2.1 / 1 Manufacturing technologies of Man-made fibres

OVERVIEW

This open educational resource has been developed by:

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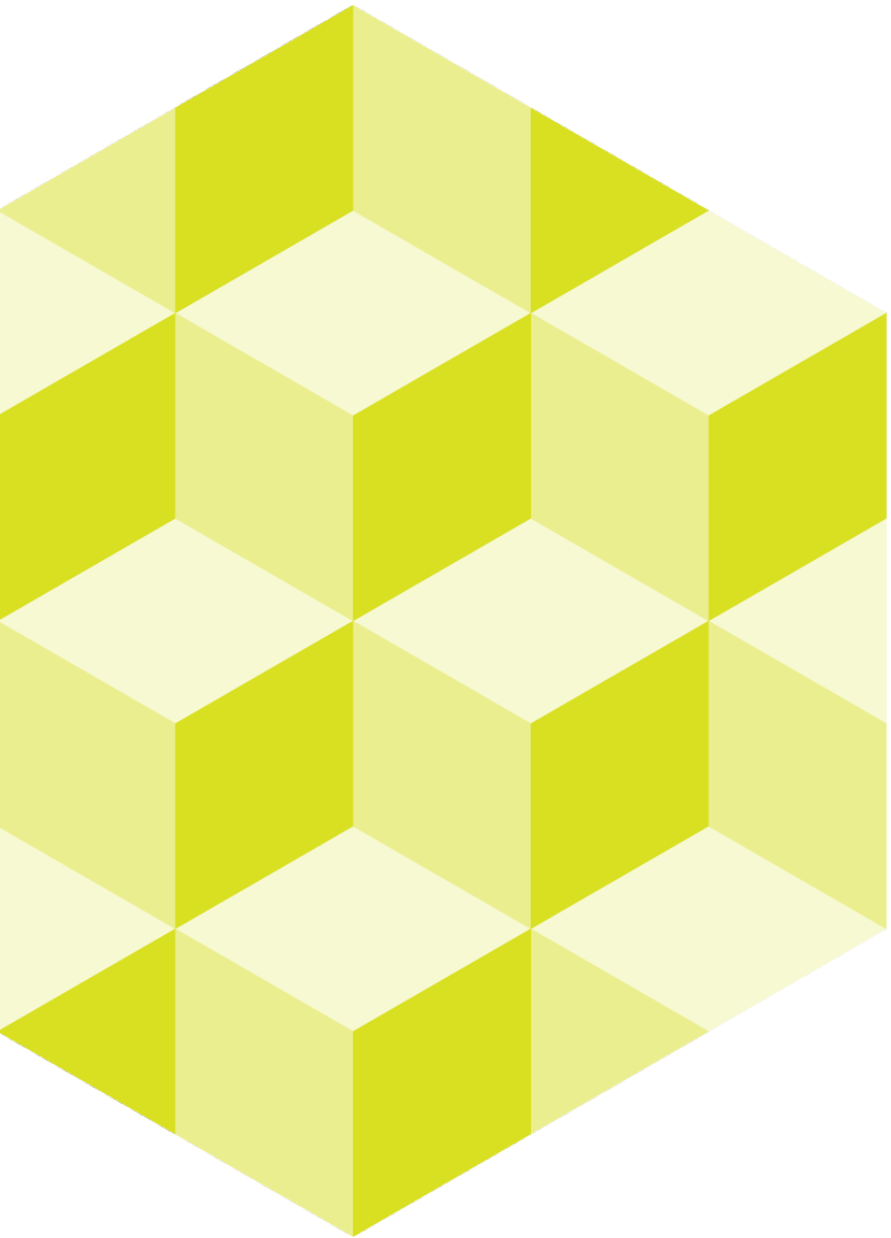
SusTexEdu

Funded by the Erasmus+ Programme of the European Union



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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

The learning unit aims to give the student in-depth knowledge of man-made fibres, their structure, properties and manufacturing.

LEARNING OUTCOMES

Ability to:

- to characterise the man-made fibres on the basis of the production methods of their diverse properties and reactions towards external influences.
- to name special, innovative fibres for clothing and interior textiles and to identify their end use.
- to identify textile fibres in various textile materials by means of analysis (microscope, solvent)

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

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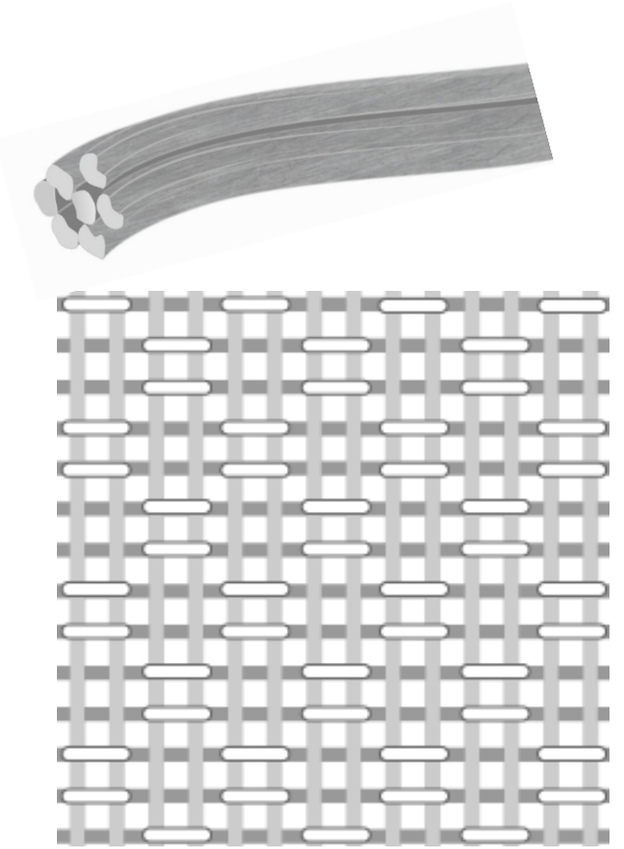
Outlines

- Introduction
- Classification of fibers
- Synthetic fibers
- Classification of synthetic fibers
- Common properties of synthetic fibers
- Fiber spinning techniques
  - Melt spinning
  - Solution wet spinning
  - Solution dry spinning
  - Gel spinning
- Regenerated fibers
  - Viscose rayon fibers
  - Lyocell fibers
- Application areas

What is a textile material?

- The word textile originates from Latin word “textilis” which means woven, fabric, cloth. The textiles can be defined as the products which are formed by the interlacement of fibres or yarn. The broad definition covers any product intermediate or final made in textile industry. Therefore, the term textile includes fibres, filaments, yarns, woven, knitted and braided cloths as well as non-woven fabrics. What is Textile | History of Textile | Importance of Textile on Textile Engineering 2023
- “Textile material has planar structure and consists of textile fibres or yarns”. (K. Hatch, 1998)



Images:
1. Fibres, by SusTexEdu
2. Weave by Jauncourt on Wikipedia (GFDL)

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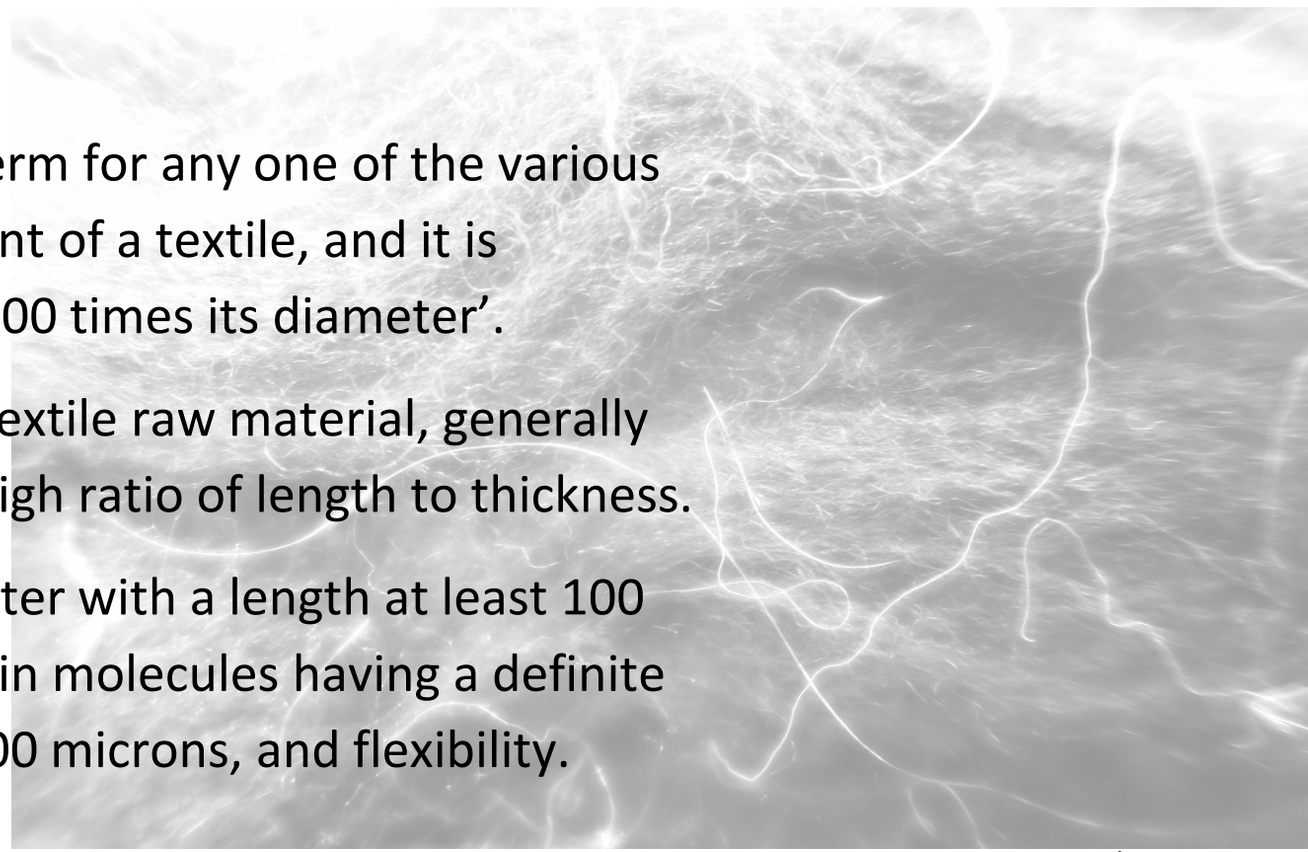
Introduction to textile fibres

Definitions of textile fibres

- According to ASTM, a fibre as a generic term for any one of the various types of matter that form the basic element of a textile, and it is characterized by having a length at least 100 times its diameter’.
- According to Textile Institute, a fibre is a textile raw material, generally characterized by flexibility, fineness and high ratio of length to thickness.
- Another industrial definition is, a unit matter with a length at least 100 times its diameter, a structure of long chain molecules having a definite preferred orientation, a diameter of 10-200 microns, and flexibility.



Polyester staple fibre, photo by SusTexEdu

… introduction to textile fibres

Historical development of textile fibres

Fibres are the basic units of all textile products and are in use since from thousands of years.

They are categorized in different generations:

- 1st Generation fibres (4000 BC to 1940) > natural fibres (cotton, wool, silk etc.)
- 2nd Generation fibres (1940 to 1980) > synthetic fibres (polyamide, polyester, acrylic etc.)
- 3rd Generation fibres (1985 to 1990) > aramid, polyethylene, aromatic fibres
- 4th Generation fibres continues > inorganic fibres (carbon, ceramic, glass etc.)

… introduction to textile fibres

Product development & serviceability of textile fibres

Fibre performance influences the final product:

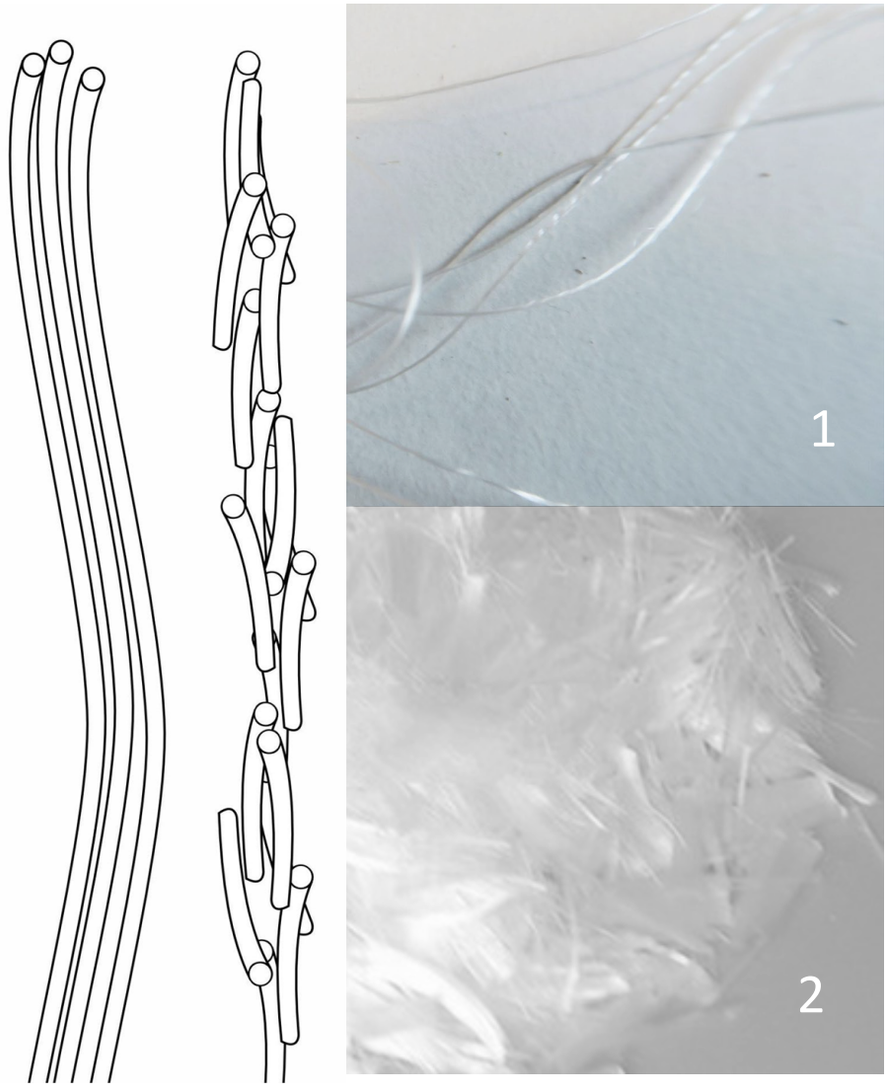
- aesthetics
- durability
- comfort
- appearance retention
- care
- environmental impact
- sustainability
- cost

Successful textile fibres must have:

- cost effectiveness, continuous availability
- good strength
- pliability
- length
- cohesiveness to be processed in suitable products

… introduction to textile fibres

- Fibres can generally be divided in two types:
  - filaments
  - staple fibres
- Filaments
  - are long, continuous fibre strands of indefinite length
  - can be measured in miles or kilometers
  - can be mono or multi filaments
- Staple fibers
  - are of short length, measured in inches or centimeters
  - depending on the type of fibres, the length range from few millimeters to around one meter



Filament and staple fibres. Drawing by SusTexEdu, 1. photo by SusTexEdu and 2. photo by Henan Botai Chemical Building Materials, Wikipedia (CC BY-SA 3.0)

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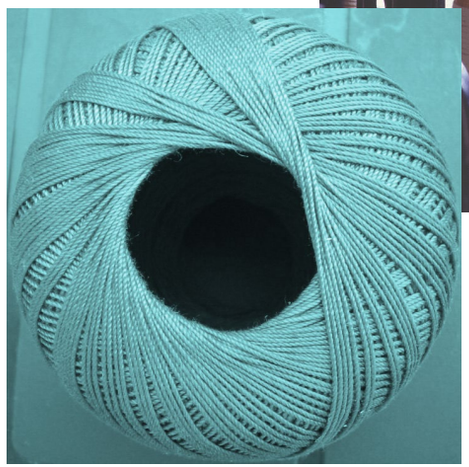
… introduction to textile fibres

Yarn

- consists of fibres and/or filaments with or without twisting, referred to filament yarn.
- has sufficient length and relatively small cross-section.

or

- it is grouping of fibres to form a continuous strand, referred to staple or spun yarn.



Images from Wikipedia: 1. blue crocheting thread, photo by Dicemani (CC BY 2.0), 2. spinning machine, photo by Scott Bauer and 3. S- and Z-twist yarn, image by Dfred (2 and 3 Public Domain).

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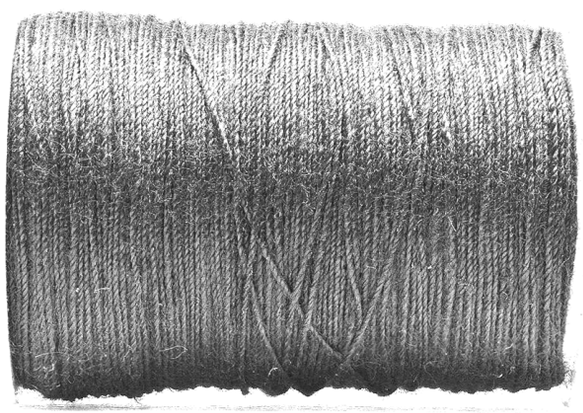
… introduction to textile fibres

- Spun yarn is obtained from staple fibres through a process of drawing, spinning and twisting.
- The performance of filament yarns and spun yarns is different in actual product.
- Spun yarns are more comfortable than filament yarn but handling would be difficult, they are also more expensive.

Filament yarn, photo by Odzir on Wikipedia (CC BY-SA 4.0)



Spun yarn, photo by 多多123 on Wikipedia (CC BY-SA 4.0)

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… introduction to textile fibres

Classification of yarns

- Staple yarns
- Continuous filament yarns
- Novelty yarns
  - Produced for decoration, seldom used for fabrics
  - Fancy or metallic yarns are well know Nys.
- Industrial yarns
  - Yarns with specific properties, high tech apps.
- High-bulk yarns
  - High level of fullness, remain bulky always
- Stretch yarns
  - Textured yarns for high extensibility

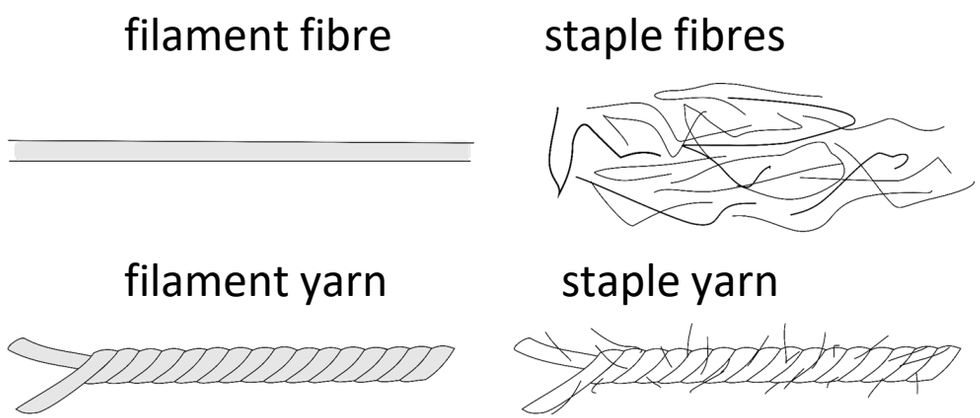

Image by SusTexEdu

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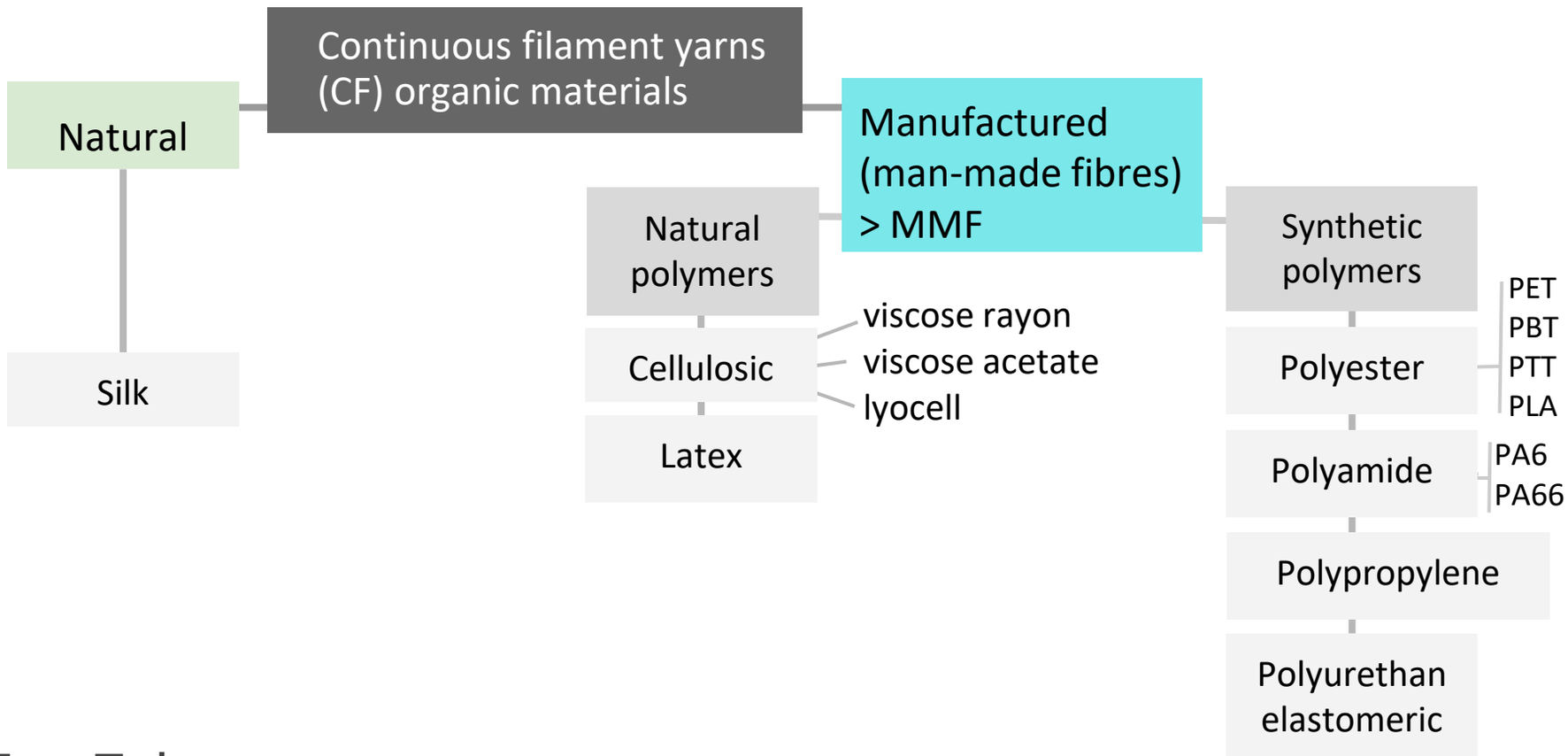
… introduction to textile fibres

Classification of continuous filament yarns



… introduction to textile fibres

Classification of textile fibres

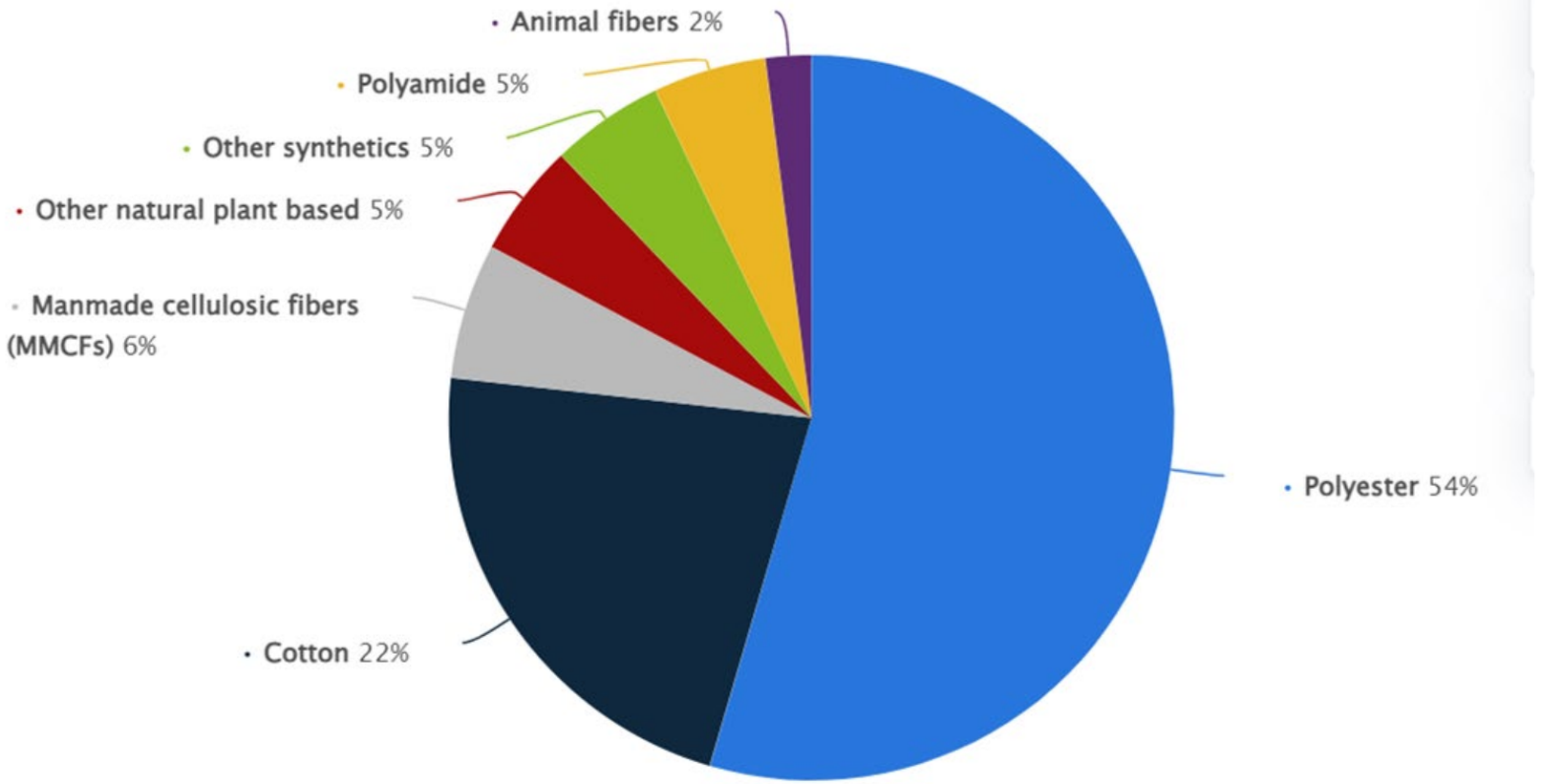
Fibres can be classified into two main groups:

- Natural fibres, which are obtained from nature and available in a ready-made fibrous form.
  - vegetable fibres, cotton, jute, hemp, etc.
  - animal fibers, wool, silk, hair, etc.
  - mineral fibers, asbestos, etc.

- Man-made fibres, which are obtained from something which was not previously in fibrous form, either by chemical or physical processes.
  - natural polymer/man-made fibres, viscose, lyocell, cupro etc.
  - synthetic fibres, polyester, polyamide, polyolefins etc.

… introduction to textile fibres

The global fibre production



Global fibre production 2022. Source: Statista.com

Synthetic Fibres

Synthetic fibres are man-made fibres that are manufactured industrially from low molecular raw materials.

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Synthetic Fibres

Synthetic fibres

- Chemically synthesized polymers and also referred to as chemical fibres, manufactured synthetic fibres or non-cellulosic manufactured fibres.
- Polymers for fibres are synthesized from small simple molecules (not naturally occurring)

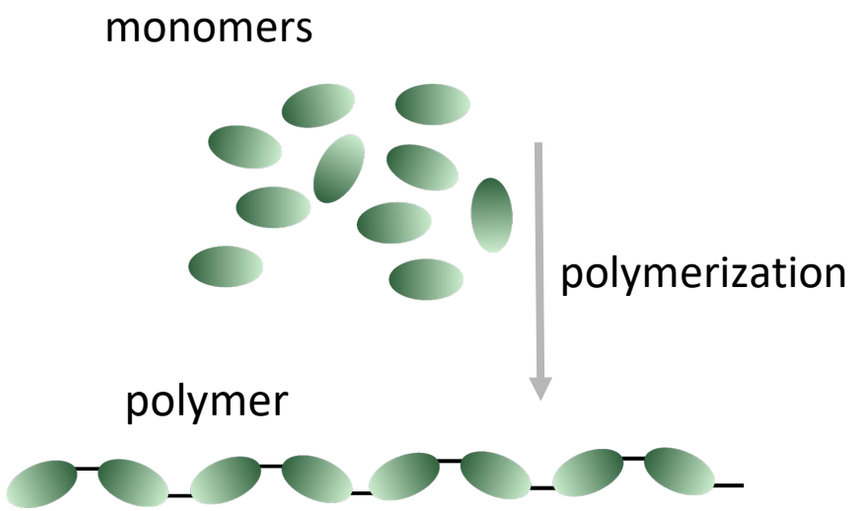
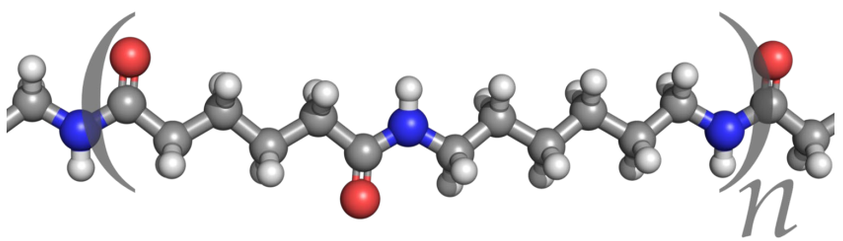


Image by SusTexEdu



Nylon 6,6 3D structure, image by Yassine Mrabet on Wikipedia (CC BY 3.0)

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… synthetic fibres

- Petroleum-based chemicals or petrochemicals are raw materials.
- Less than 1% of the petroleum-based compounds for synthetic fibres are
  - strong and durable,
  - don’t wrinkle easily,
  - chemical resistant,
  - resistant to insects and fungi,
  - low moisture absorbance,
  - and don’t shrink when washed.

Petrochemical Plant in Saudi Arabia.
Photo by Secl on Wikipedia (CC BY 3.0)

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… synthetic fibres

Polyamide

- The first synthetic fibres were developed by DuPont in 1940.
- During World War II, nylon fabrics were used for waterproof tents and light wt. parachutes.
- Nylon is the generic word (trade name) representing polyamide polymers and signify the fineness of the filament.
  (‘NY’=New York, ‘LON’=London) ?

Wallace Carothers, who directed the polymer research group in DuPont. Through his inventions of nylon and neoprene in 1930, Carothers helped demonstrate the macromolecular theory of polymers and establish the field of modern polymer science.
Photo: Wikipedia (Public domain)

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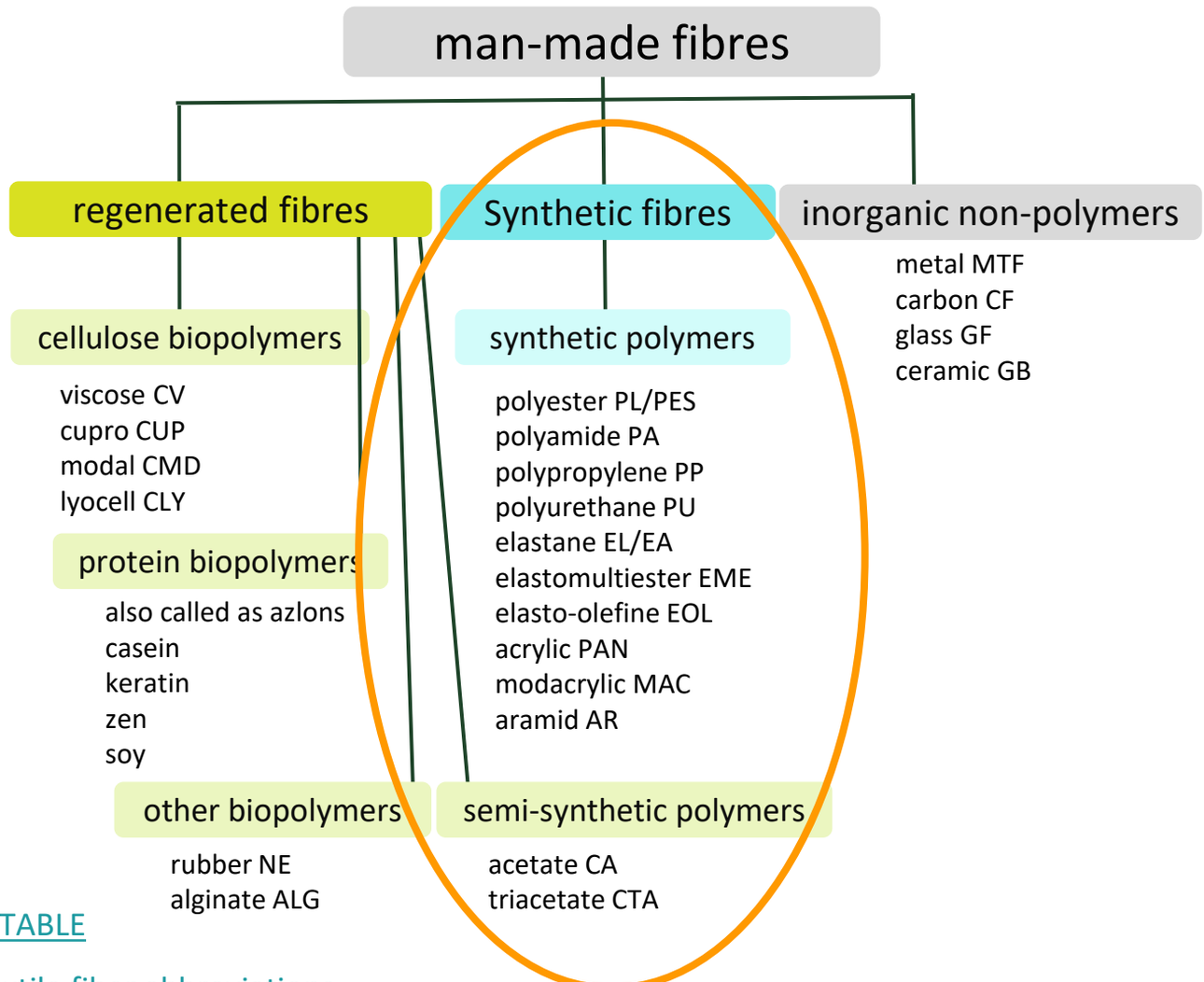
Classification of synthetic fibres



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GINETEX FIBRE TABLE

International textile fiber abbreviations

Common Properties of Synthetic Fibres

Heat Sensitivity

- Synthetic fibres soften or melt with heat.
- Glazing occurs with too hot iron at one spot for longer period.
- Creases, seams are hard to press in or out.
- Use care washing, ironing and dry cleaning.

Chemical resistance

- Synthetic fibres don’t absorb water or other liquids difficult to dye and resist solvents, creates problem with comfort and static.
- Chemical resistant means broad range of technical applications

Permanent pleated skirt 55% pes, 45% wool by Modelia, Turku Museum Centre (FI) collections. Photo on Finna.fi (CC BY 4.0)

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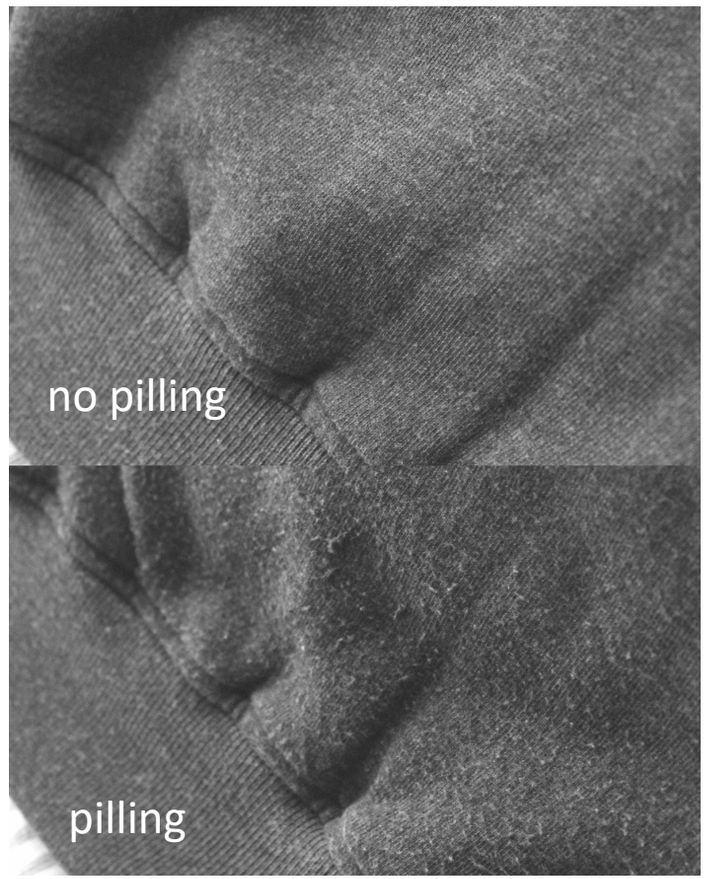
… common properties of synthetic fibres

Pilling

- Formation of tiny balls entangled fiber ends called fabric pills, and fibers pick up during care called lint pills.
- It occurs mostly on staple fiber fabrics.
- Can be minimized by fiber modification, compact weaves, yarn twist and by using longer-staple fibers.



Photos by Jspark93 on Wikipedia (CC BY-SA 3.0)

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… common properties of synthetic fibres

Static electricity

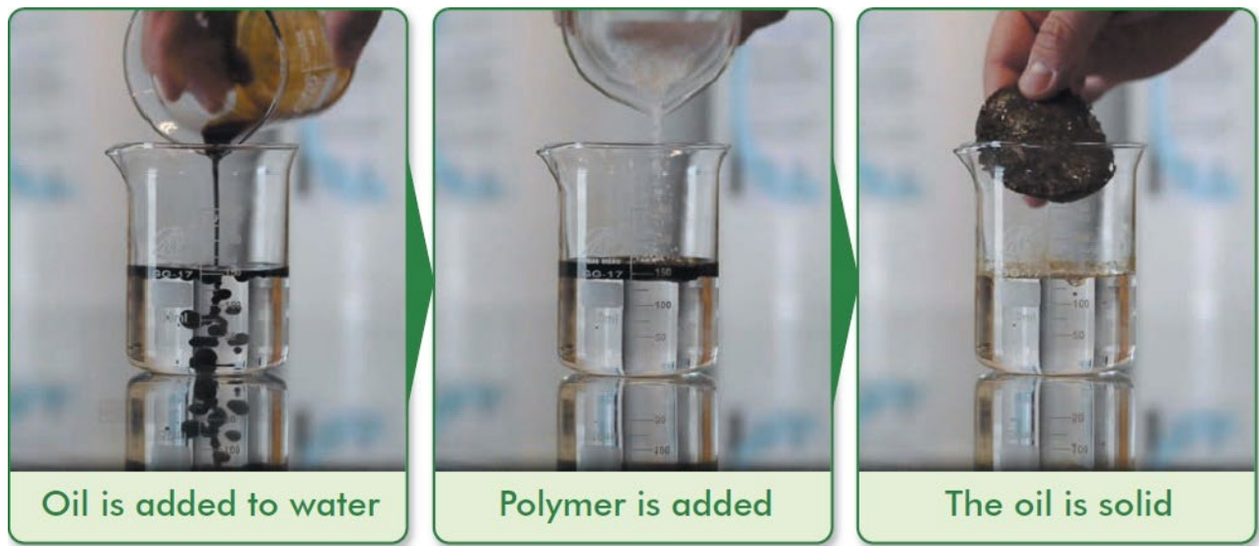
- Synthetic fibres have ability to build static charges due to friction.
- More problematic in cold and dry regions.
- Attracts dust, soil and lint
- Can be improved by using antistatic finishes and additives in spinning solution which increase cost.

Photo by Chris Darling on Wikipedia (CC BY 2.0)

… common properties of synthetic fibres

Oleophilic

- Synthetic fibres have more affinity for oils and creases which causes fibres swelling.
- Difficulty to clean



"Smart Polymer" solidifies oil and makes the removal of oil from the sea easier https://www.themanufacturer.com/articles/green-rhino-cleans-up-oil-pollution/

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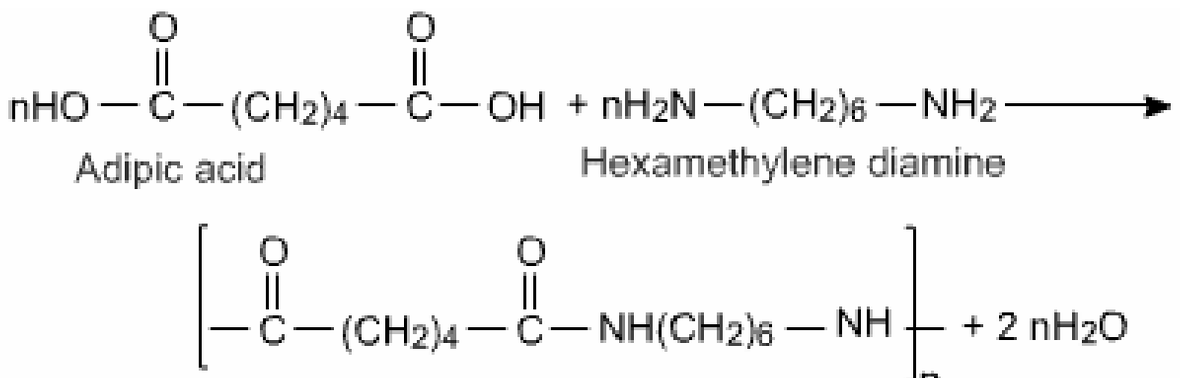
Polyamide Fibres

Types of Nylon

- Two types of nylon can be represented as nylon XY and nylon Z.
- In XY, X= # of carbon atoms in diamine monomer and Y= # of carbon atoms in diacid monomer.
- In nylon Z type, Z= # of carbon atoms in the monomer



- Nylon 66 and nylon 6 are the examples of these two types respectively. Both types are commonly used in apparels, ropes, carpets, tire cords and in technical textiles.
- Other types are, nylon 46, nylon 610, nylon 612, nylon 10 and nylon 12.

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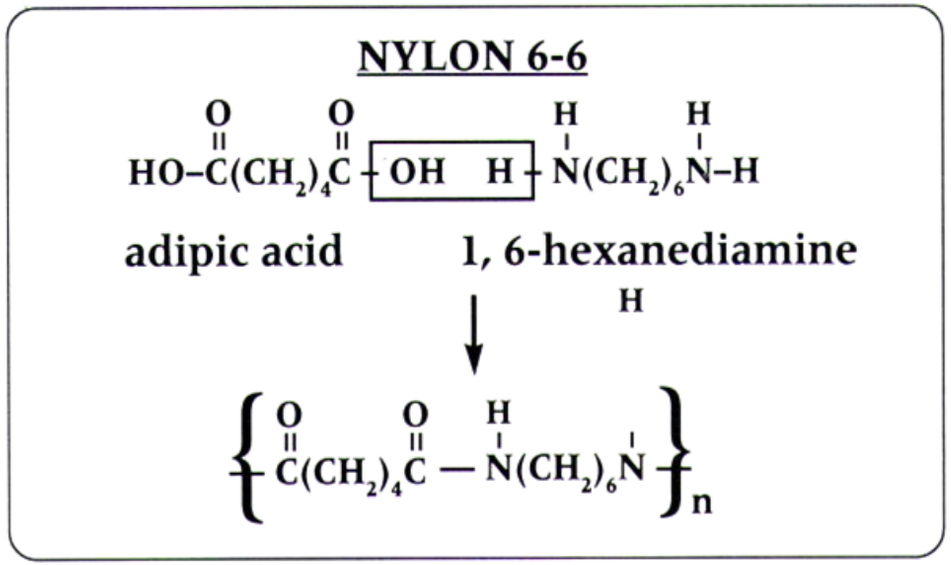
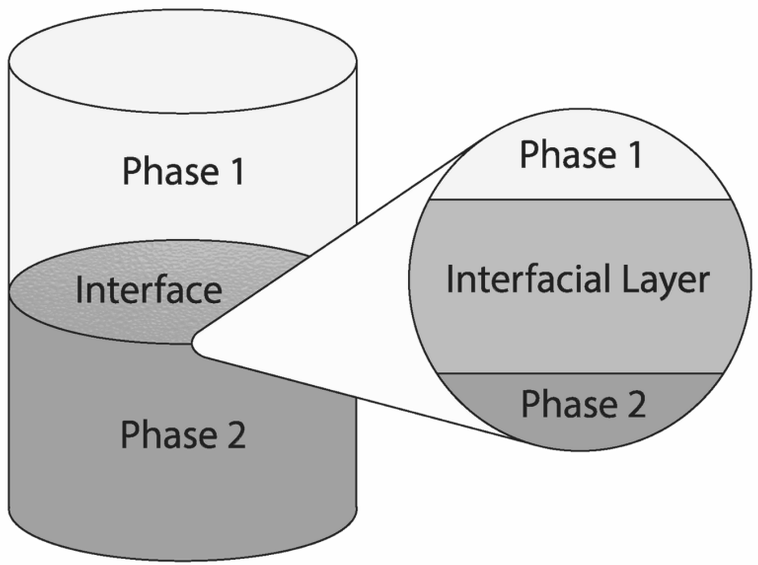
… polyamide fibres

Nylon 66

Nylon 66 is a condensation polymer, made by reacting a diacid with a diamine.

The polyamide forms between the two liquid phases.





A typically experimental setup for interfacial polymerization. One phase is above the interface, and the other phase is below. Image by Iamhumanyear from Wikipedia (CC BY-SA 4.0)

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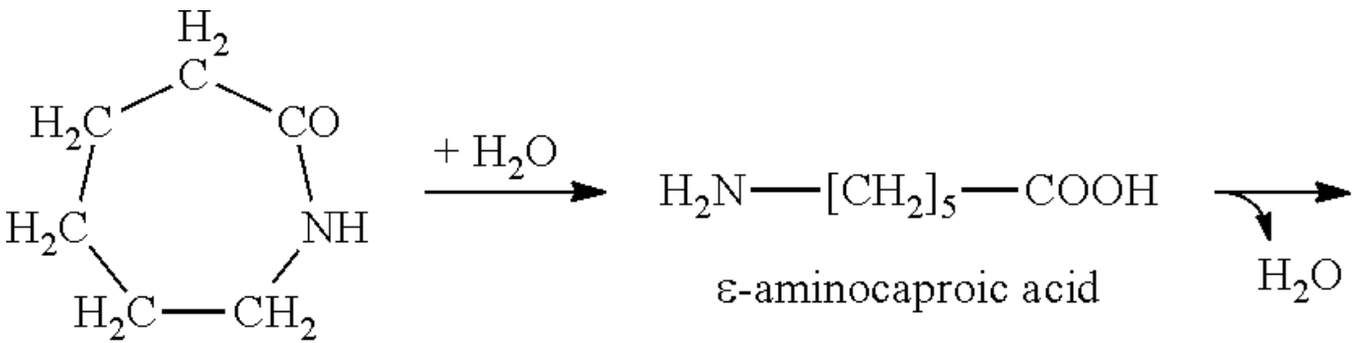
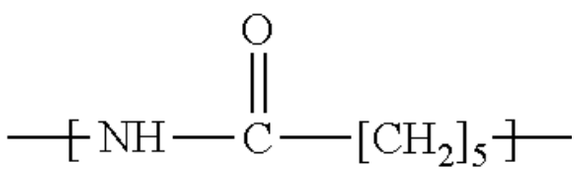


ε-caprolactam

Nylon 6

- Hexymethylene diamine + adipic acid gives hexymethylene diadipate salt in methanol at high temperature.
- Salt dissolves in water at concentration of 60%.
- Solution is heated at 250 °C for poly-condensation reaction and nylon 66.



polyamide 6

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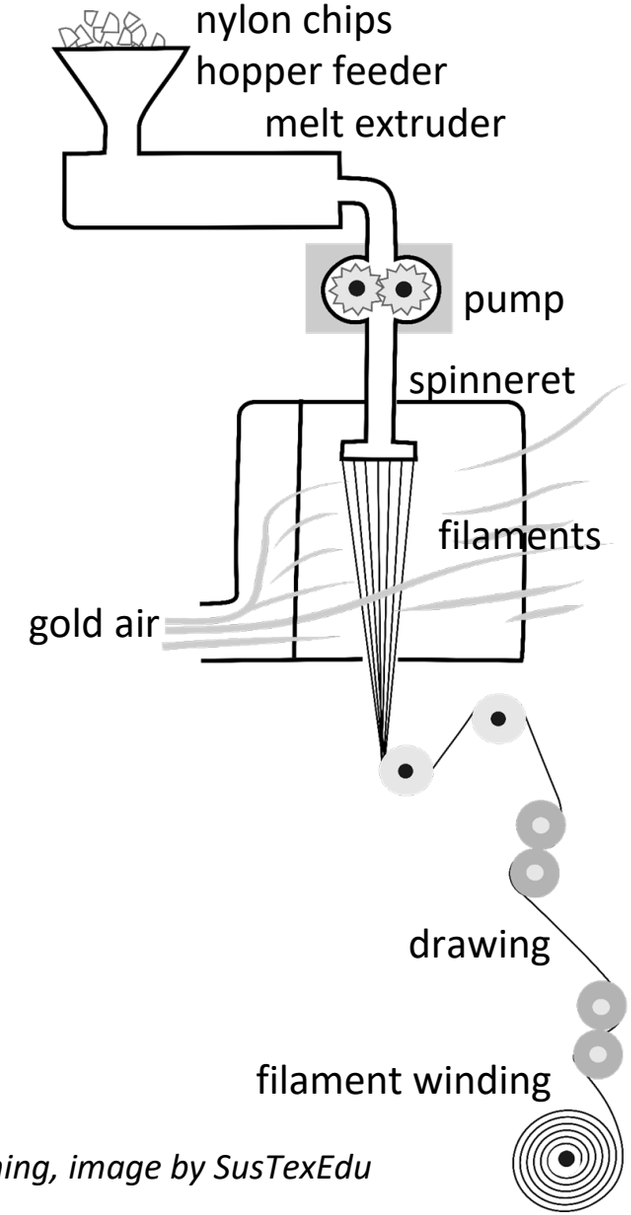
… polyamide fibres

- Mn of nylon 6 and nylon 66 is usually 18 000 to 20 000.
- Nylon chips follow melt spinning.
- The melting temperature for nylon 6 is 260 °C and nylon 66 is 280 °C.
- Polymer melt converts into continuous filaments when passed through the spinneret.
- After solidification, the filaments are drawn to get better mechanical properties.



Melt spinning, image by SusTexEdu

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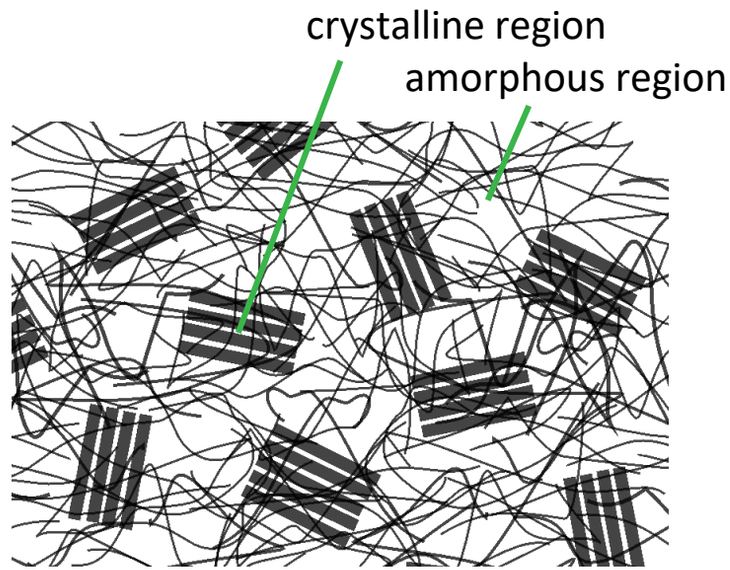
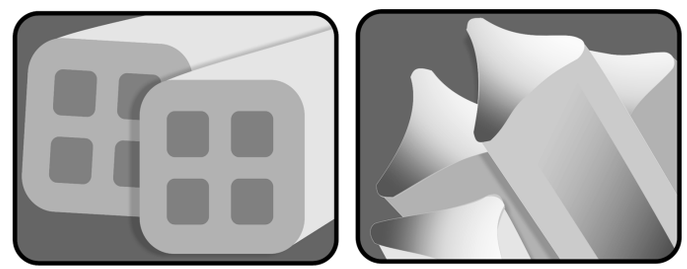
… polyamide fibres

Structure and properties of nylon fibres

- Molecular chains are long, straight but no side chains or Xlinks.
- Cold-drawing aligns the chains in lengthwise direction.
- Nylon 6 and nylon 66 have slightly different molecular arrangements that affects the crystallinity.
- Both are semi-crystalline, contains both amorphous and crystalline regions.





hollow fibres trilobal fibres

Images by SusTexEdu

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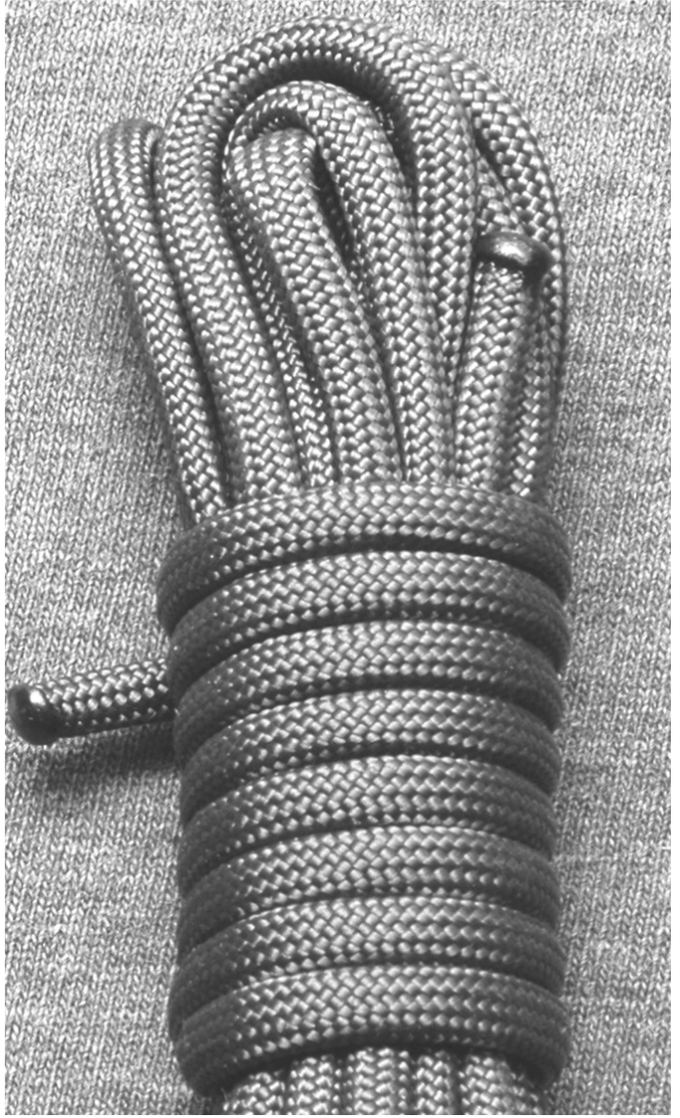
… polyamide fibres

- High crystallinity limits the moisture regain to 4%
- Nylon 66 is thermally more stable than nylon 6
- Nylon fibres have:
  - excellent tensile strength
  - elastic recovery
  - excellent abrasion resistance
  - higher energy required to break the fibre
  - excellent chemical resistant
  - light weight
  - resistant to mildew, insects and fungi
  - low sunlight resistance



Parachute cord, 100% nylon, photo by David J. Fred on Wikipedia (CC BY-SA 2.5)

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… polyamide fibres

Applications

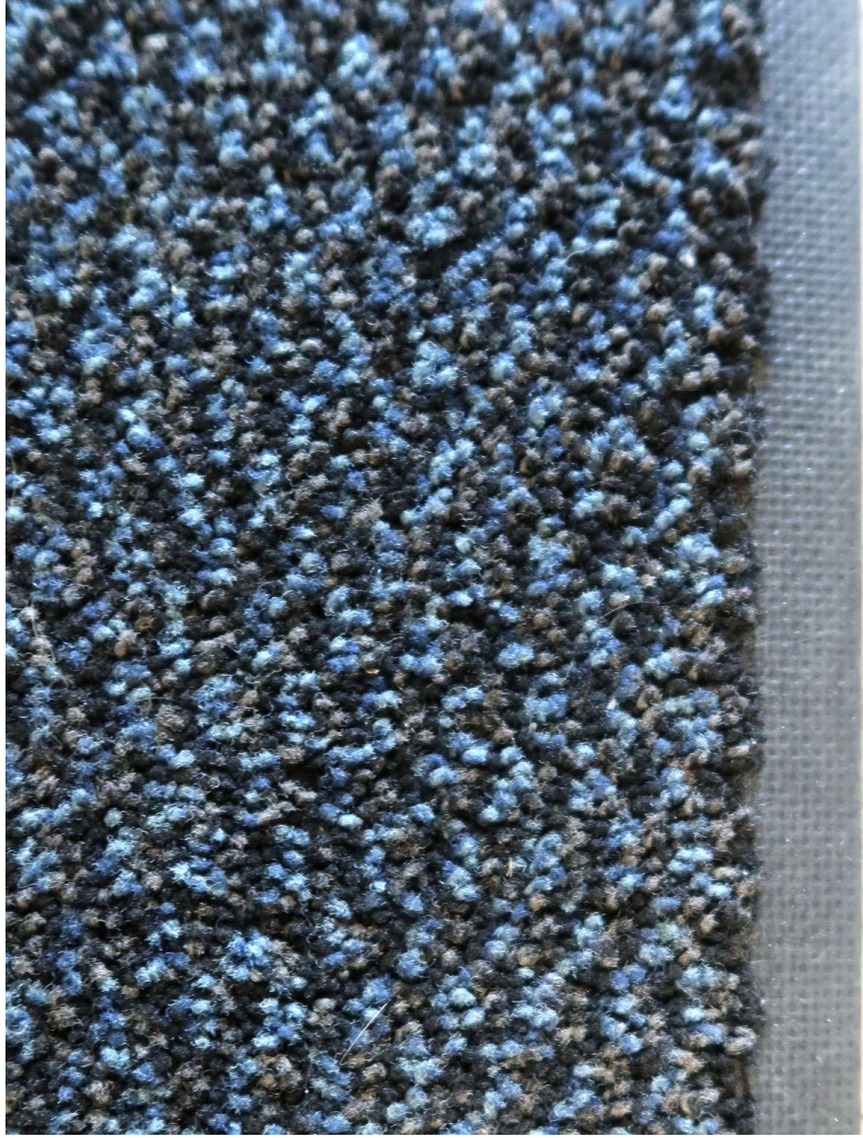
parachutes
air balloons
tires
tents
rucksacks
ropes
door and corridor carpets
outerwear
sportswear …

Tunnel tent, ripstop nylon, photo by LHOON on Wikipedia (CC BY-SA 2.5)

… polyamide fibres

Environmental Concerns and Sustainability

- all concerns associated with petrochemicals— made from by-products (waste)
- production consumes more energy than polyester or cotton
- nitrous oxide is emitted from production facilities
- processing uses just few cleaning chemicals
- recycling reasonable: e.g. carpets can be recycled to a nylon 6 raw material or mixed with plastic or concrete; performance enhancing additives pose challenge.

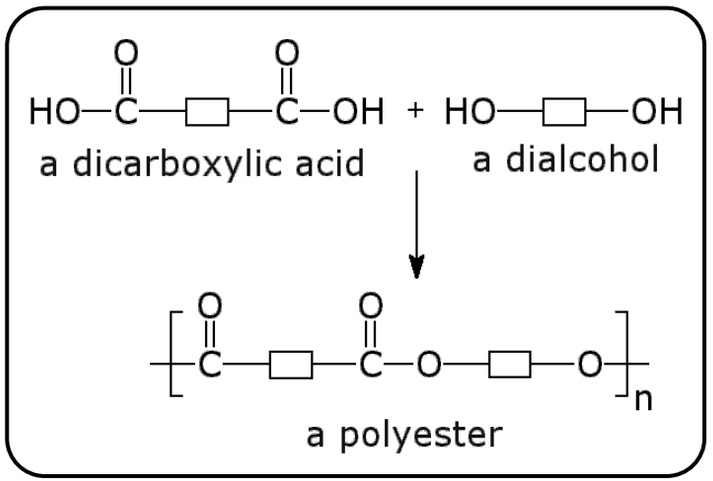


Polyamide hallway carpet. Photo by SusTexEdu

Polyester Fibres

Polyesters

- contain ester groups in their main polymeric chain.
- are derived from poly-condensation of dicarboxylic acids and diols.
- are 2nd largest fibres produced after cotton.



Polyesters can be classified into two groups

- Thermoplastic polyesters
  - present in solid form and recycled several times, e.g. PET
- Thermoset polyesters
  - present in liquid unsaturated forms, curing gives cross-linked solid structures.
  - are widely used to make fiber reinforced composites

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… polyester fibres

Structure and properties of Polyester Fibre

- Morphological structure of PET and Nylon is similar as both are form by melt spinning.
- The polymer chains are partially oriented and have semi-crystalline nature.
- Degree of crystallinity is 55%.
- *Tg* is about 70 ^{o}C and melting temperature range from 255-270 ^{o}C.
- The properties of PET fibers are:
  - Hydrophobic (0.4% moisture regain), quick drying
  - Excellent tensile strength, resistance to stretching
  - Minimum shrinkage and wrinkle resistant
  - Excellent abrasion resistance
  - Resistant to chemicals, mildews and easy care

Image by SusTexEdu

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… polyester fibres

Applications

- Apparel: all forms of clothing
- Home furnishings: carpets, curtains, sheets and pillowcases etc.
- Industrial uses: hoses, ropes, tire cord and furniture.

Moisture transferring fabric. Photo by Thermos on Wikipedia (CC BY-SA 3.0)

… polyester fibres

Environmental concerns and sustainability

- Uses less energy than nylon but more than cotton.
- Catalytic agents and chemicals contaminate water and soil
- Polyester is extensively recycled which significantly reduces the environmental pollution.
- Achieving an appropriate quality of recycled polyester is big challenge.
- Products made by recycled PET are extensively used

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… polyester fibres

Environmental concerns and sustainability

Photo by Clean the bay 2012 on Wikipedia (CC BY 2.0)

Plastic PET bottles being sorted for recycling,
photo by Green tress on Wikipedia (CC BY-SA 4.0)

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Find **VIDEOS** of recycling plastic bottles for manufacturing polyester fabric with keywords
e.g.: *how it's made polyester, recycling polyester, pet bottles*

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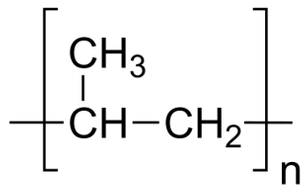
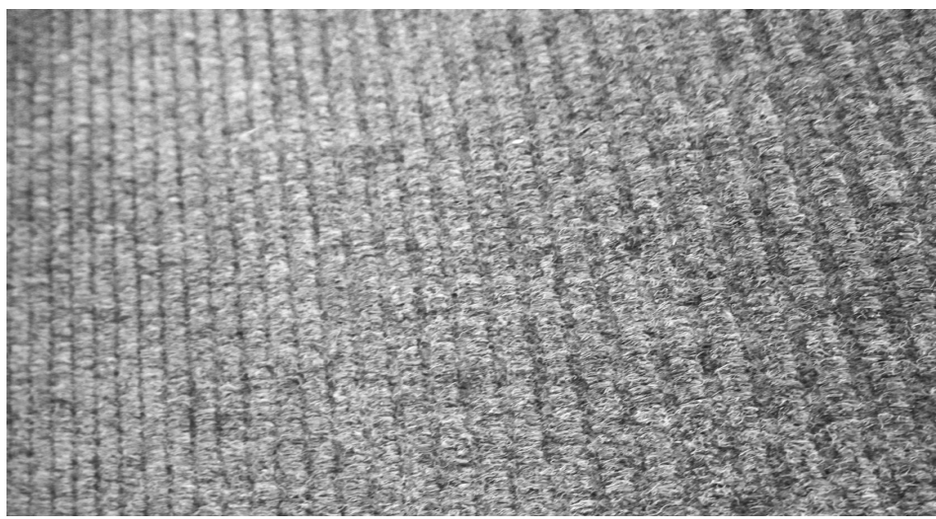
Polypropylene (PP) Fibres

Polypropylene

- is a simple linear structure of repeating units (-CH2-CH-CH3-)
- replaces jute for carpet backings and bast fibres for rope.
- has high strength, high toughness and good resistance to chemical attack.
- is difficult to be dyed without modification.
- shares more than 90% of polyolefin > fibre production.
- is heat sensitive and used for interiors and apparels which don’t need ironing.





Polypropylene carpet. Photo by SusTexEdu

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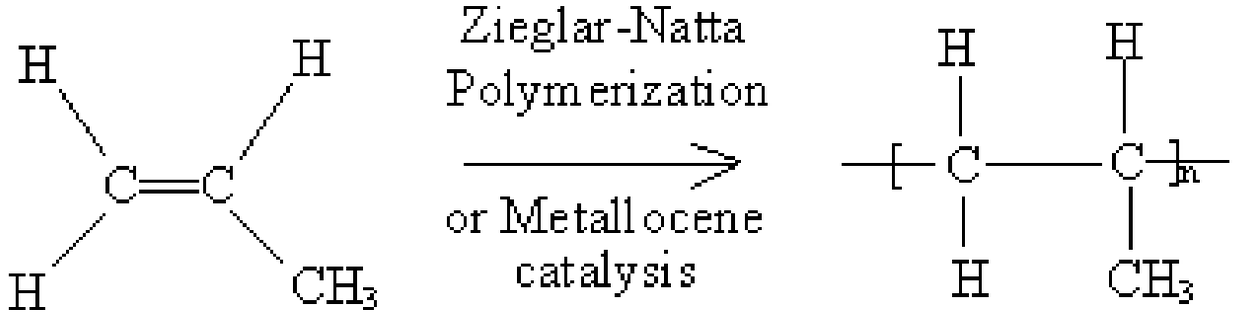
… polypropylene fibres

Production

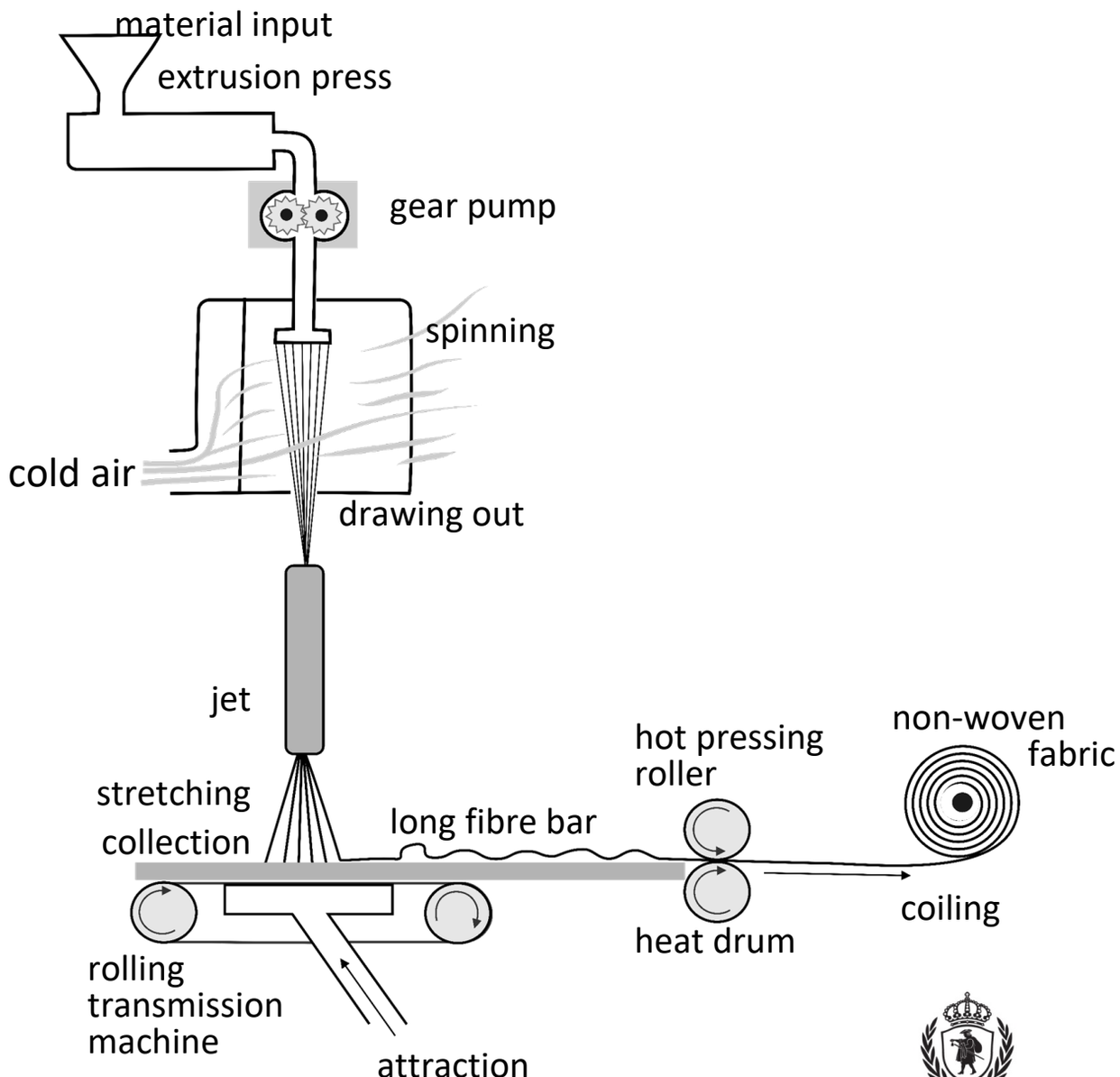
- The polymerization of propene, which is the by-product obtained in the cracking of oil, gives polypropylene.



- The polypropylene fibres are produced by different melt extrusion processes and choice of process depends on the type of fibre required and application areas.
- Multifilament yarns, monofilament yarns, staple fibres, spun yarns, tape and non-wovens can be produced.

… polypropylene fibres

Melt-blown process for non-woven PP



Simplified PP nonwoven fabric production process.
Image by SusTexEdu

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… polypropylene fibres

Spin Finish

- Spin finish is applied to protect the filament surfaces and to dissipate any static electricity generated during the spinning process.
- It reduces the friction during the fibre production and increase the production rate.
- Spin finish usually contains a complex mixture of chemical compounds and applies as an emulsion.
- It can increase the hydrophilicity of PP fibers and protect them from micro-organisms.
- Wrong selection of spin finish causes fibre swelling which reduces the strength.

Additives

- Some additives are added to facilitate the processing of PP and introduce properties.

… polypropylene fibres

Fibre Properties

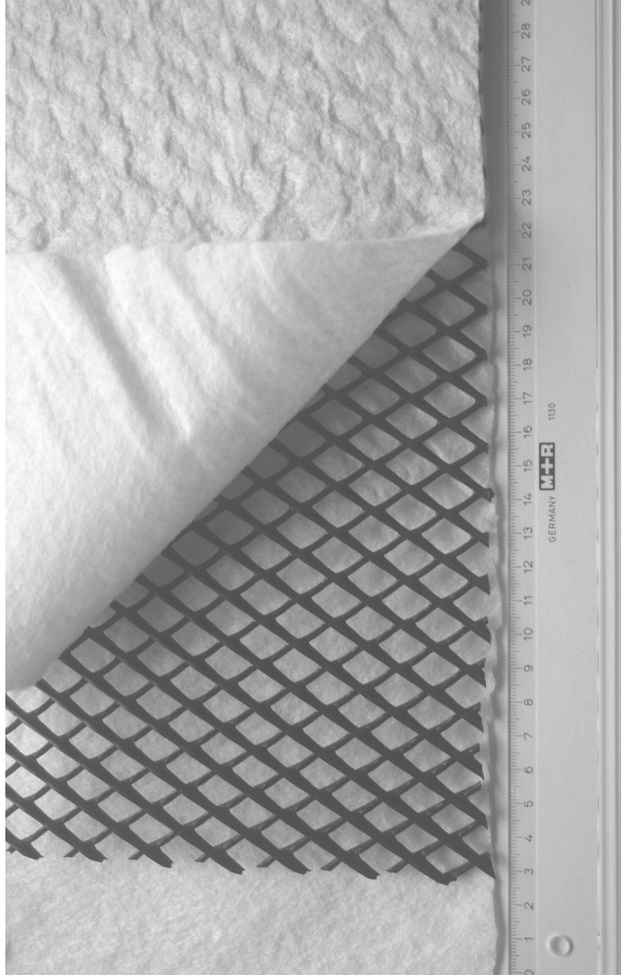
- PP fibre properties depend on different factors, such as:
  - the grade of PP used
  - fibre-processing conditions
  - additives present
- PP is highly resistant to chemicals
- It gets swollen or dissolved in some organic liquids
- It is weakened by UV radiation and contains light stabilizers
- PP is resistant to micro-organisms
- PP is non-absorbent and it has excellent wicking
- PP has good heat retention properties
- It recovers quickly from wrinkling, light weight

Effect of UV exposure on polypropylene rope. Photo by Peterlewis on Wikipedia (Public domain)

… polypropylene fibres

Applications

- PP fibres are used in technical applications, for geotextiles, car and boat interiors etc.
- PP fibres are also used in interior textiles such as, carpeting, slipcovers, replaced jute as carpet backing, nonwoven fabrics, mattress covers etc.
- PP has limited applications in clothing because of difficult dying. Anyway, PP fibres are used in sportswear and activewear, such as walking socks, cycle shorts, swimwear etc. PP garments are comfortable next to the skin, can transport sweat to the outer layer of fabric.



Geocomposite drain consisting of needle-punched nonwoven filter and carrier geotextiles of polypropylene staple fibres. Photo by Werner W Müller and Fokke Saathoff on Wikipedia (CC BY 3.0)

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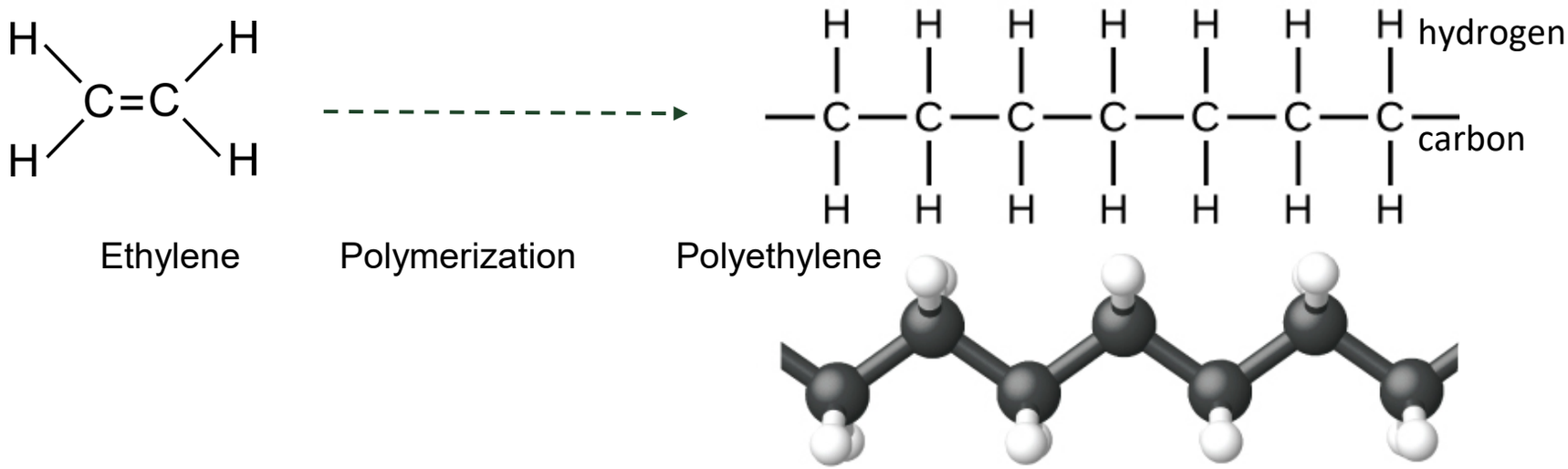
Polyethylene (PE) Fibres

Polyethylene is produced by the polymerization of ethene (ethylene) by the Ziegler-Natta process.



CNX Chem 20 01 monomer. Photo by OpenStax on Wikipedia (CC BY 4.0)

… polyethylene fibres

Structure of PE

PE polymer doesn't have side groups as PP has, but it can have branches which have strong impact on fibre properties.

Stress cracking in HDPE

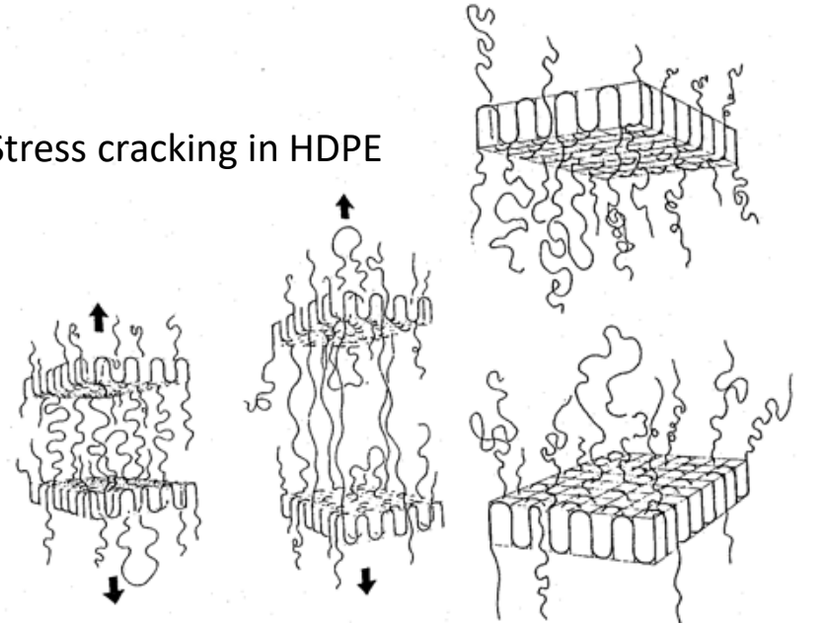


Image above from the article by Yashodhan Kanade on Linkedin 3.4.2020: Environmental Stress Cracking in HDPE Pipes and Blow Moulded Tanks (Part-1)

Effect of branching on density from left:
linear HDPE, short branched LLDPE and long branched LDPE.
Image by SusTexEdu

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http://www.geosynthetica.net/

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… polyethylene fibres

Applications

- PE is extensively used for protective clothing due to its light weight and protective properties.
- PE has a good cut and puncture resistance and it hence provides good protection against knife attack.
- PE is used in gloves, fencing suits and for ballistic protection.

Coverall protective suits, photo by Jarek Tuszyński on Wikipedia (CC-BY-SA-3.0)

A recyclable bag manufactured from polyethylene. Photo by Kriplozoik on Wikipedia (Public domain)

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http://uniplasinternational.com/

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Elastomeric Fibres

Elastomers

- Polymers having high extensibility, with rapid and significantly complete recovery.
- Previously, the fibres made from rubber were more extensively used but now they are produced from other type of polymers.
- Most important commercially available are *elastane.*
- Elastane contains 85% or more by mass of
  - segmented polyurethane.
- Fibres have up to 99% elastic recovery and high extensibility up to 500%.
- In EU elastomers are known as *Lycra* and in USA as *Spandex*.

A cycling and running spandex suit.
Photo by Adamlazer on Wikipedia
(CC BY-SA 4.0)

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… elastomeric fibres

Elastomers

- Other types are:
  - Elastodiene fibres
  - Elastomultiester fibres
- Elastane fibres
  - Polymeric chain consists of alternate blocks of ‘hard’ and ‘soft’ segments.

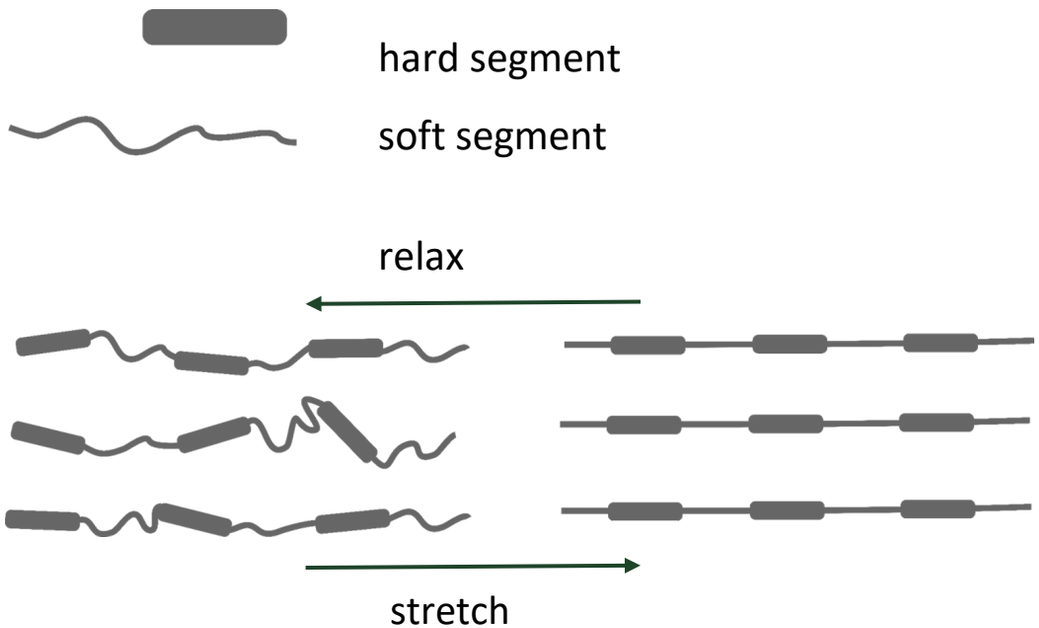

Image by SusTexEdu

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… elastomeric fibres

- ***Fibre manufacturing***
  - Solution dry spinning
  - Solution wet spinning
  - Melt spinning
- ***Fibre structure***
  - have either round or square cross-sections.
  - linear density range from 20 to 6000 dtex depending on the applications.
  - for some applications elastane fibers are covered with yarns of other types

Spandex fibre. Photo by Luigi Chiesa on Wikipedia(GFDL)

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… Elastomeric Fibres

Application Areas

- Elastomeric fibres are widely used in clothing to provide stretch, comfort, and shape retention in garments, in sportswear, activewear, swimwear, underwear, leggings, socks, tights and stockings.
- Elastomeric fibres are utilized in medical garments, such as compression stockings and sleeves, to provide a supportive fit.
- Elastomeric fibres can be incorporated into bandages and wraps to provide compression and support for injuries or medical conditions.
- Elastomeric fibres are also used for industrial and technical textiles, such as automotive textiles, upholstery, and flexible materials for various industries.

Hartmann Pütterbinde bandages.
Photo by Jacek Halicki
on Wikipedia (CC BY-SA 4.0)

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Courtesy: Martin Stråat, Swerea IVF

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Learning material

1. *"Pearson New International Edition: Textiles"* by Sara J. Kadolph. (ebook)

2. *"Textiles and Fashion, Materials, Design and Technology"* by R. Sinclair, ISBN: 978-1-84569-931-4.

3. "*The Chemistry of Textile Fibers*", by Robert R. Mather, 2nd Edition

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Supporting Literature

Pearson New International Edition: Textiles by Sara J. Kadolph. (ebook) (Chapters 6 and 8)

Textiles and Fashion, Materials, Design and Technology by R. Sinclair, ISBN: 978-1-84569-931-4.(ebook) (Chapters 5 and 6)

Tips to read

Tent Fabric 101: Nylon vs Polyester vs Dyneema/Cuben by Tim Hunt 2019

Waste valorization in sustainable engineering materials: Reactive processing of recycled carpets waste with polyamide 6. M.A. Abdelwahab, B.P. Chang, A. K. Mohanty, M. Misra

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.

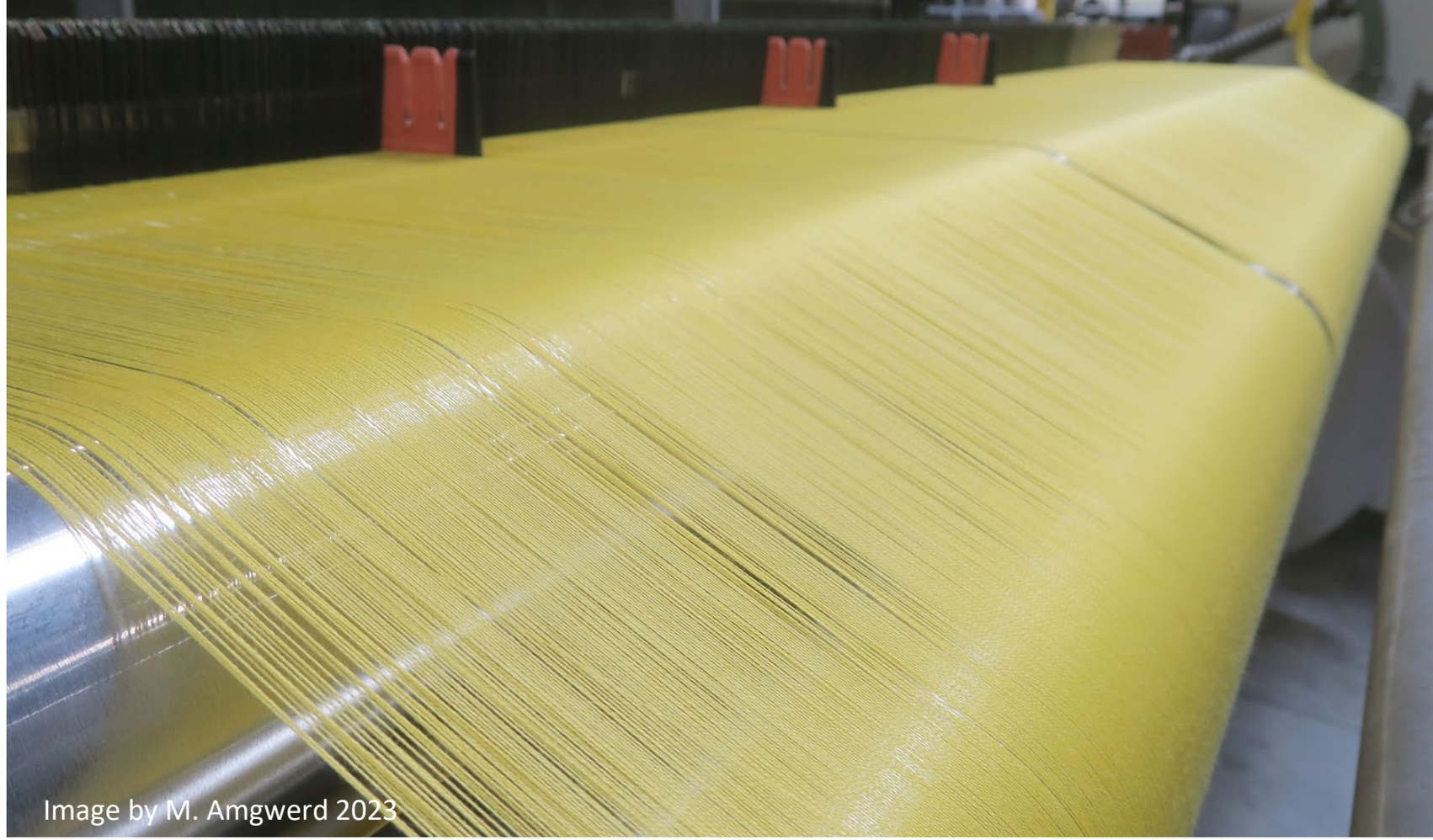

Image by M. Amgwerd 2023

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