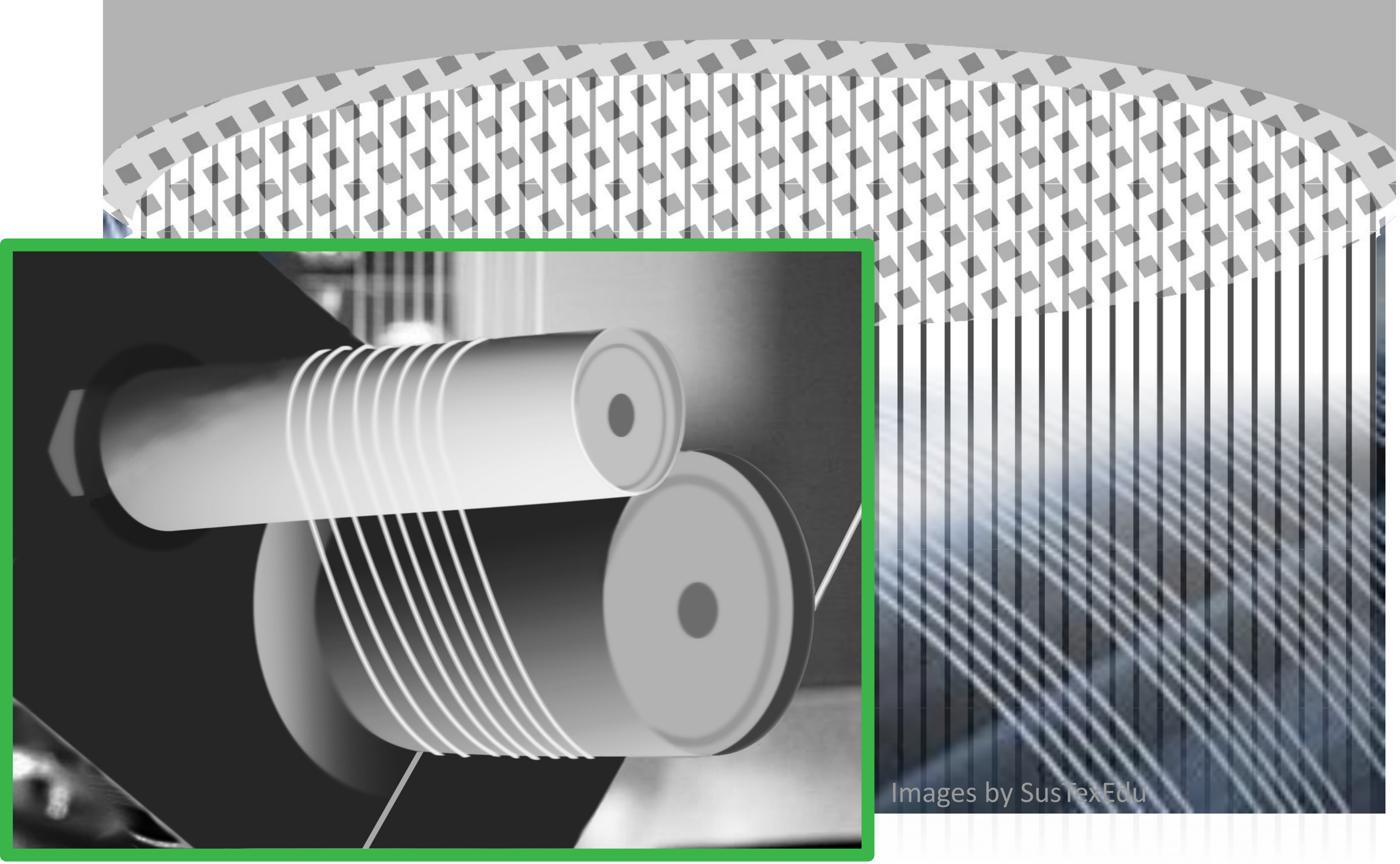


This open educational resource has been developed by:

Dr. Tariq Bashir

Textile Fashion Center, Swedish School of Textiles,
University of Borås

2.1 / 2 Manufacturing Technologies of Man-made Fibres
MELT SPINNING

SusTexEdu

Funded by the Erasmus+ Programme of the European Union

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

SusTexEdu

About this learning unit

CONTENT DESCRIPTION

The learning unit aims to give the student in-depth knowledge of manufacturing technologies of man-made fibres.

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

SusTexEdu

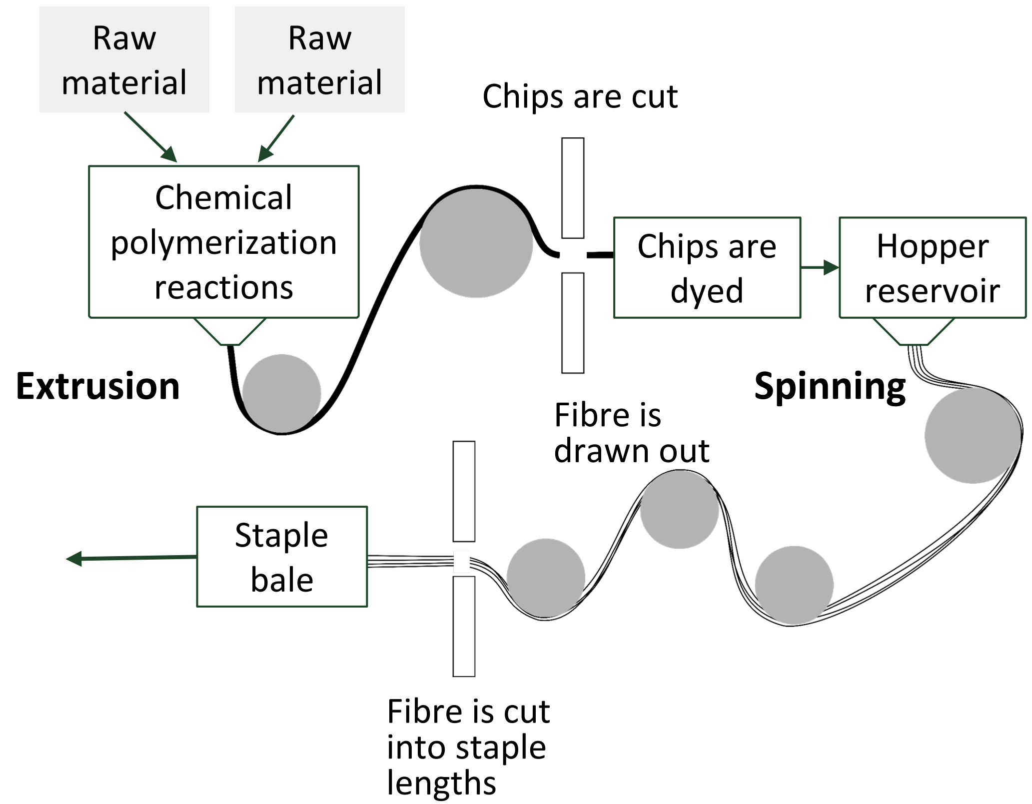
Outlines

- Introduction
- Fiber spinning techniques
  - Melt spinning
  - Solution wet spinning
  - Solution dry spinning
  - Gel spinning
- Regenerated fibers
  - Viscose rayon fibers
  - Lyocell fibers
- Application areas

Production of Synthetic Fibres

Steps included in production of synthetic fibres are

- Complex chemical reactions of raw materials
- Extrusion to make the chips/solution with suitable solvents
- *Spinning* the melted chips/solvent solutions through spinneret
- Drawing the produced fibers
- Finishing steps
- Produced *yarn(s)*



Melt spinning process

1. Polymerization of raw material

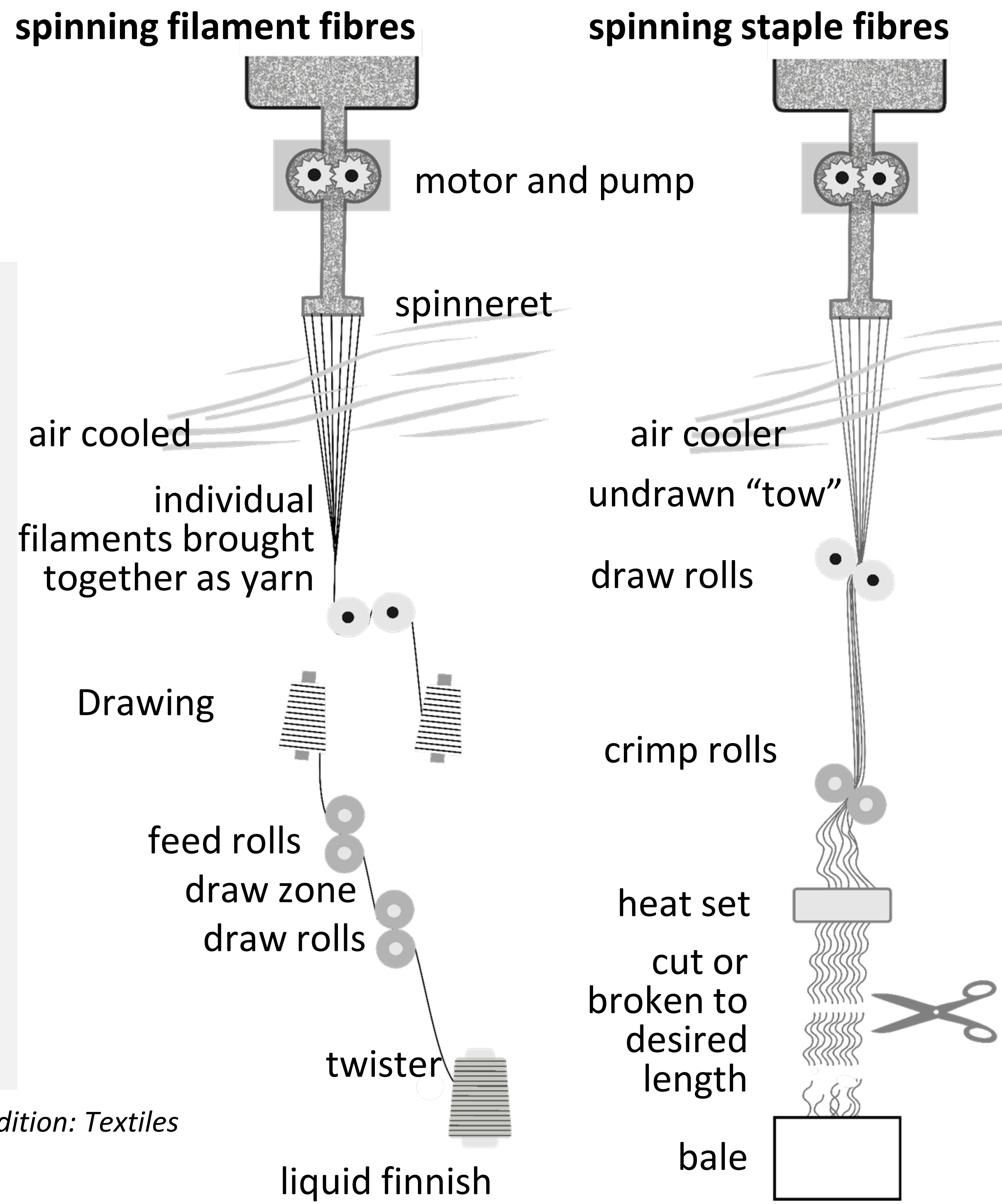
Chemicals are reacted under pressure to form a polymer resin that is extruded as fibre like strands or as a solid sheet and then cut into chips. The chips are melted in an autoclave and pumped to the spinneret. Delusterants or other additives may be combined with the melt.

2. Extrusion and cooling

The mett is pumped through the spinneret. It emerges in strands. The size of the fibre is determined by the size of the holes and the speed with which the fibre is withdrawn from the spinneret. The fibres are cooled by contact with cold air. The same melt is used for either filament or staple.

3. Drawing or stretching after cooling

Filament fibres can be drawn 4-5 times their original length to orient the molecular chains and develop the fibre's mechanical properties and hand. The fibres are heat-set and wound on cones or spools. Staple fibres emerge as undrawn tow. It is drawn, crimped and heat-set, cut to the desired length, and baled.



SusTexEdu

Reference: *Pearson New International Edition: Textiles* by Sara J. Kadolph. Images: SusTexEdu

Fibre Spinning Techniques

Fibre spinning

- The process of making continuous filaments/strands by extrusion followed by solidification steps is known as *spinning*.
- Depending on the type of the materials and user end required properties, different spinning techniques are used, such as:
    - Melt spinning
    - Solution dry spinning
    - Solution wet spinning
    - Gel spinning
    - Electrospinning
    - Air jet spinning
- Selection of a particular spinning method depends on the *chemical nature of the material* to be spun and the *final required properties* of fibres.

… Fibre Spinning Techniques

Unit operations involved in spinning processes

All spinning processes involved following common steps:

Melting of polymer chips or solution preparation

Removal of contaminants or materials, *Filtration*

Material supply to the spinneret, *Metering*

Filament/strand formation through spinneret

Solidification of spun fibers

Finishing steps

Drawing
Heat & surface treatment
Crimping
Chopping

Dry spinning, solvent evaporation

Melt spinning, orientation-induced crystallization

Wet spinning, with pptn of polymer by non-solvent

SusTexEdu

Photo: Polyethylene chips. Photo by Lluis tgn on Wikipedia (CC BY-SA 3.0)

HÖGSKOLAN I BORÅS

VIDEOS to be found with keywords e.g.: ***Polymer melt spinning***

… Melt Spinning

- Continuous production of polymeric fibres by extruding the molten material, pumped through the ***spinneret*** (die) having small diameter holes (one to several thousands).
- The molten fibres are ***solidified, stretched*** and collected on a take-up wheel.
- To orient the polymer chains and provide the required mechanical properties, stretching in both molten and solid state plays very important role.

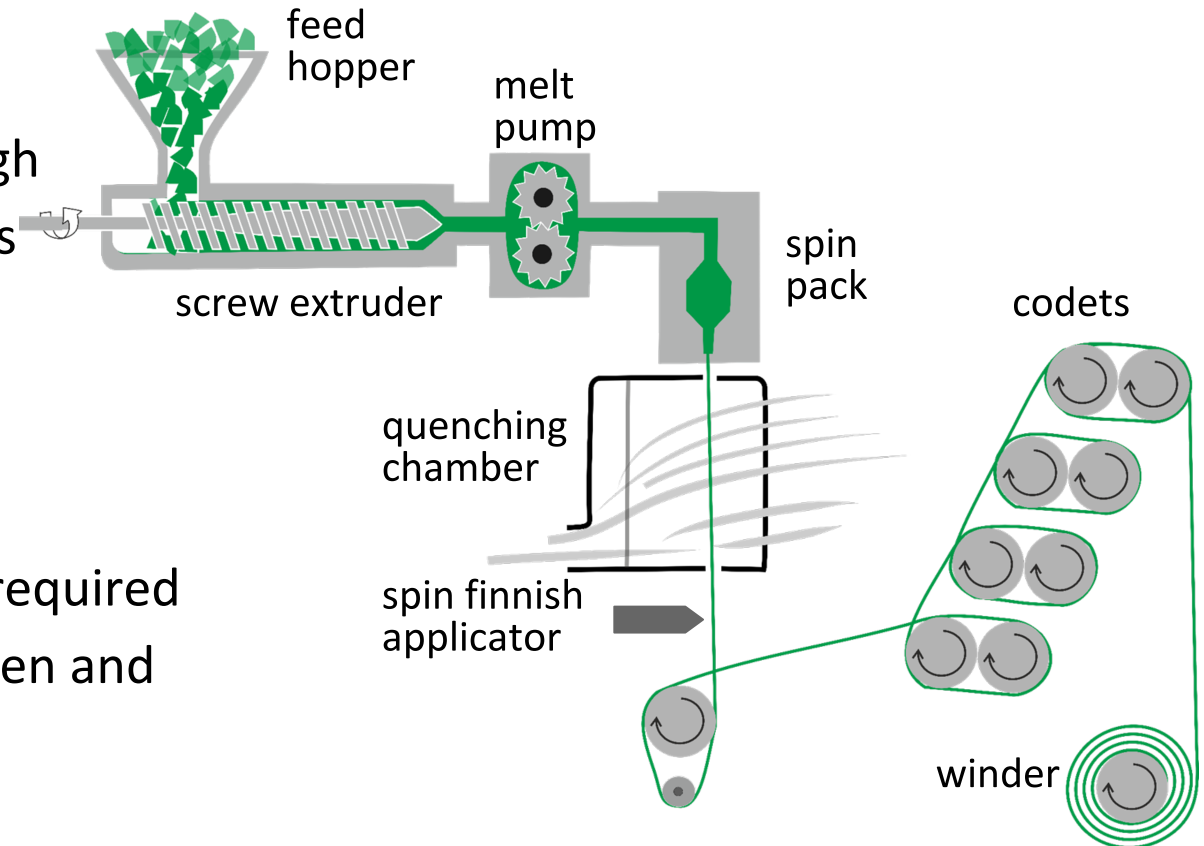
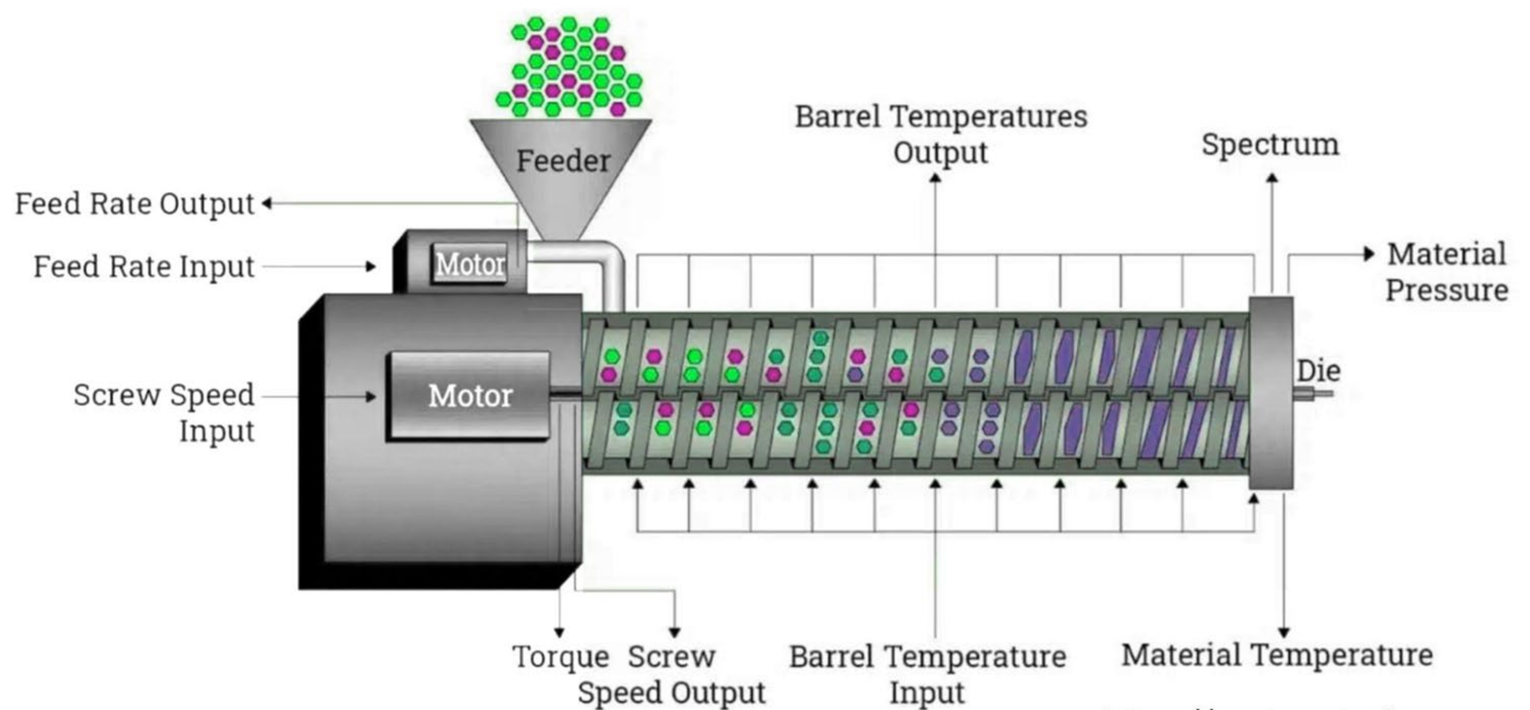


Image: SusTexEdu

Melt-Spun Fibers for Textile Applications. R. Hufenus, Y. Yan, M. Dauner, T. Kikutani (2020)

… Melt Spinning

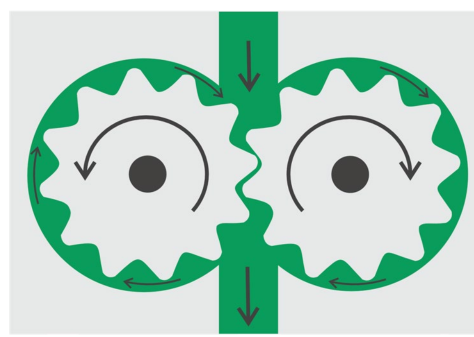
Extruder



https://engineeringlearn.com

Gear pump

Image: SusTexEdu

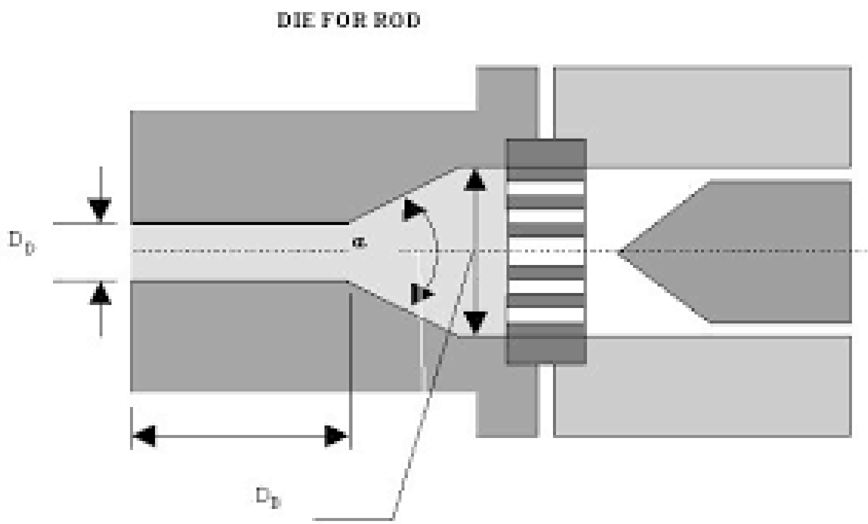


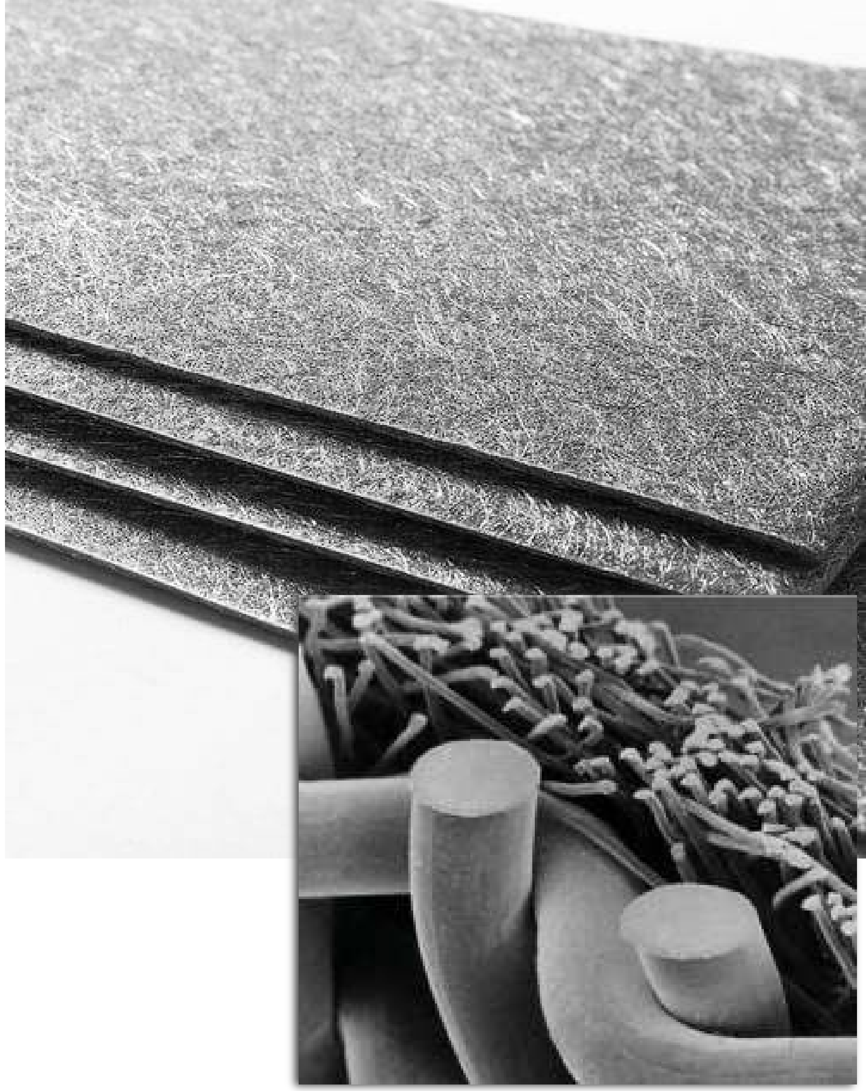
SusTexEdu

HÖGSKOLAN I BORÅS

… Melt Spinning

Breaker plate and filter





Sintered metal fibre felt

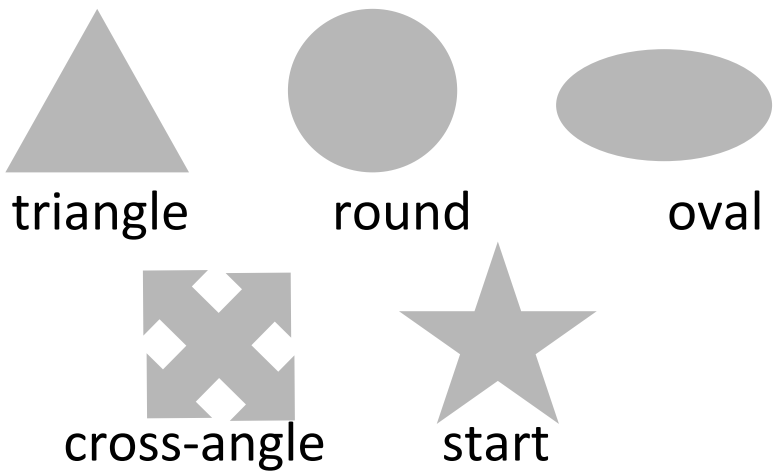
SusTexEdu

UNIVERSITY OF BORÅS
SCIENCE FOR THE PROFESSIONS

… Melt Spinning

Spinneret

Different shapes of spinneret:



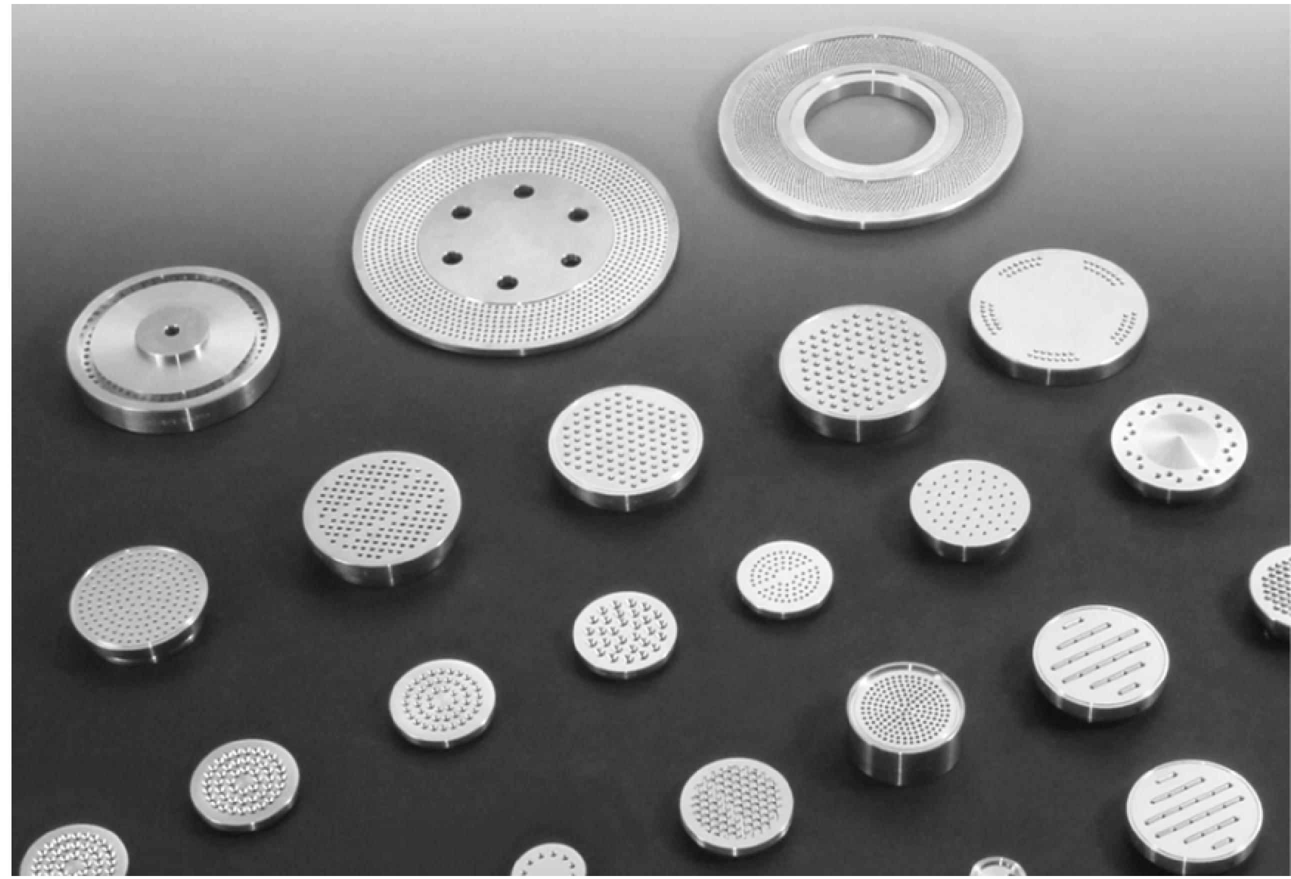


Image: SusTexEdu

Photo: Conjugate Spinneret Assembly (Kasen Nozzle)
https://www.kasen.co.jp/english/product/spinneret/assembly.php

… Melt Spinning

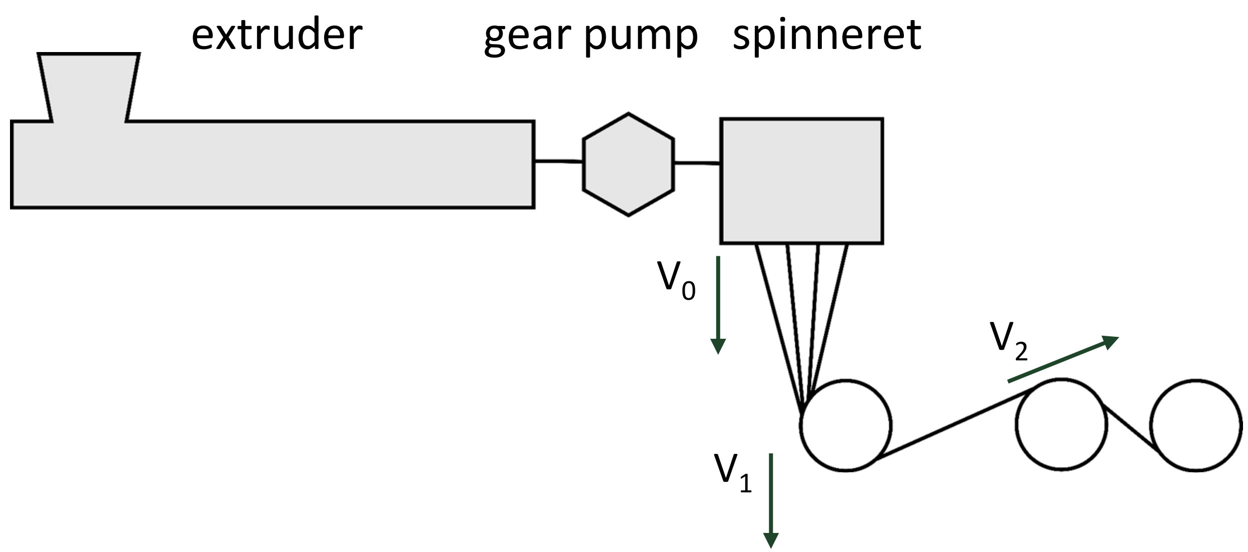
Melt draw and solid draw ratios

Melt drawing ($T > T_m$)

$MDR = V_1 / V_0$

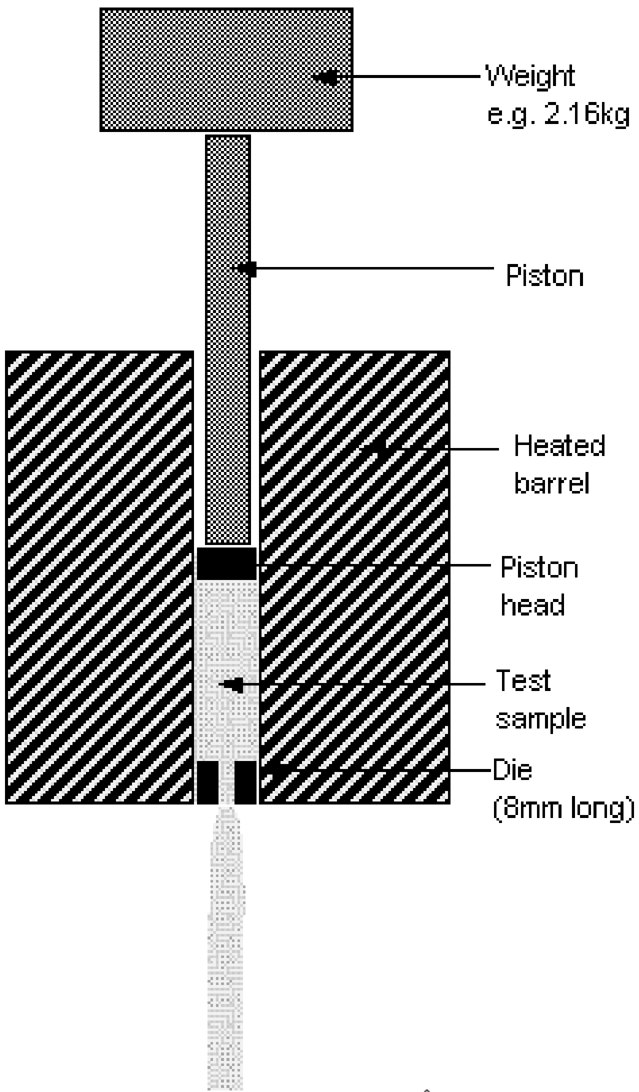
Solid state drawing ($T_g < T < T_m$)

$SSDR = V_2 / V_1$



… Melt Spinning

- The ***final diameter*** of the fibres depends on the ***MDR*** and ***SDR*** values.
- ***Melting temperature & melt flow*** determines the melt viscosity which is the function of ***mol. wt.*** of polymer.
- High molecular wt. polymers are suitable for textile fibre productions.
- The study of melt flow behavior is known as the rheology of the molten liquid.
- ***MFI*** is the mass of polymer, in grams flowing in 10 minutes through a capillary of specific diameter and length at particular temperature and pressure. It determines the pump pressure required for steady flow through spinneret.



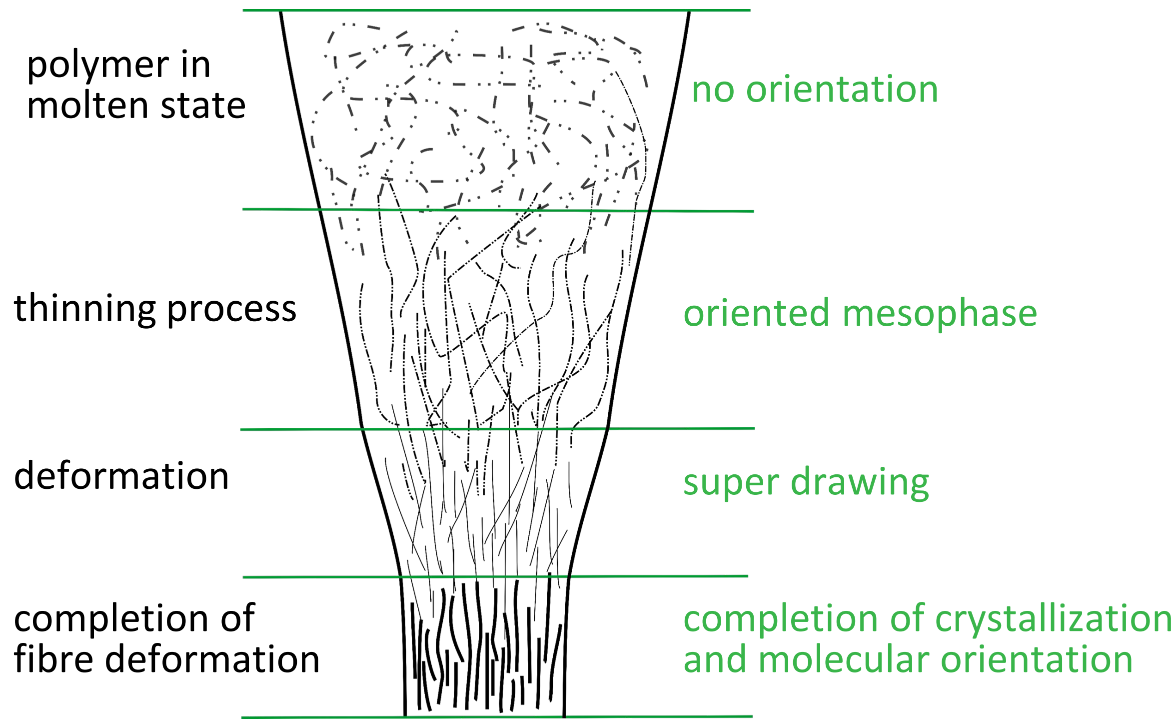
SusTexEdu

UNIVERSITY OF BORÅS
SCIENCE FOR THE PROFESSIONS

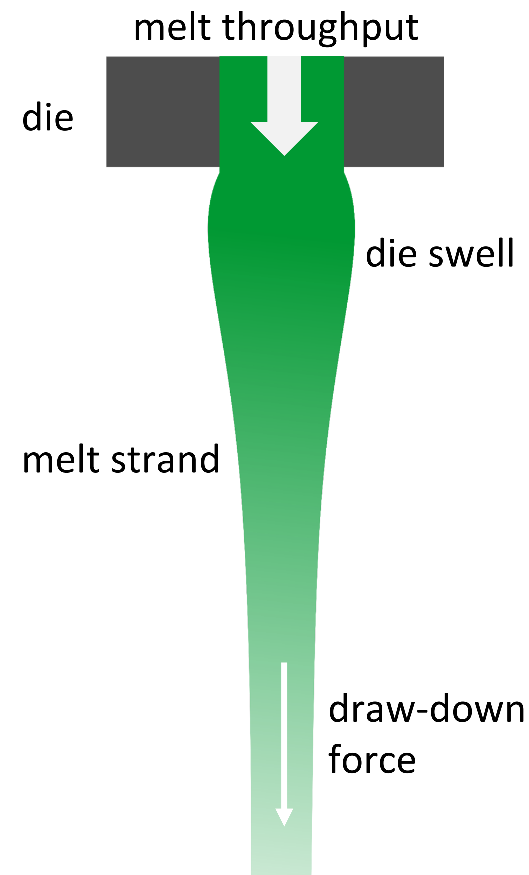
You can find **VIDEOS** with keywords: *Die Swell*

… Melt Spinning

Orientation of polymer chains



Die Swell occurs when polymer melt come out from the die

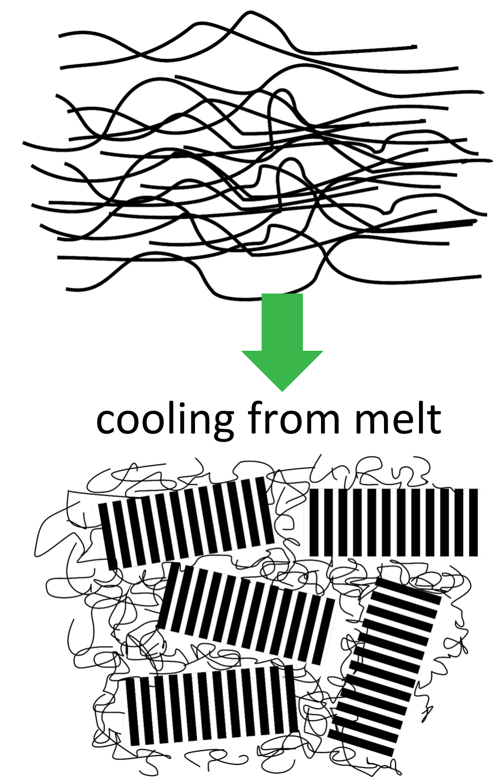


SusTexEdu Images: SusTexEdu

UNIVERSITY OF BORÅS
SCIENCE FOR THE PROFESSIONS

… Melt Spinning

- ***The length to diameter*** of the spinneret ratio also important to achieve steady flow and it varies according to the type of the polymer.
- The structure and properties of spun yarn strongly dependent on ***drawing*** the fibres in fiber axis.
- At lower temperature, polymer chains start to pack in regular way. The packed (crystalline) regions are attached with amorphous chains.
- Fibres are drawn in two ways depending on the draw down ratios used for specific materials.
  1. *Can be drawn during the spinning process by introducing heated godets after the pull-down godet.*
  2. *Can also be drawn separately*

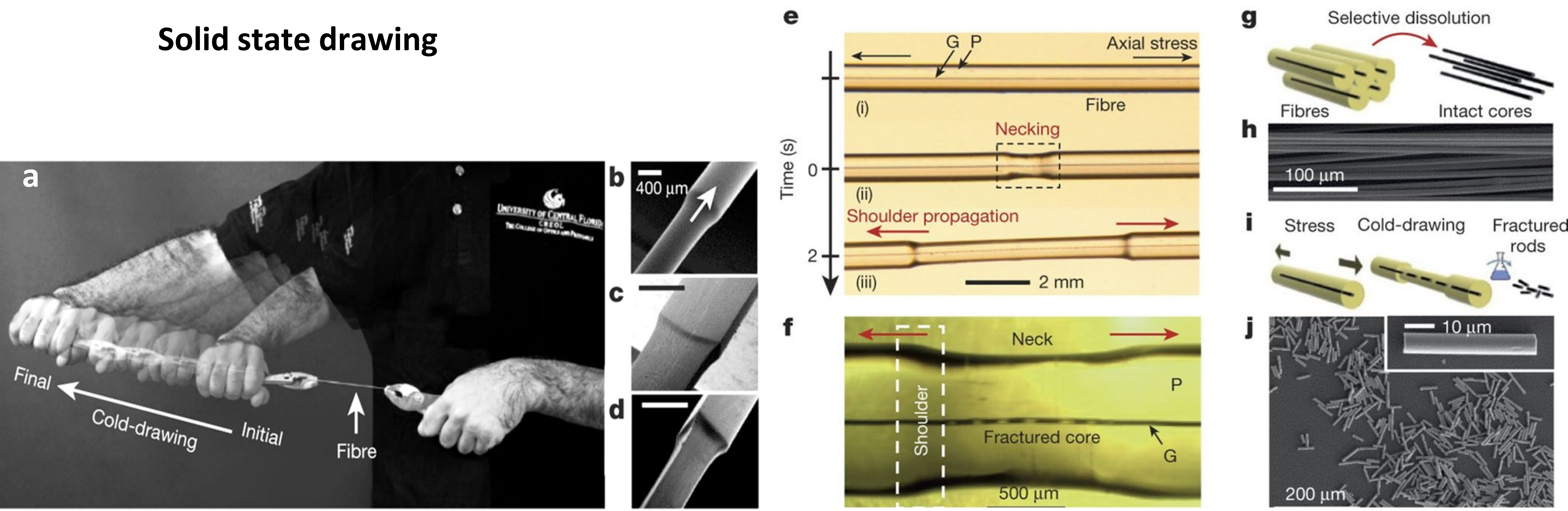


SusTexEdu Image: SusTexEdu

UNIVERSITY OF BORÅS
SCIENCE FOR THE PROFESSIONS

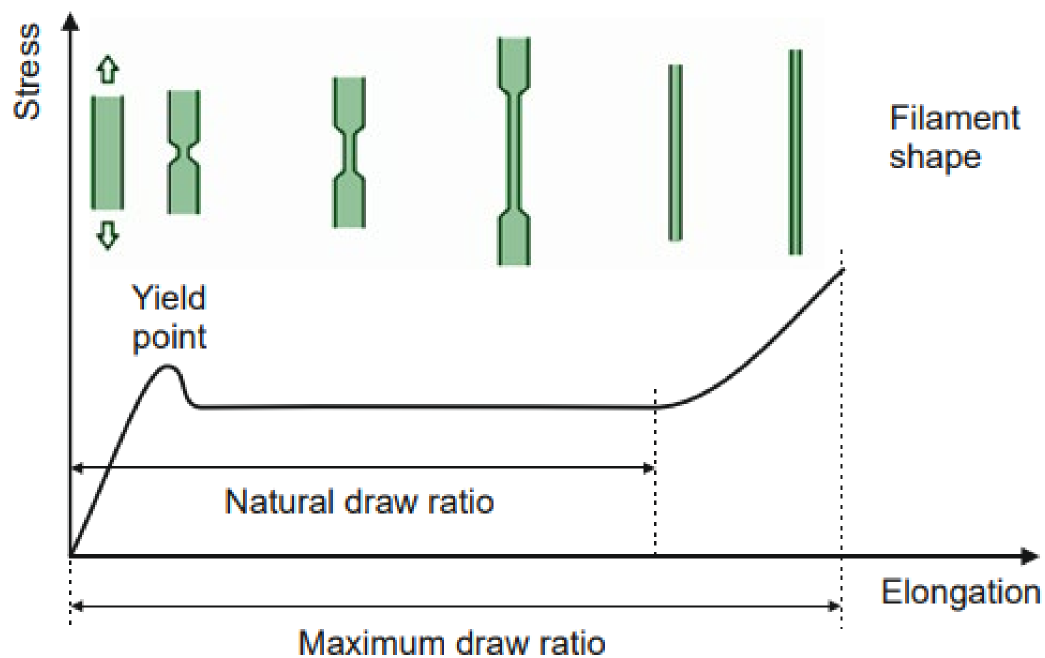
… Melt Spinning

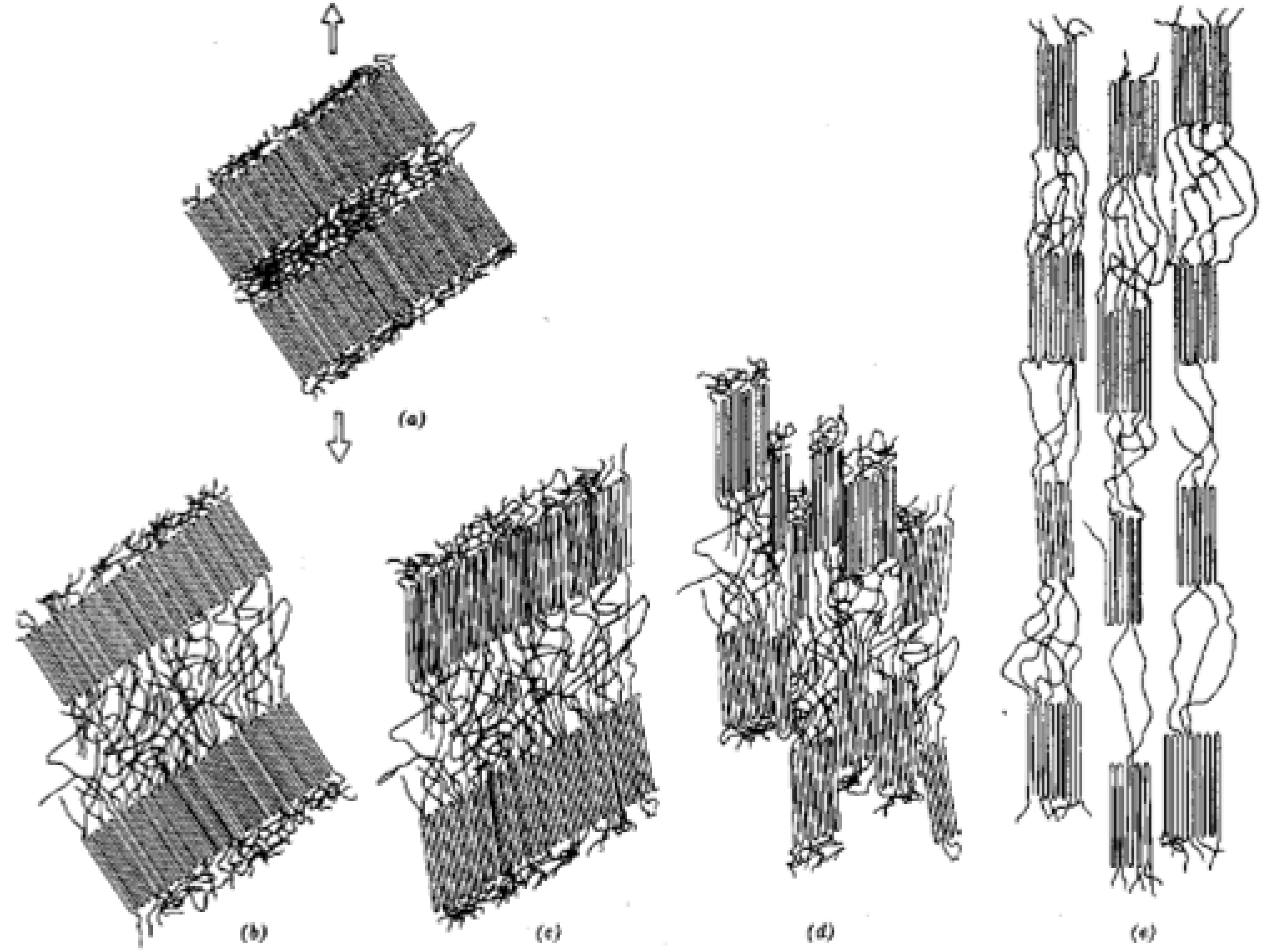
Solid state drawing

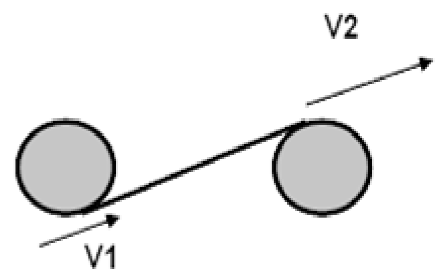


… Melt Spinning

Solid state drawing



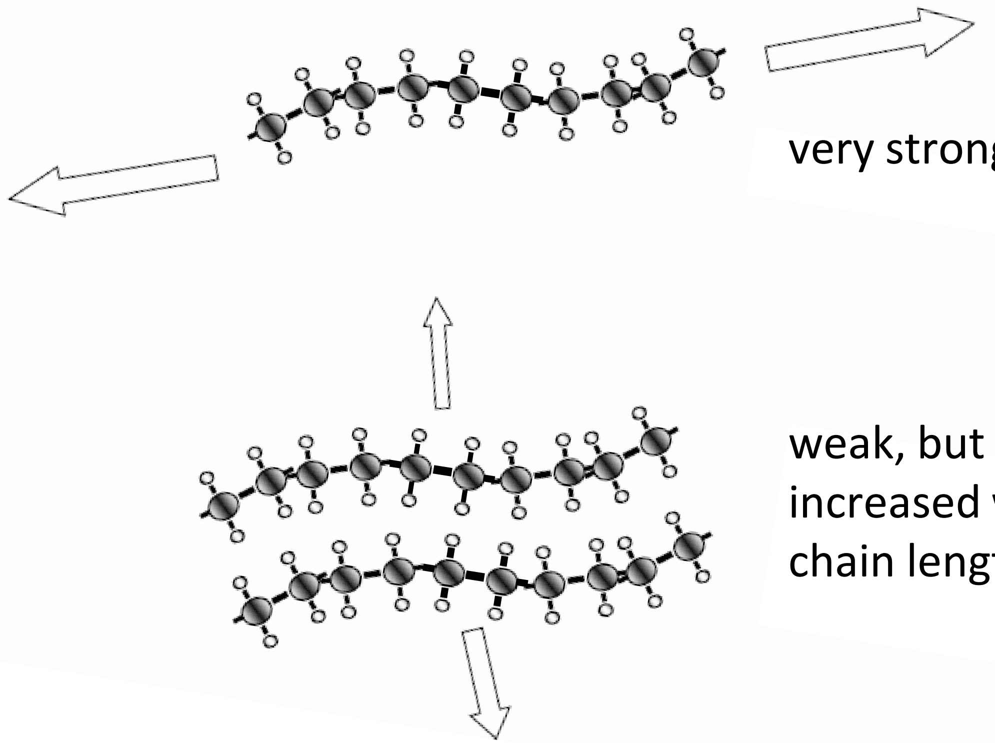




Courtesy Prof. Bengt, Swerea IVF

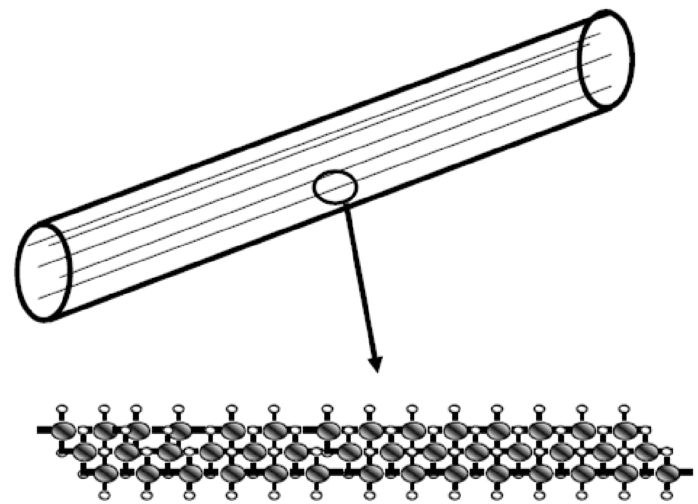
… Melt Spinning

Bond strength within and between polymer chains



very strong

weak, but
increased with
chain length

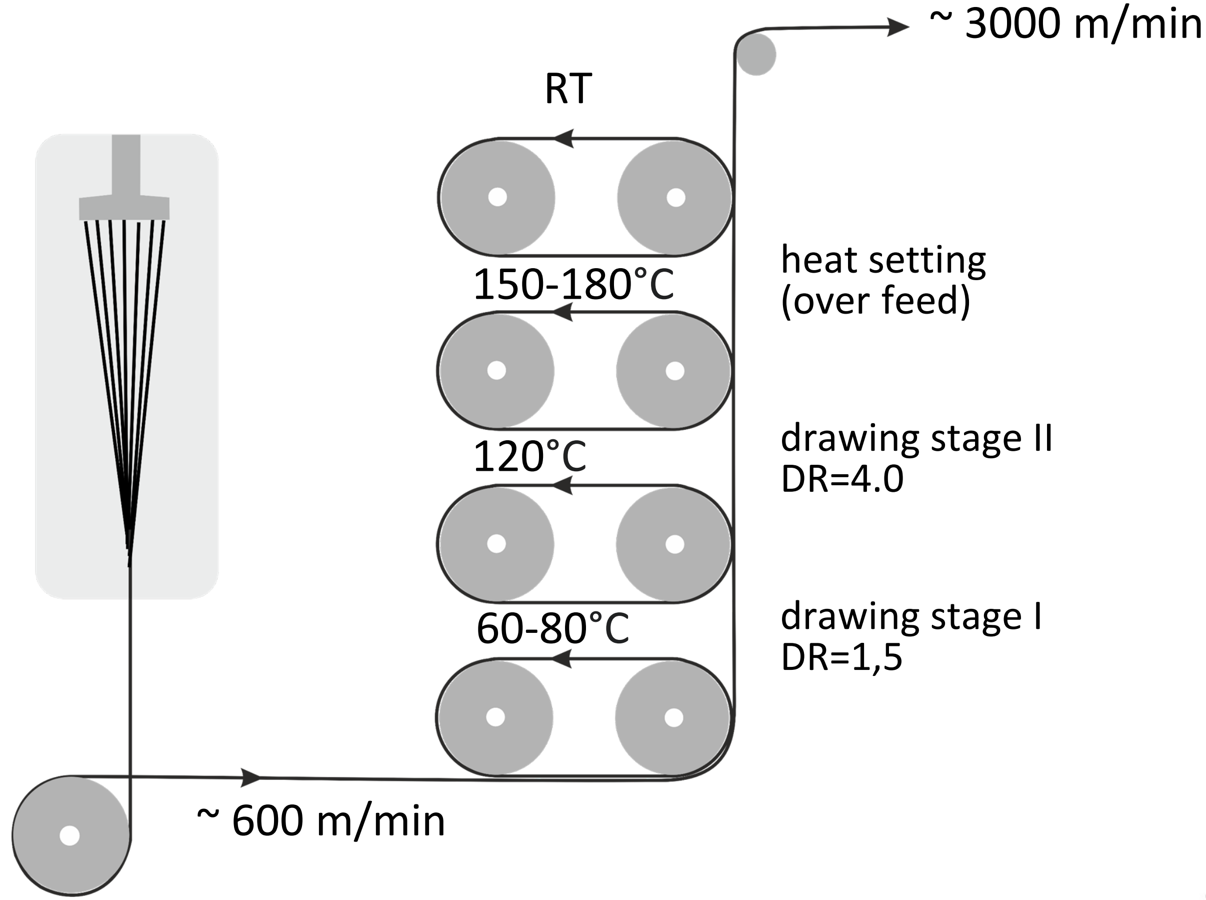


PE: Dyneema, Spectra

Courtesy Prof. Bengt, Swerea IVF

… Melt Spinning

Solid state drawing



… Melt Spinning

- Classification of melt-spun CF yarns
  - Low oriented yarns (LOY)
  - Fully drawn yarns (FDY)
  - Spin-drawn yarns (SDY)
  - Partially oriented yarns (POY)
  - Highly oriented yarns (HOY)
- FDY/SDY are used in textile and fashion fabrics
- Most of the produced yarns are POY

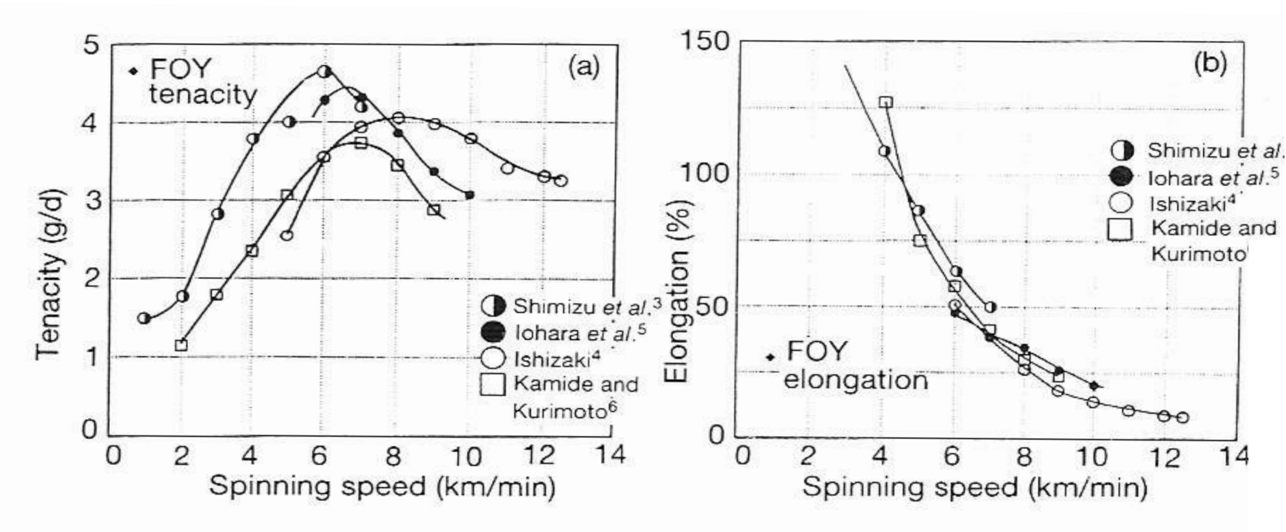
… Melt Spinning

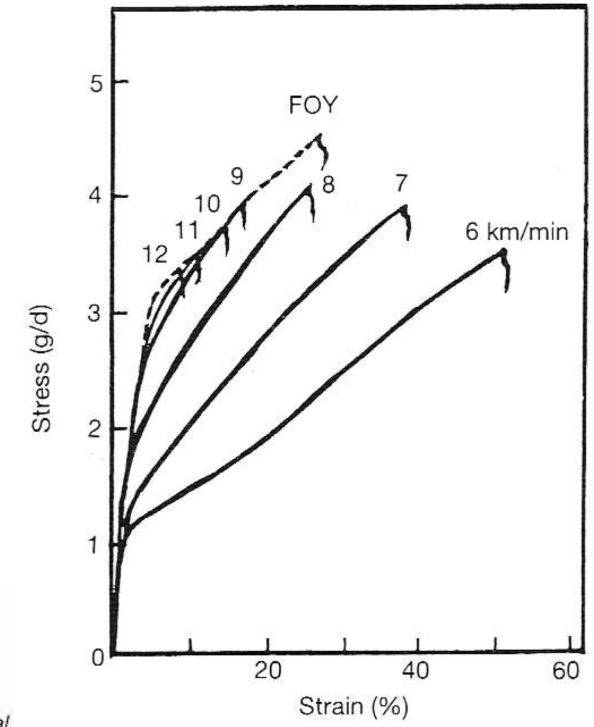
Classification of melt-spun CF yarns

Parameter	**Take-up speed**	**Elongation**
LOY	slow 500-2000 m/min	> 200%
POY	medium 2000-3500 m/min	100-150 %
HOY	high 3700-6500 m/min	40-100 %
FOY/FDY	typically > 4000 m/ min, using draw rolls	< 40 %

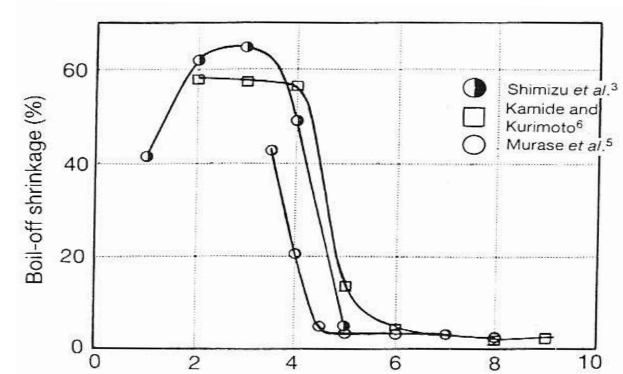
… Melt Spinning

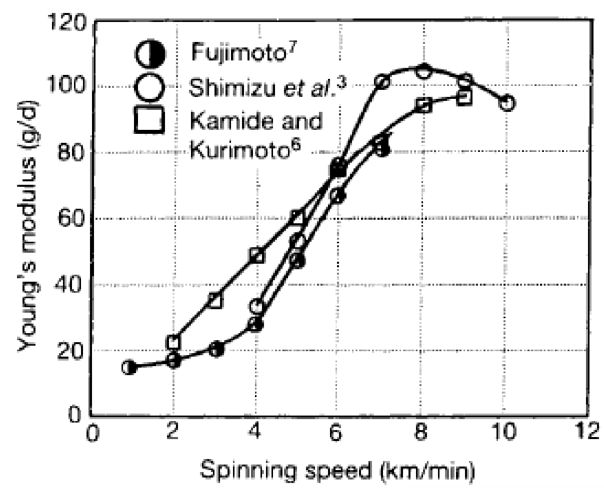
Effect of spinning speed on the yarn quality

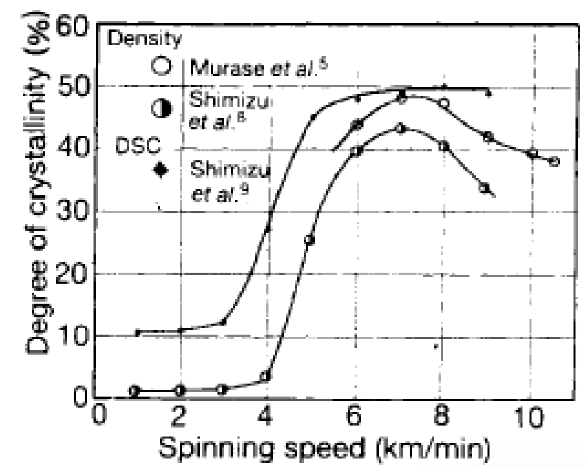




2.3 Stress–strain curve at various spinning speeds.







SusTexEdu

UNIVERSITY OF BORÅS
SCIENCE FOR THE PROFESSIONS

… Melt Spinning

Table 4. Physical properties of PET filaments as a function of spinning speed (one-step process) [169].

Spinning Speed [m/min]	2000	4000	6000	8000
Ultimate tensile stress [MPa]	140–220	290–470	440–570	430–500
Ultimate tensile stress [cN/tex]	10–16	21–34	32–41	31–36
Ultimate tensile strain [%]	200–250	110–125	45–65	25–35
Young's modulus [GPa]	2.1–2.8	3.5–6.1	8.2–9.5	11.5–12.8
Boiling water shrinkage [%]	58–62	20–57	3–5	2–3
Birefringence Δn	0.01	0.05	0.11	0.10–0.11
Degree of crystallinity [%]	2–11	4–27	40–48	41–50

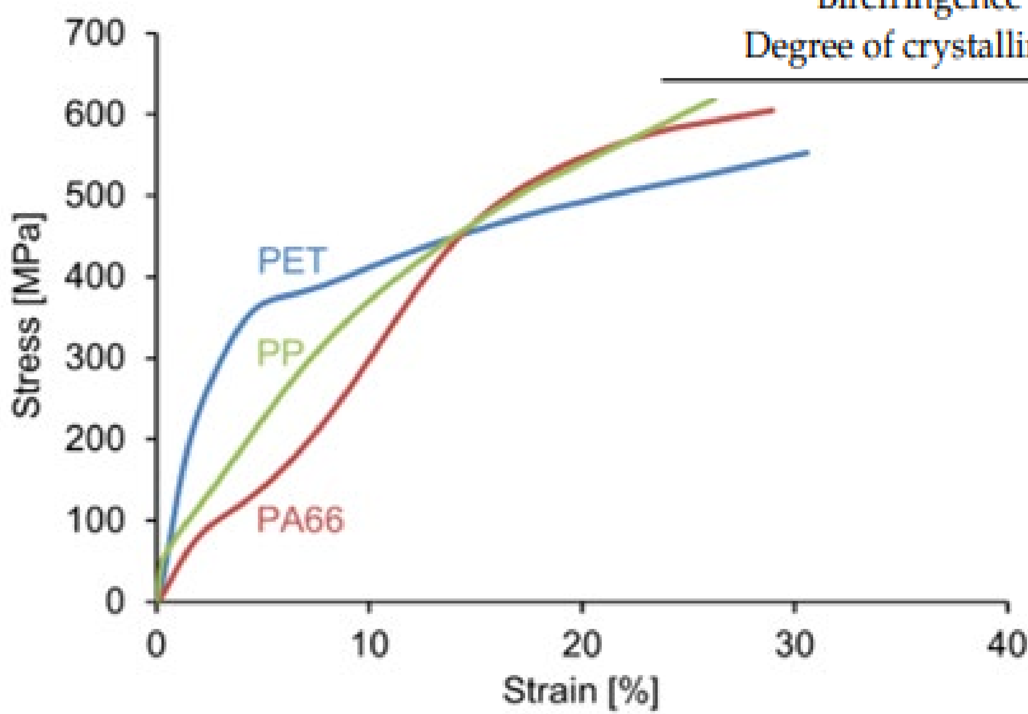
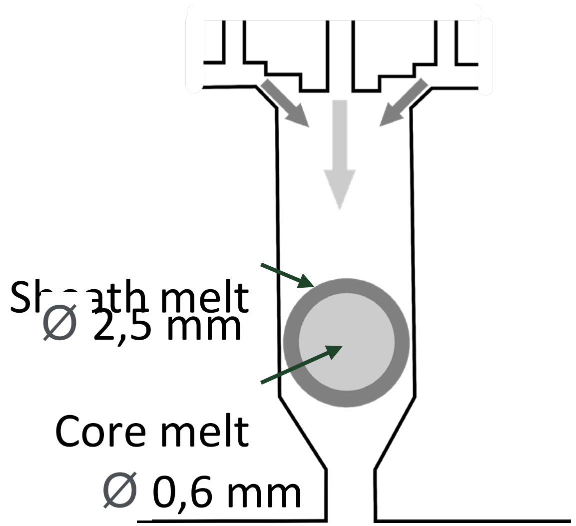


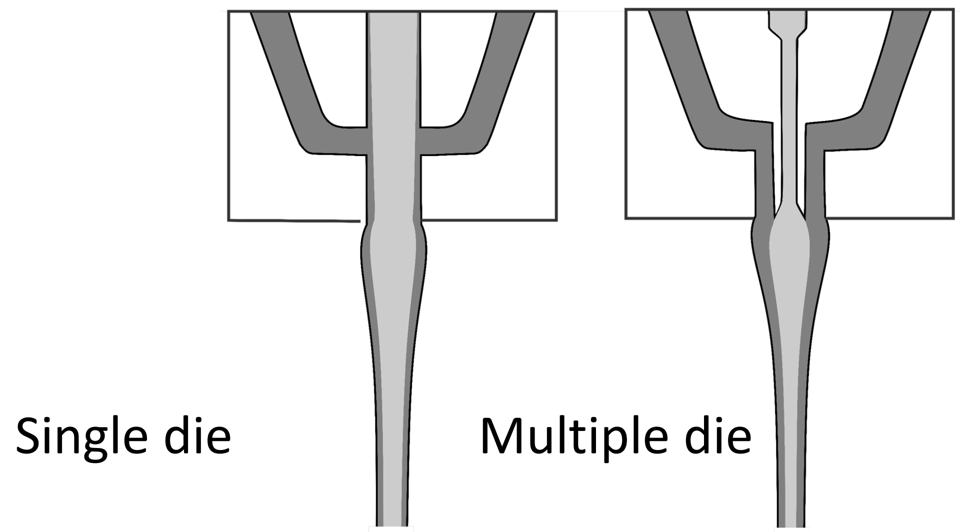
Figure beside (figure 8 of the source): Typical stress-strain curves (own unpublished data) of common melt-spun mono filaments (PA 6.6, PP and PET), all diameter 80 mm

Melt-Spun Fibers for Textile Applications. R. Hufenus, Y. Yan, M. Dauner, T. Kikutani (2020)

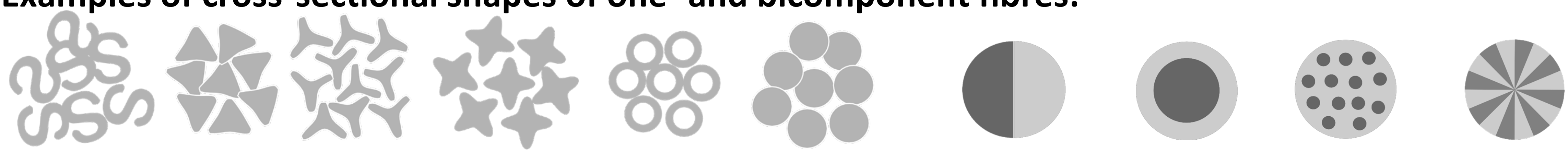
… Melt Spinning

Examples of core-sheath bicomponent spinnerets:





Examples of cross-sectional shapes of one- and bicomponent fibres:



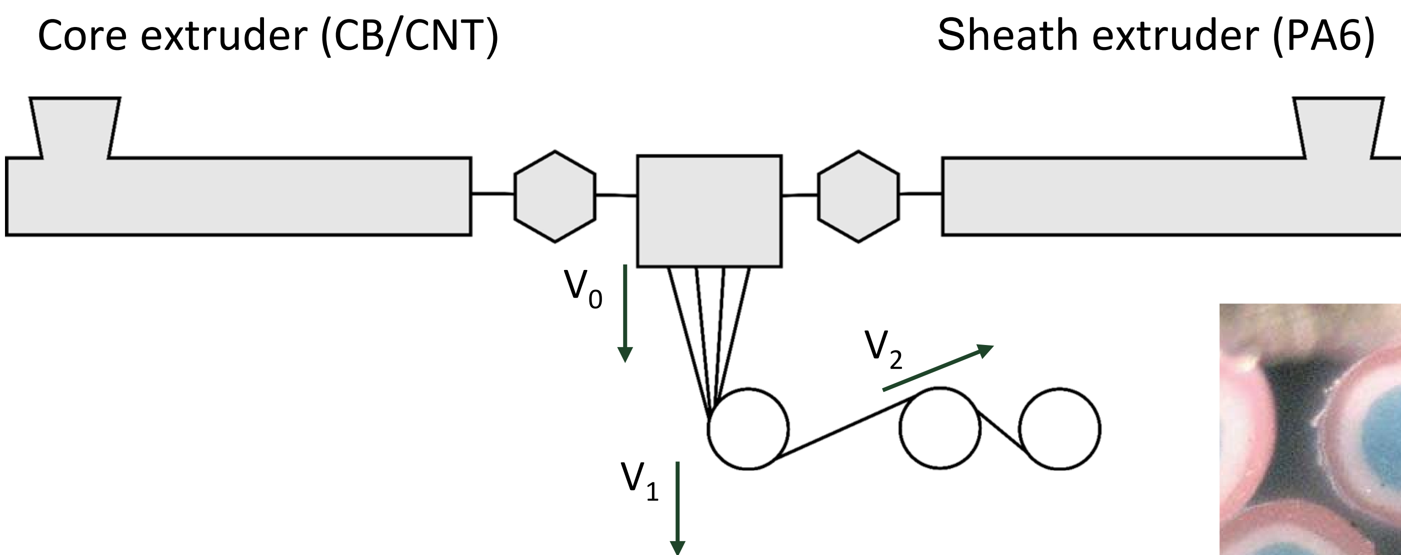
S type, trilobal types, X type, hollow fill type and round type - bicomponent cross sections

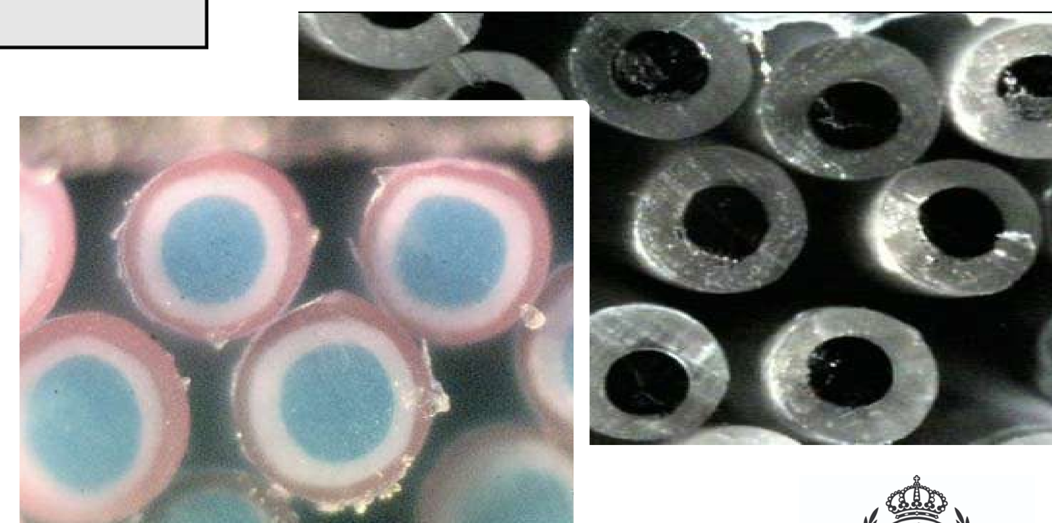
SusTexEdu Images: SusTexEdu

HÖGSKOLAN I BORÅS

… Melt Spinning

Electrically conductive fibres





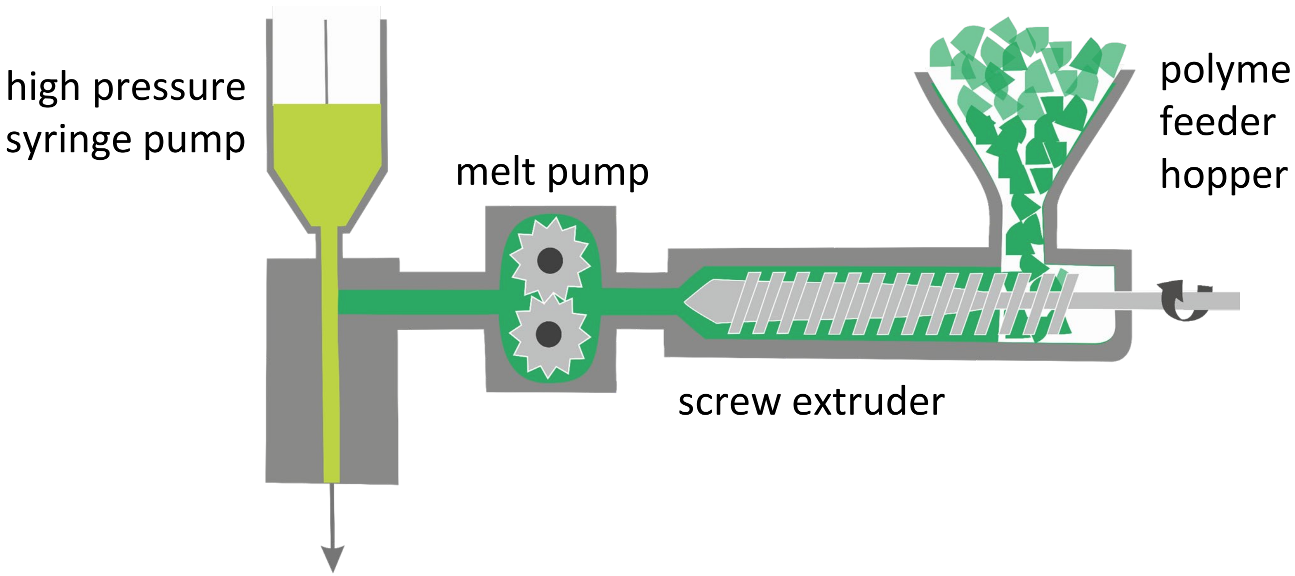
SusTexEdu

Courtesy Prof. Bengt, Swerea IVF

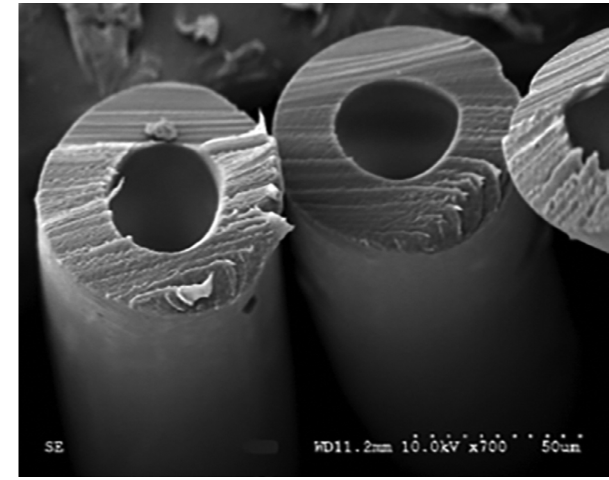
HÖGSKOLAN I BORÅS

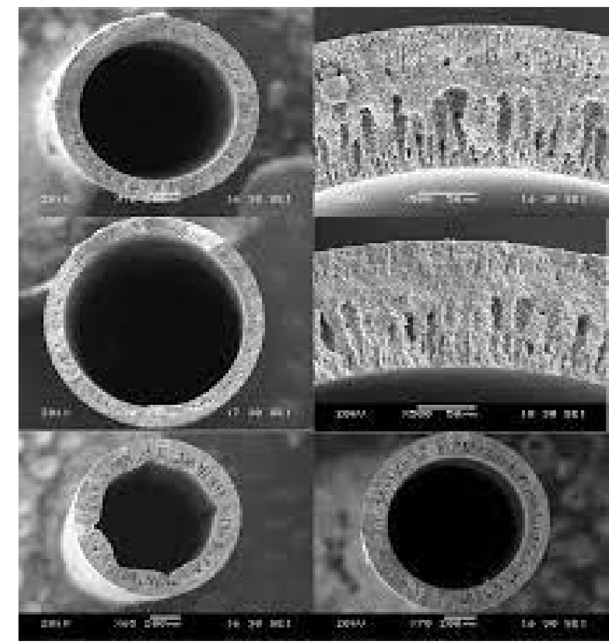
… Melt Spinning

Production of hollow fibres



Schematic of liquid-core fibre production. Polymer and liquid are represented in the image of SusTexEdu in green and lime.





SusTexEdu

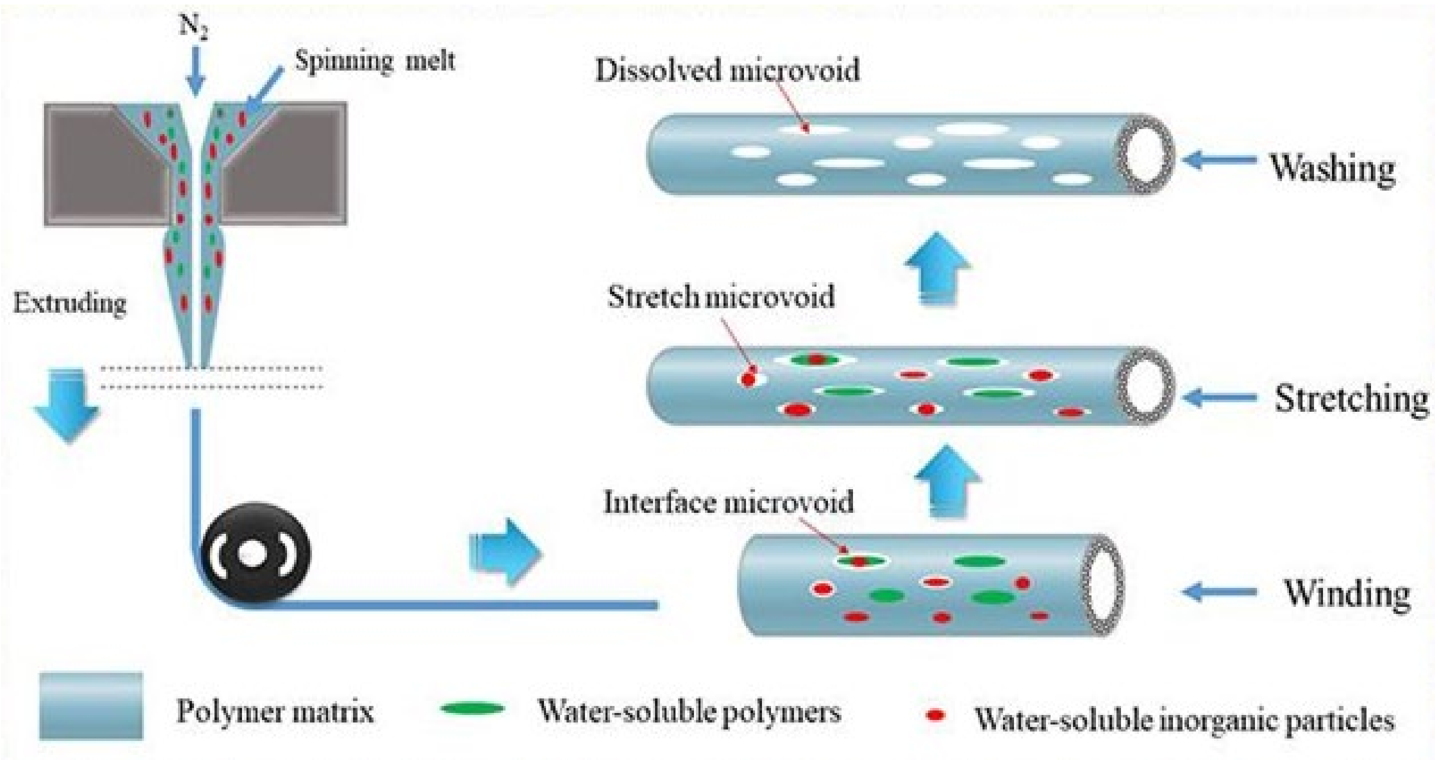
[Melt-Spun Fibers for Textile Applications](). R. Hufenus, Y. Yan, M. Dauner, T. Kikutani (2020)

HÖGSKOLAN I BORÅS

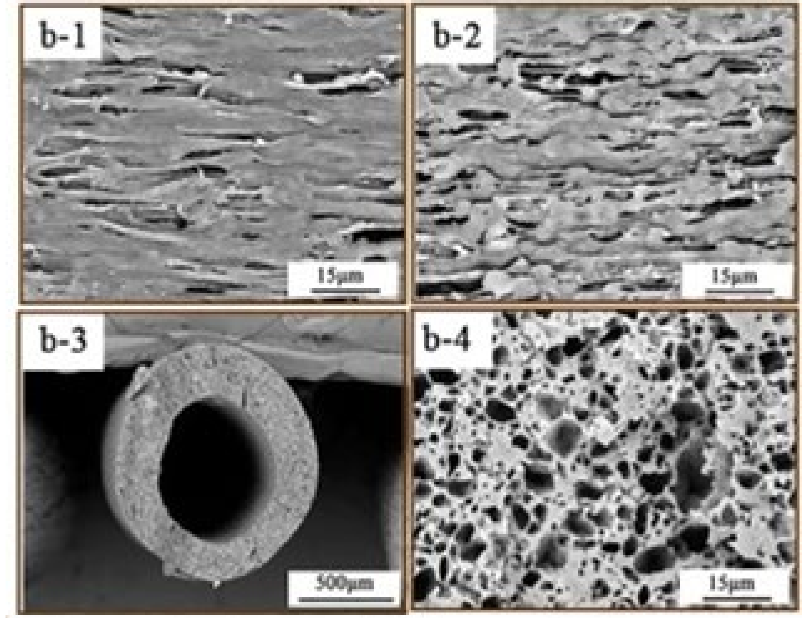
… Melt Spinning

Production of hollow fibre membrane

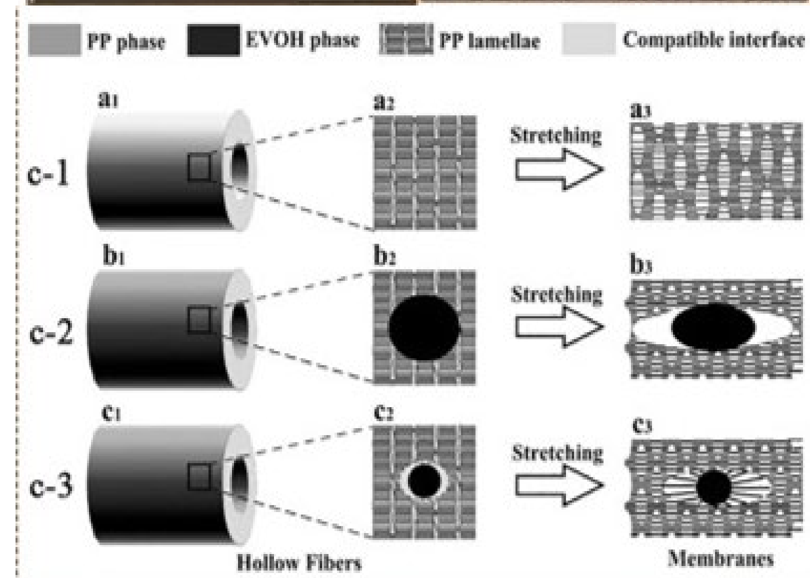
a)



b)



c)



SusTexEdu

Ref: Huang, Y., Huang, Q., Liu, H., Xiao, C., & Sun, K. (2020). A facile and environmental-friendly strategy for preparation of poly (tetrafluoroethylene-co-hexafluoropropylene) hollow fiber membrane and its membrane emulsification performance. Chemical Engineering Journal, 384, 123345.

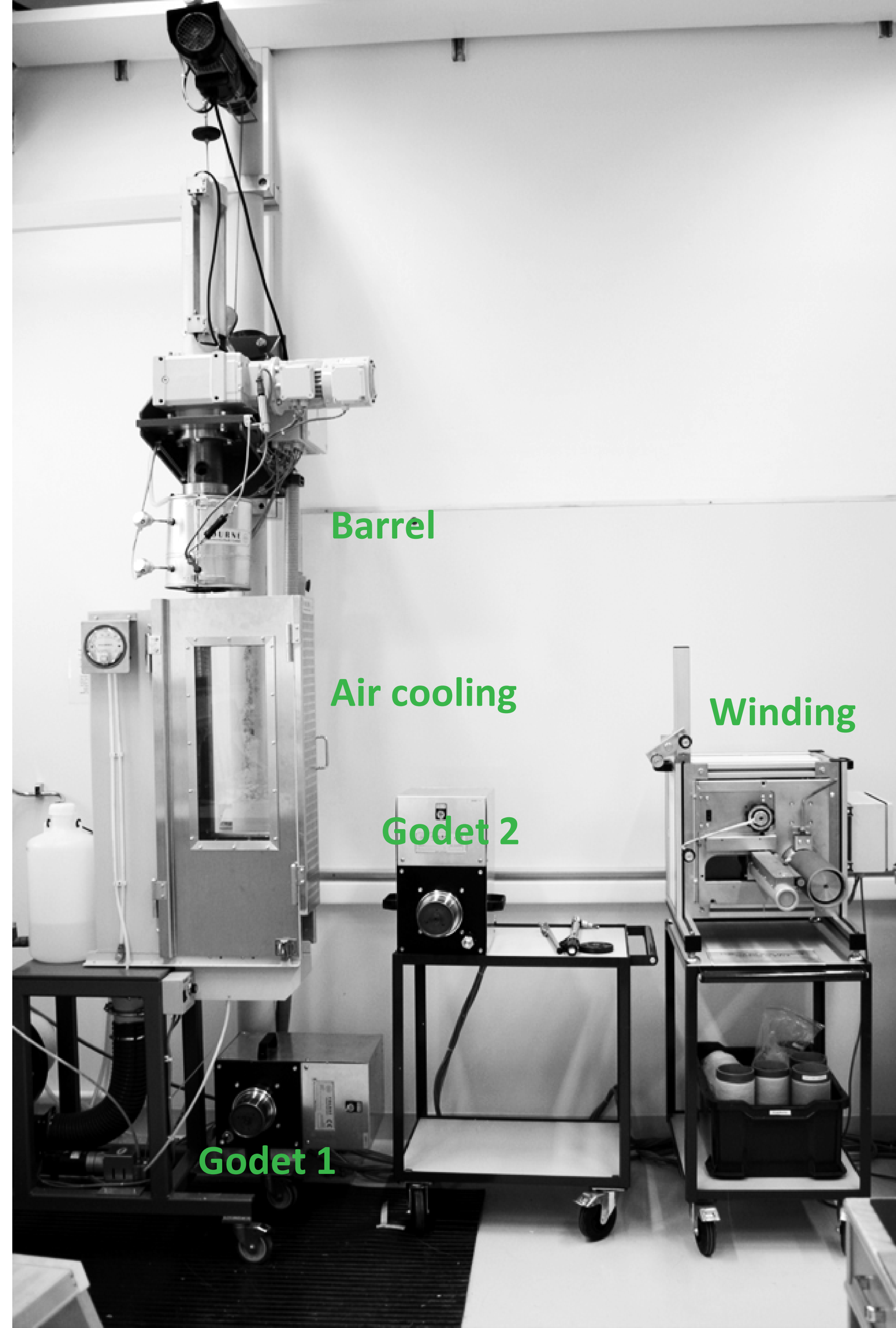
HÖGSKOLAN I BORÅS

… Melt Spinning

Factors affecting fiber properties

- Molecular weight of the polymer
- Melting temperature
- Moisture contents
- Density of material
- Composition of material
- MFI
- Melt draw ratio
- Solid draw ratio
- Winding speed
- Cooling mechanism
- Die swell
- L/D of spinneret

Piston Spinning Machine in Lab



SusTexEdu

Man-made fibre spinning process. University of Highlands and Islands. Fibre Technology.

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)

SusTexEdu

UNIVERSITY OF BORÅS
SCIENCE FOR THE PROFESSIONS

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

SusTexEdu

UNIVERSITY OF BORÅS
SCIENCE FOR THE PROFESSIONS

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

SusTexEdu

Funded by the Erasmus+ Programme of the European Union