergenic fibre.

Hemp stems and fibre, photos by authors

UV protection afforded by textile fabrics made of natural and regenerated cellulose fibres
Kocic,Bizjak, Popovic, Poparic, Stankovic 2019
Antibacterial Properties of Hemp and Other Natural Fibre Plants: A Review
Khan, Warner, Waning 2014

The use of Hemp

- Hemp fibre is very similar to linen and the interest of the textile industry in using hemp fibre is growing.
- Hemp has good wet strength, so it is been used in ropes and sails. However, synthetic fibres have reduced the use of hemp.
- It can be refined into a variety of commercial items beside textiles and ropes, including paper, biodegradable plastic, paint, insulation, biofuel, food and animal feed.

Photos:
Hemp rope by Travis Isaacs / Wikipedia CC BY 2.0 DEED
Hemp sack by Katorisi/ Wikipedia CC BY 2.5 DEED
Hemp shorts by Matti Blume / Wikipedia CC BY-SA 4.0 DEED
Hemp brique by Sauvageot / Wikipedia CC BY-SA 4.0 DEED

SusTexEdu

Defining Hemp: A Fact Sheet Defining
Congressional Research Service (U.S.)

Ramie (RA)

- Ramie is classified as a nettle plant and is cultivated as a perennial. The plant is also called Chinese grass.
- The plant grows very quickly, reaching a harvesting length of 1-2.5 meters in just under two months. It can be harvested up to 6 times a year.
- Almost all ramie fibre is produced in China. In addition it is cultivated in Laos, the Philippines and Brazil.

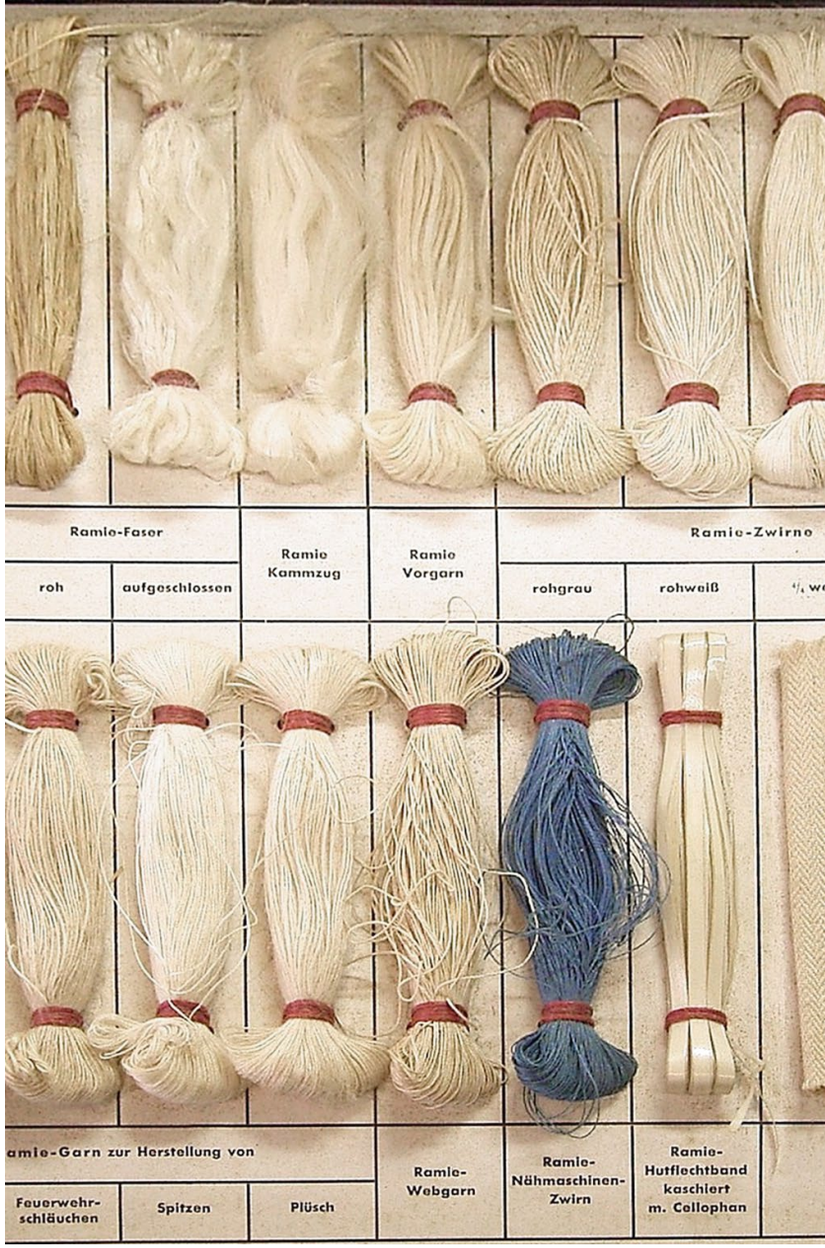
Ramie plant, photo by Sphl on Wikipedia CC BY-SA 3.0

SusTexEdu

Ramie plant Britannica.com

Ramie fibre

- Rami is a white and shiny fibre and it has many excellent textile properties. It is the strongest of all plant fibres. The threads often feel hairy because the fibres are coarse and stiff.
- Its use is limited by the difficulty of separating the fibre from the plant stem. The fibre comes from the inner bark of the vegetative stalks and not the woody stem itself or the outer bark.
- Rami is used on its own or mixed with cotton, linen, silk or synthetic fibers. It is used both for knitwear and woven fabrics.



Rami yarns, photo by Frank Vincentz on Wikipedia CC BY-SA 3.0 cropped

SusTexEdu

Properties and Uses of Ramie Fibre. Textile Engineering

Nettle

- Nettle is a bast fibre. It is strong as linen, but more flexible. The thickness and tightness of fibres varies, making it possible to offer resistant, supple and light fabrics by working with tight fibres, or very warm by working with looser fibres.
- As a perennial plant, nettle can be harvested several times a year. Only three species of nettle can be harvested for textiles. Nettle is explored to get it more common used as a green fibre.
- The European nettle is mainly produced in Germany. The giant nettle (Allo) is produced e.g. in Nepal.

Wild growing nettle in Finland, photo by authors

SusTexEdu

Nettle fiber: The eco-friendly resurgence in sustainable fashion. Rahna Mohan 2023
The new textile innovation composed of nettle fibre. Promostyle
Allo textiles - Himalayan Giant Nettle of Nepal. asiainchorg

Nettle

- Nettle fibre production in Europe began in the 19th century and during the World Wars the fibre was promoted as a substitute for cotton. It was cultivated in Germany and Austria and used for textile production. Processing facilities for nettle fibres were destroyed during the 2nd World War and other cost-effective fibres became better available.
- At present, acceptable methods and technology for large scale processing of nettle fibre do not exist. However, a recent processing method for flax and hemp fibres might be adapted for processing of nettle fibres, too.

Nettle fibre, yarn and fabric, photo by Textile Museum Tilburg on Wikipedia CC BY-SA 4.0 DEED

SusTexEdu

Applications of Nettle Fibre in Textile - A brief review
Singha, Nayak, Lakshmanan Ammayappan, Alok Nath Roy 2021

Sustainability of flax and other bast fibres

Bast fibres are seen environmentally friendly for following reasons:

- Some nitrogen fertilizers are used in the cultivation of flax, which grow its stem, not much in other bast fibres.
- Fertilizers may end up in waterways. Bast fibres are undemanding to both soil and irrigation. They require few or no watering.
- Pesticides are used in small amounts or not at all in the cultivation, mainly for flax.
- Even though they take up arable land, the bast fibres act as fast-growing (2-5 months) carbon stores and prevent the erosion of poor soil. They also benefit biodiversity.

Harvesting of Flax in Belgium, photo by Alexandre Dulaunoy on Wikipedia CC BY-SA 3.0

Differences between flax and hemp. J.Wiener, V.Kovacic, P. Devloja

Other plant based natural fibres

- Seed: Kapok
- Leaf: Sisal, Abaca, Banana, Pineapple and Phormium
- Bast: Jute, Bamboo, Bagasse and Kenaf
- Fruit: Coir

Kapok seeds, photo by J-M. Garg on Wikipedia.
GNU Free Documentation License

Review of the history, properties and application of plant fibres. Leonard Y. Mwaikambo 2006

Animal based natural fibres

- Animal hairs are natural fibres grown by animal that covers most of their body. They are made up of the protein keratin, the same protein found in human hair.
- The fleece protects the animal from the weather, keeping it warm during winter and cool during the hot summer due to the natural insulating and cooling properties of its own fleece.
- Also threads made by certain insects as silk are animal based fibres. Their function is to protect the maggot during its development to an insect.

Wool fibres, photo by authors

SusTexEdu

Wool (WO)

- The term wool is used for fibres obtained from sheep.
- Sheep have been kept as domestic animals for 10 000 years. There are hundreds of sheep breeds known in the world. The natural colors of wool vary from white and brown to different shades of greys.
- Australia is the world's leading producer of wool, followed by China, Russia, New Zealand, Argentina, South Africa, the UK and Uruguay. Merino sheep is originally from Spain, but was brought to Australia in the 18th century.

Gotland sheep, photo by authors

SusTexEdu

Sheep: Genetics Selection Evolution, IWTO
Wool fibre: Yashasree Ingle

Sustainability of wool

- Sheep are raised by grazing them in fields and meadows. Grazing, on the other hand, takes care of nature and increases its diversity. However, in harsh conditions, sheep can cause environmental damage by eating all the vegetation. Urine and droppings from sheep can also eutrophicate waterways when they get there.
- Pesticides can be used in wool production. Sheep have been sprayed to kill parasites and worms or may have been bathed in insecticide. The use of pesticides is not permitted in wool classified as organic cotton.
- Wool as a protein fibre is lasting longer than cellulose fibres, it is also recyclable. The fibre can withstand the process when removed from e.g. an old woolen garment by "shredding" for use again.

About sustainability of wool: The International Wool Textile Organisation

Wool fibre

- Sheep can have only underwool (merino sheep) or only coverwool (such as Leicester) or their intermediate form (crossbreeds).
- Some sheep breeds have both under and coverwool / dual coated fleece (as Finnsheep).
- The underwool is finer, shorter and more woolly, when the coverwool is longer and more hairy.
- The sheep are commonly sheared twice a year.

Raw sheep wool has many impurities, photo by Rob MacEwen on Wikipedia CC BY 2.0 DEED

SusTexEdu

About shearing: sheep 101 info

… Wool fibre

- After shearing, the wool is sorted according to fibre fineness, length, strength and color and washed to remove debris, additives and wool grease.
- New wool is classified to 1st class, 2nd class and to not-usable wool.

Fibre length

- The fibre length of the new wool varies between 25 and 750 mm, depending on, for example, the breed of sheep.

Fibre density

- Wool is also separated into grades based on the measurement of the wool's diameter in microns and also its style. These grades may vary depending on the breed or purpose of the wool, e.g.:

  Merinos Diameter in microns / Name:

  - < 15.5 Ultrafine Merino
  - 15.6–18.5 Superfine Merino
  - 18.6–20 Fine Merino
  - 20.1–23 Medium Merino
  - > 23 Strong Merino

Environment-friendly processing of protein fibres. S.R. Shukla 2001

…wool fibre

- Curl is valued in wool fibre. The curliness of wool creates air pockets that insulate heat. Thanks to its high thermal insulation capacity, wool is warming in cold and cools in hot weather, making it suitable for year-round use.
- The underwool is often shorter, finer and softer, but also curlier than the cover wool. It also has better water absorption.

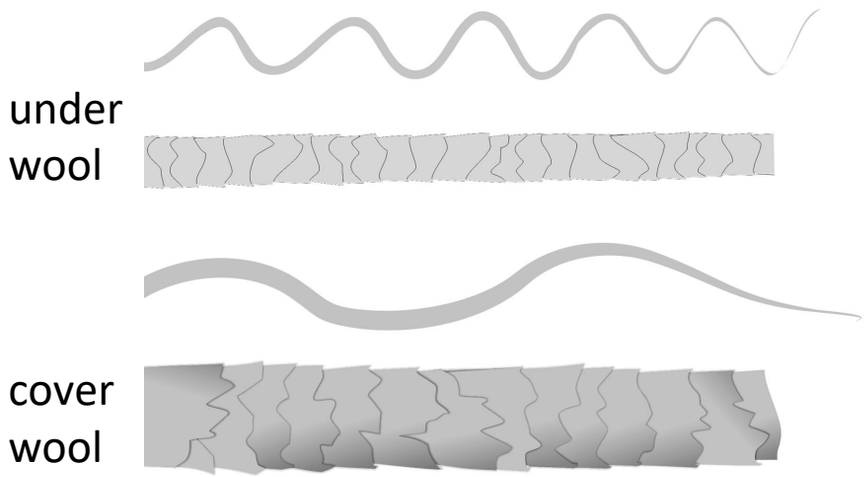
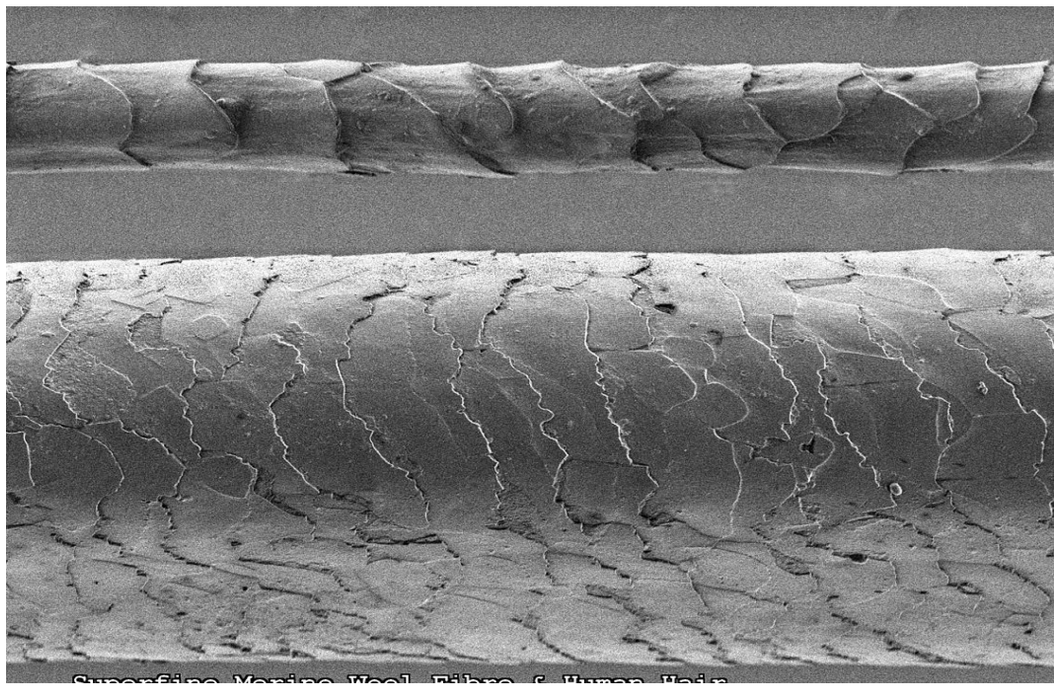


Image by authors

Wool properties: Huzaifa Javaid

… wool fibre

- Wool fibres have a scale-like surface structure. The inner layer of the fibre contains two parts: paracortex and orthocortex. The tension between the parts creates makes the fibre curly.
- When wool gets wet, the orthocortex swells and increases the curliness and therefore also heat insulation. In addition to heat insulation, curliness provides flexibility.



Microscope image by Textile and Fibre Technology CSIRO: on top merino wool and under human hair, Wikipedia CC BY 3.0 DEED, Attribution 3.0 Unported license

SusTexEdu

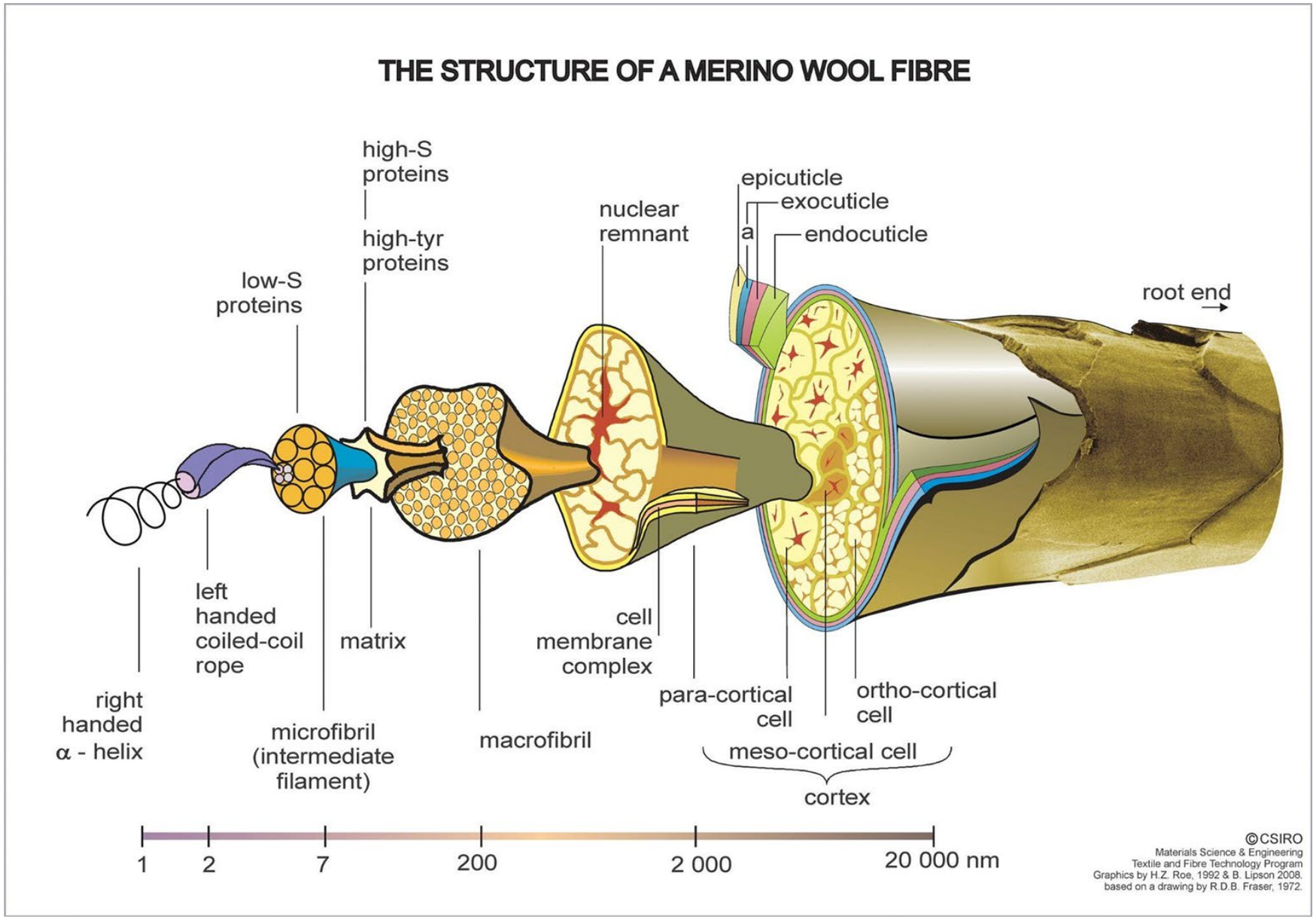


Image from Wikipedia by Textile and Fibre Technology CSIRO.
CC BY 3.0 DEED, Attribution 3.0 Unported license

SusTexEdu

Properties of Wool

Heat regulation

- Wool possesses unique physical and chemical properties. Its bilateral structure causes crimpiness to the hair, giving rise to a large number of air pockets, which are capable of retaining warmth.
- When wool absorbs moisture, it produces heat, so if you go from a warm room into a cold, the wool picks up water vapour from the air, keeping you warm. The reverse occurs when you go into the warm room – the moisture in your garment passes into the atmosphere, cooling you down. Wool also has:
  - low creasing tendency
  - antistatic properties
  - low flammability
  - decreased absorbance to dyes and chemicals
  - felting tendency
  - non-easycare properties
  - harsh feel

SusTexEdu

Environment-friendly processing of protein fibres. S.R. Shukla 2001

…properties of Wool

Water absorption

- Wool fibres have a waxy surface, which makes the wool repel water drops but still allows water vapor to be absorbed.
- The small pores of the surface layer allow water vapor inside the fibre, while the air pockets between the surface of the fibre and the surface of the fibre remain dry. This makes the wool comfortable in both warm and cool weather.
- Wool can absorb up to 30% of its weight in water without feeling damp. Cellulose does not have a similar property, but wet cotton, for example, feels cold.

Royal navy duffle coat 1942 by Royal Navy on Wikipedia, Public Domain

Environment-friendly processing of protein fibres. S.R. Shukla 2001

… properties of Wool

Other properties of wool

- does not wrinkle
- antistatic
- hardly electrified
- low flammability
- low absorbency of dyes and chemical
- felting
- may irritate the skin

Felted woolen insoles, photo by authors

Environment-friendly processing of protein fibres. S.R. Shukla 2001

… properties of Wool

Felting

Felting is an undesirable characteristic of woolen clothes, which is caused by the scales of wool fibres sticking to each other as a result of rubbing, e.g. during washing.

To reduce felting, complete removal of scales is detrimental to fibre properties. However, a smoother surface is necessary if, for example, you want to make the wool garment machine washable.

Removal is sometimes essential for getting better out of the wool characteristics.

- A non-environmentally friendly method is to use chlorination.
- Enzymes provide an ecologically smoother surface structure, which reduces scales sticking to each other.

Effect of enzymatic treatment on wool fabric. Dr. Pooja 2021

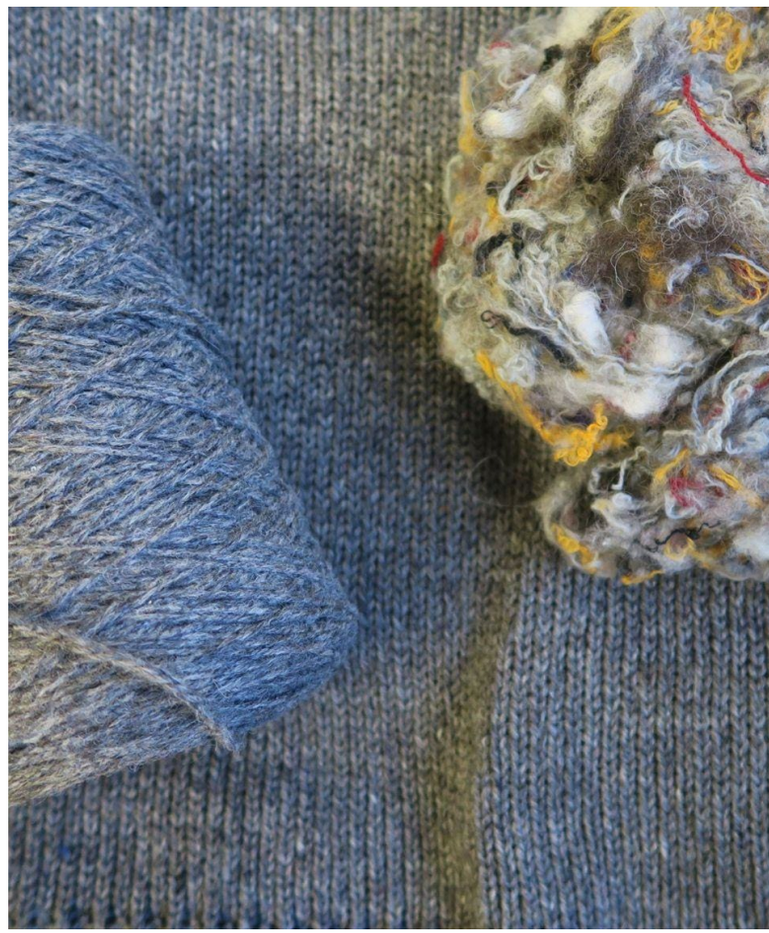
Use of Wool

Different wool qualities are used for different purposes, where fibre length and density are essential factors.

Any wool finer than 25 microns can be used for garments, while coarser wools are used for outerwear or rugs. The finer the wool, the softer it is, while coarser fibres are more durable and less prone to pilling.

Wool is used for textiles as follows:

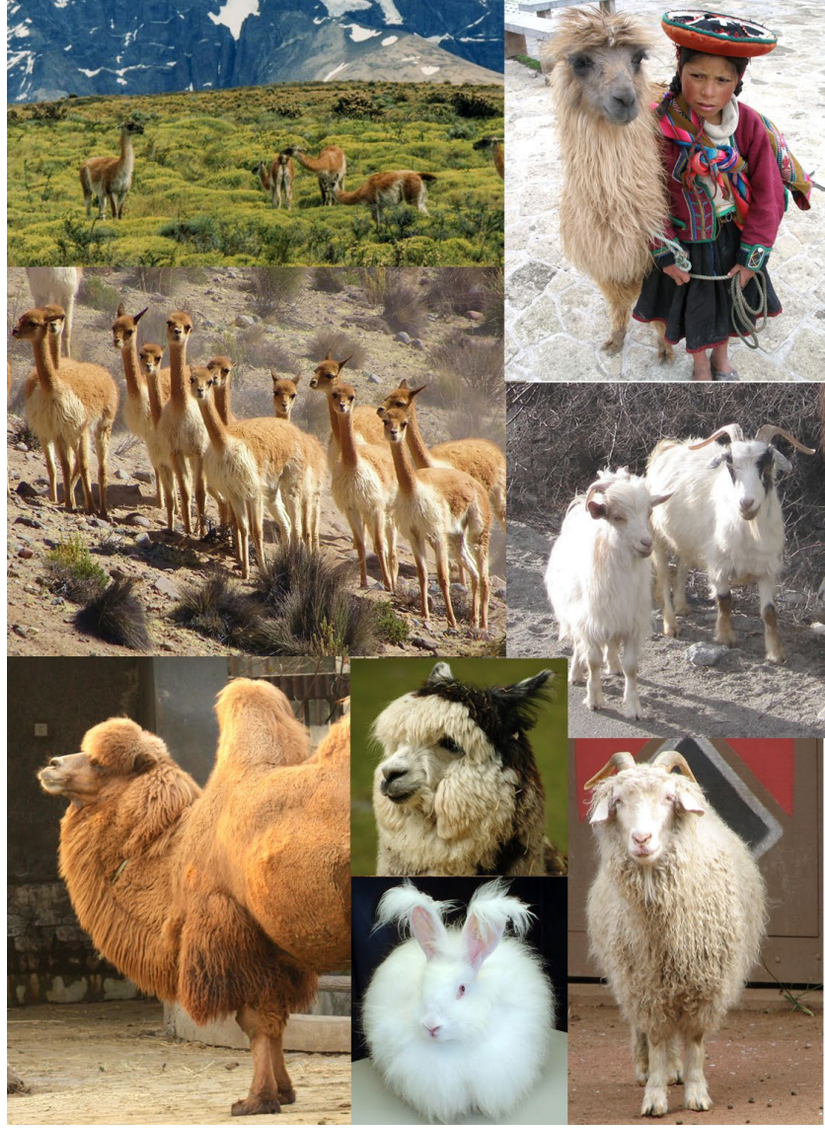
- Fibre (wadding and felt)
- Yarn (for hand knit and industrial)
- Knitwear, underwear, pullovers, outdoor accessories as socks, caps and scarves
- Woven fabrics, coats, suits



Recycled wool fibre, yarn and knit, photo by authors

Other animal hairs

- **Mohair** wool is obtained from Angora goats. Its very soft and long fiber. Due to lack of scales on the hairs, it is often blended with wool or alpaca.
- **Cashmere** wool is obtained from cashmere goats. Both the soft undercoat and the guard hairs can be used; the softer hair for textiles and the coarse guard hair for non-apparel purposes.
- **Angora** is the hair of the angora rabbit, very fine, soft, light and fluffy. It is warmer and lighter than wool due to hollows inside the fibres.
- **Camel** hair and wool of **llama** and its related **alpaca, vicuña** and **guanaco** are also used in the textile industry.



Photos: Wikipedia, collage made by authors
Mohair goat by Ltshears - Trisha M Shears, Public Domain
Angora rabbit by Ross Little, CC BY-SA 2.0 DEED
Cashmere (Pashmina) goats by Redtigerxyz, CC BY-SA 3.0 DEED
Alpaca by Kyle Flood, CC BY-SA 2.0 DEED
Camel by J. Patrick Fischer, CC BY-SA 3.0 DEED
Llama by Thomas Quine, CC BY-SA 2.0 DEED
Vicuñas by Henrie Marshall, CC BY-SA 4.0 DEED
Guanacos by Bernard Gagnon, CC BY-SA 3.0 DEED

SusTexEdu

Mohair Cashmere Angora Camel Llama Alpaca Vicuña Guanaco

Silk (SE)

- Silk refers to the fibers obtained from the cocoons of spinner insects. Almost all the silk used in textiles is obtained from the cocoon of a cultivated mulberry butterfly maggot.
- All though silk fibre is produced also by some spiders belonging to the Arachnida family, the spiders' fibre cannot be commercially produced.
- The history of silk begins before 2000 BC in China.
- Silk represents about 0.2% of the world's fibre production. Its production has been growing all the time. The most important silk producing country is China, followed by India and Japan.

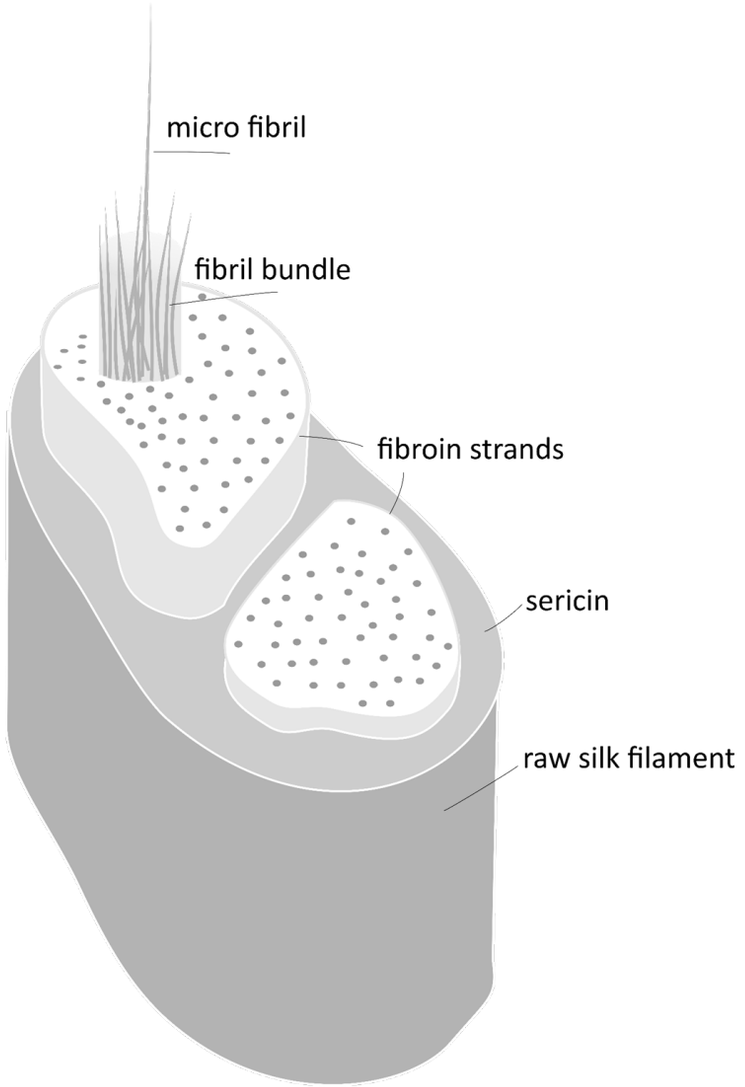
SusTexEdu

Silk cocoon, photo by Gerd A.T. Müller on Wikipedia, GDFL
Raw silk, photo by Armin Kübelbeck on Wikipedia,
CC BY-SA 3.0 DEED

Silk fibre

The cocoon consists of a continuous fiber, a filament, which the butterfly's larva has spun around itself.

- The mature silkmaggot builds its cocoon by extruding a viscous fluid from two large glands in the body of the silkworm. This solution is extruded through two ducts in the head of the silkworm into a common spinneret.
- The viscous part (fibroin) is covered by another secretion (sericin) which flows from two other symmetrically placed glands. These two components are cemented together by emerging into the air, coagulating and producing a firm continuous filament.



Structure of silk filament, image by authors

SusTexEdu

Usage of Silkworm Materials in Various Ground of Science and Research
Ghand, Ghand & Raula 2022

Properties of Silk

Silk as a protein fibre shares many properties with e.g. wool:

- good thermal insulation
- pleasant feel, lightness, smoothness (except Tussah-silk) and elasticity
- fine shine
- dirt repellency
- very good moisture absorption (without feeling wet)
- great strength and durability
- poor sunlight resistance
- poor sweat resistance
- chemicals and heat damage the fibre

There are two main types of silk maggots:

1. mulberry silk, also called 'cultivated silk'
2. 'wild silk' of which Tussah silk is the most important representative.

A view to the sustainability of silk

Butterfly larvae do not feel pain like we do. The nervous system is different from ours and the larva is just developing. One can't know exactly what they feel.

In the wild, they get into the digestion of lizards, snakes, frogs, and many insects, and can possibly suffer longer than when placed in hot water (the way much used before taking the fibre out of cocoon).

There is also a method of silk production in which the maggot is not killed but is allowed to develop into a butterfly: Peace silk or Ahimsa silk.

In the production of organic silk, no poisons or artificial fertilizers are used for the silk moth's food plant, the mulberry tree.

The dead larvae are used to fertilize the trees, i.e. the nutrients return to the cycle. The berries of the mulberry tree are delicious and the bark can be used to make tea.

Silk production brings income in developing countries and as a perennial plant, the mulberry tree prevents soil erosion. The production of organic silk can therefore be considered quite eco-efficient and an activity that sustains societies.

Raija Marja-aho, biologist 2019

Identification of textile fibres

- **Cellulose fibres** (Cotton, Linen, Rayon) burn constantly with light grey smoke, don't melt or shrink, smell like burning paper, and leave grey feathery ash.
- **Proteins** (Silk, and Wool) burn slowly, curl away from the flame, smell like burning hair and leave crushable black ash.
- **Acrylic** melts and burns, moves away from the flame, with a chemical smell and leaves a black, brittle hard bead.
- **Polyester** melts and burns, with a sweet smell and leaves a hard, black bead.
- **Nylon** melts and burns, with a celery smell and leaves a hard, grey, tan bead.
- **Spandex** melts and burns, with a chemical smell and leaves soft, black ash.

Photo by Осадчая Екатерина, Wikipedia CC BY-SA 4.0 DEED

SusTexEdu

Burn test / FabricLink Identification of textile fibres / The Textile Journal

Assignments and topics to discuss

1) DEFINITION OF TEXTILE FIBRES Looking with microscope different fibres (when possible)
2) FILAMENT & STAPLE FIBRES Looking for example polyester garments/fabrics, if they are filament or staple, comparing with a cotton garment/fabric
3) CLASSIFICATION OF TEXTILE FIBRES BY CHEMICAL STRUCTURE What is the difference between organic and inorganic?
4) TIMELINE OF TEXTILE FIBRES Why agriculture was significant for textile fibre development? When did industrialism start and what it means? What means nanotechnology? What means circular economy and why it started to get important? etc. questions and topics teacher sees important for the group.
5) NATURAL RAW MATERIALS Where can you find cellulose and where proteins?
6) SYNTHETIC RAW MATERIALS What are carbon and hydrogen? What problems, challenges the use of petroleum has?
7) ENVIRONMENTALLY ADVANTAGED TEXTILE FIBRES What means polymer?
8) COTTON FIBRE Why you think waxes improve cotton´s spinnability?
9) BIOLOGICAL PROPERTIES OF COTTON Transportation from Asia to Europe by ship, how to avoid mold and fungi?
10) THE USE OF COTTON Why blends can improve the properties of cotton? Which properties of cotton should be improved?
11) PROPERTIES OF LINEN Which properties of linen could be improved by blending with other fibres? With which fibres linen is mainly blended with?
12) SUSTAINABILITY OF HEMP How sustainable fiber you estimate hemp is and why?
13) WOOL Talk about mulesing of merino sheep
14) WOOL FIBRE What is the reason why wool keeps us warm even though it has no thermal conductivity properties?
15) PROPERTIES OF WOOL For what can the felting feature be used for? What is an enzyme?
16) IDENTIFICATION OF FIBRES Burning test

Learning material

Books: e.g.

- Textiles and Fashion Materials, Design and Technology. Part 1: Fibre Types. Rose Sinclair 2014

Online learning material: e.g.

- International textile fiber abbreviations
- “Natural products” by Britannica.com
- Textile Fibers © 2013 Cotton Incorporated PDF
- Textiles for Circular Fashion. Paulien Harmsen, Wouter Post, Harriette Bos. Wageningen University & Research 2022 PDF
- “Textile University” by Fabriclink

Tips for learning more

The International Wool Textile Organisation (IWTO)

Global Organic Textile Standard (GOTS)

Silk Story. Mulberries.org

Sustainable Fibres: Features, Properties, Application, Advantages and Market. Shamiksha Chougule 2023 in Textile Learner

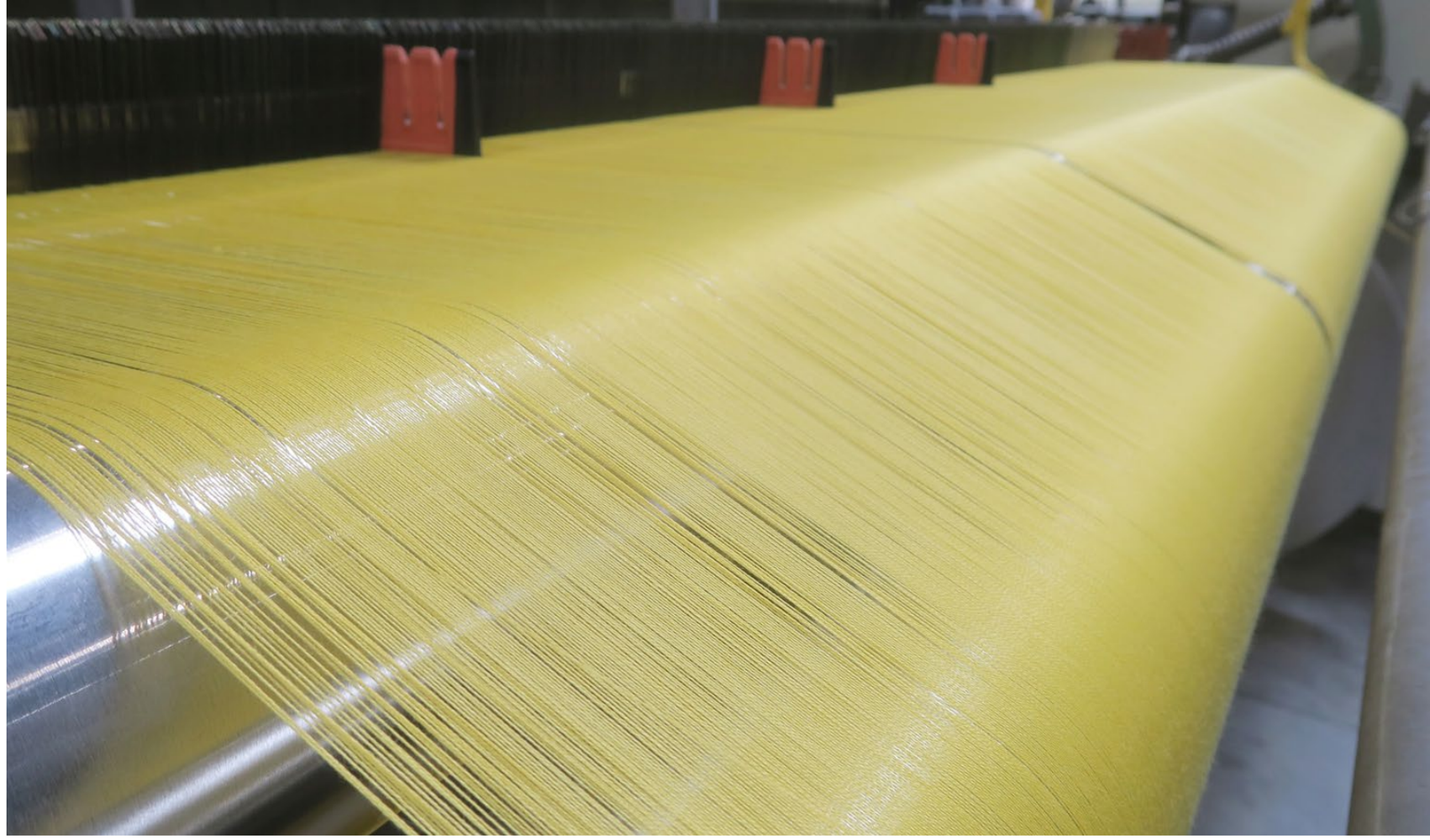
Harnessing Hemp's Sustainability Potential. Textile Exchange 2023

On keeping warm at sea – how the Faroese do it? Roar Heini Olsen 2007

SusTexEdu

SusTexEdu project (Education Partnership of Textile and Clothing Sector Materials & Sustainability, Agreement number 2021-1-FI01-KA220-HED-000023002) was funded by the Erasmus+ programme of the European Union.

Visit the project website to see all the intellectual outputs of the project.



SusTexEdu

Funded by the Erasmus+ Programme of the European Union