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Properties of Cork and Bottling

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Cork is “the suberous parenchyma developed by the subero-phellodermic meristem of the cork tree (*Quercus suber L.*) whose trunks and branches it envelops.”

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Cork oak tree (*Quercus suber* L.)

Young tree (chaparro)

Adult tree

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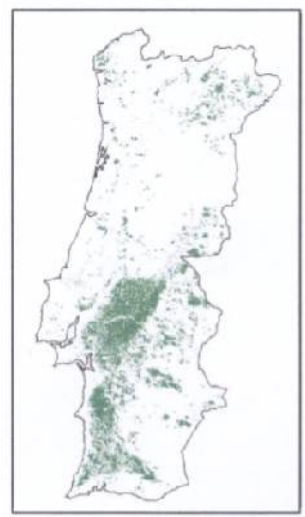
Distribution of cork oak tree



- **Cork** is produced almost exclusively in the Mediterranean countries of European Union
- **Area of cork oak tree**: 2.3 millions ha (Portugal+Spain more than 50%)
- **Average cork production**: 374 000 t/year

Portugal
32% area of cork oak
51% cork production

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Removal of cork from the cork oak (stripping)

During Summer by very specialised workers, using axes, make axial and transverse incisions

Young tree (20-35 years)

Virgin cork: growth stresses; poor quality; not used to produce natural cork stoppers

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Removal of cork from the tree (stripping)

Adult tree (every 9 years; 30 - 200kg/tree; 8 - 11kg/m2 of harvested area)

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Cork oak trees after stripping

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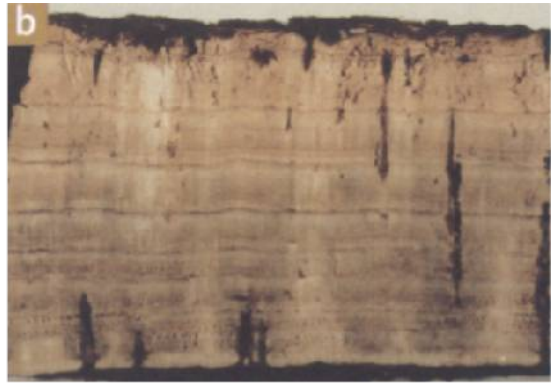
Reproduction cork (amadia)



Reproduction cork: good quality and uniform thickness;
used to produce natural cork stoppers

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Preparation of reproduction corkboards

Corkboards after removal from the tree are curved (growth stresses)

To relieve growth stresses in the corkboards and to give the first cleaning
⇨ **Boiling** (in water at 100ºC for one hour) + **Drying** in open air

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Boiling of corkboards

Tank (open)

Autoclave (closed)

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Boiled corkboards

Boiling:

⇨ relieve growth stresses ⇨ **boiled corkboards** are **more planar**

⇨ surface **cleaning**

⇨ **water absorption** ⇨ **drying** in open air (2 - 4 weeks)

⇨ **volume expansion** (cell walls become straighter)

Thickness of boiled corkboards: 1 – 8cm

Boiled cork is classified in various **qualities** (porosity)

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Production of natural cork stoppers

- **Slices** (rabanadas) with their longest side parallel to the tangential direction are cut from the boiled corkboards; other dimension is the thickness of the board (radial direction); and the other dimension (axial direction) is large enough for a cork stopper to be cut out with its axis running in this direction
- **Cylindrical stoppers** are cut automatically by mechanical means in a range height: 38 – 45mm)

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Production of natural cork stoppers

⇨ **Cork stoppers** are usually submitted to:

- ✦ **washing** operations to clean and sterilize the stoppers
- ✦ **drying** operations
- ✦ **classification** in different qualities (usually 9 classes)

- ✦ **surface finishing** operations with paraffin and silicone to improve sealing power and for easy insertion and removal from the bottle
- ✦ **printing** of commercial brand names on the stoppers

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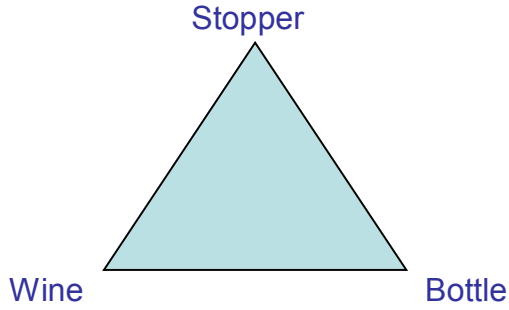
Cork stoppers



Cork stopper { **natural**; agglomerated

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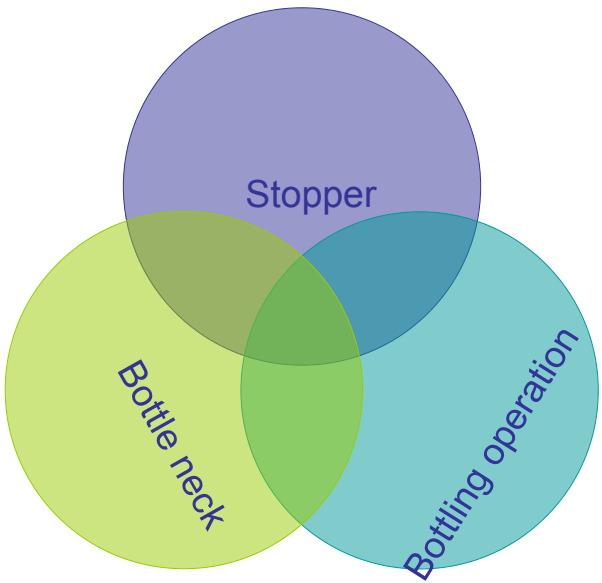
Perfomance of cork stoppers



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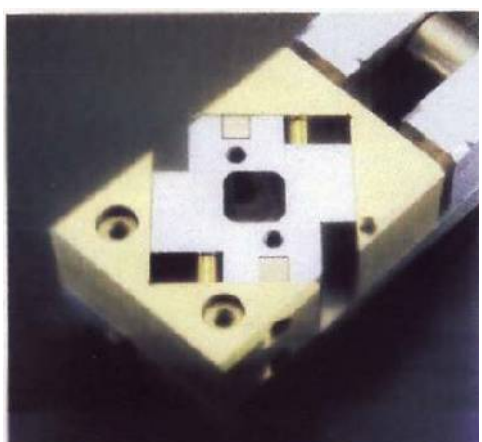
Bottling operation

⇨ Bottling machine reduces the initial diameter of the stopper $\phi_0 \rightarrow \phi_m$



ϕ_m = 14 - 16mm

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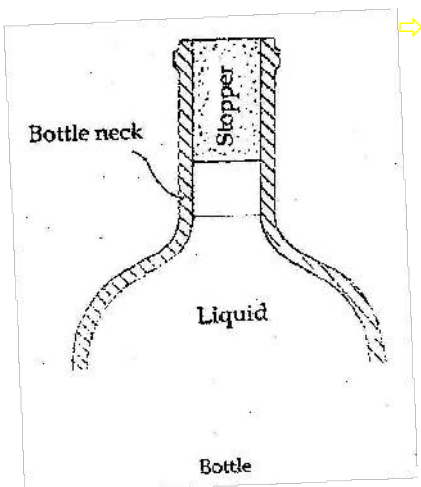
Bottle

⇨ Bottle neck **is not cylindrical**



⇨ Diameter: top ϕ_{gt}

$$\phi_m < \phi_{gt} < \phi_{gb}$$

bottom ϕ_{gb}

Example: Bordeaux bottle (CETIE standard)

ϕ_{gt} = 18,5±0,5mm 19,5mm < ϕ_{gb} <21mm

↳ Stopper deformation inside bottle neck **is not uniform**

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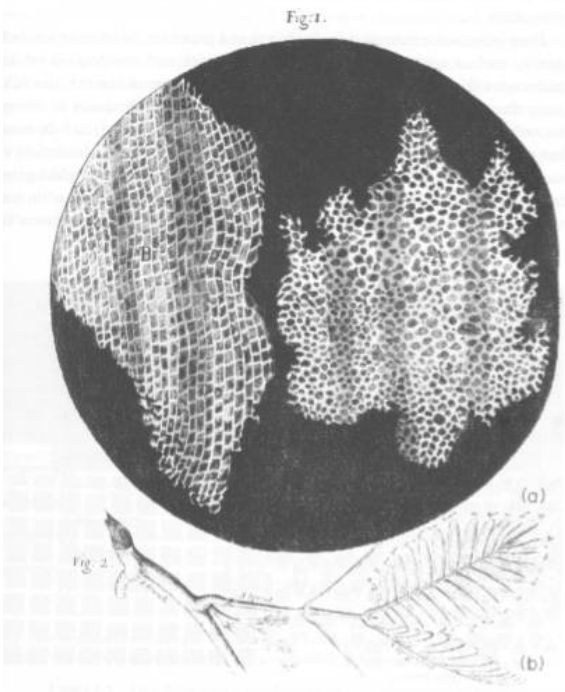
- Robert Hooke, 1660: **CORK** was one of the first materials he examined at his microscope.



Cork **cellular material**

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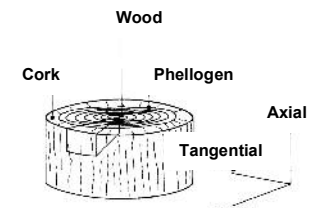
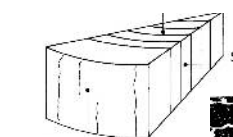
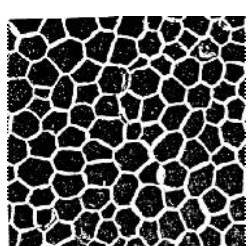
Cork

⇨ Cellular material







Other examples:

- Wood
- Bone
- Coral
- Polyurethane foam
- Polystyrene foam
- Bread
- Chocolate

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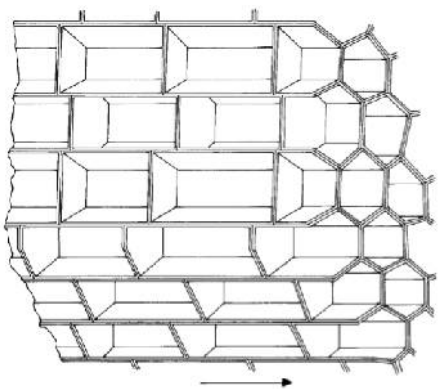
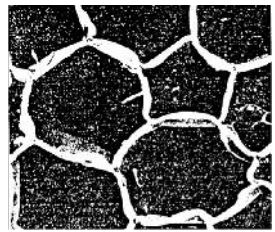
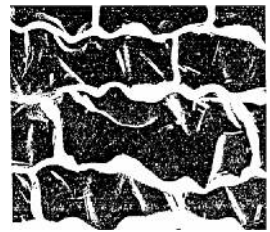
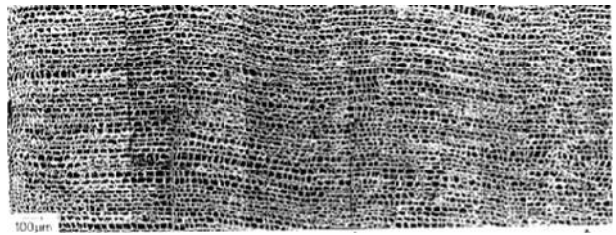
Cork cells



Radial direction







- Cell walls are **undulated** (growth stresses)
- Variation in **cell dimensions** (early/Spring cells higher and thin walls; late/Autumn cells thicker walls)

ϕ_0

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Typical chemical composition

- ⇨ **Suberin**: 40%
- ⇨ Lignin: 20%
- ⇨ Cellulose: 10%
- ⇨ Hemicelluloses: 10%
- ⇨ Extractives: 15%
- ⇨ Ashes: 5%

Virgin cork Ξ **Reproduction** cork
Unboiled cork Ξ **Boiled** cork

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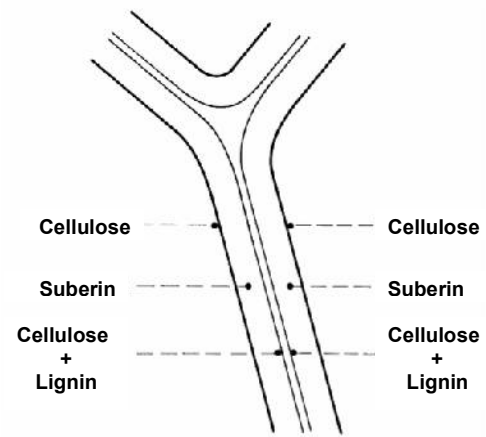
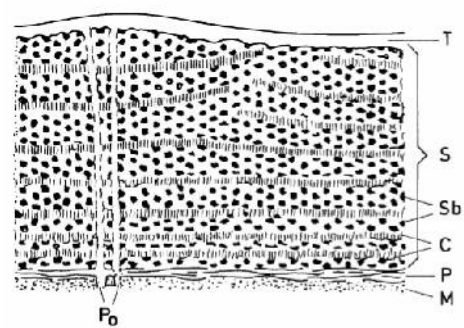
Cell wall models

⇨ von Hohnel model (1877)



Sitte (1962)



M - Middle lamella
C - Waxes
Sb - Suberin
Po - Plasmodesmata
P - Primary wall
S - Secondary wall
T - Tertiary wall

⇨ Pereira (1988) claims that lignin (20%) must appear in secondary wall

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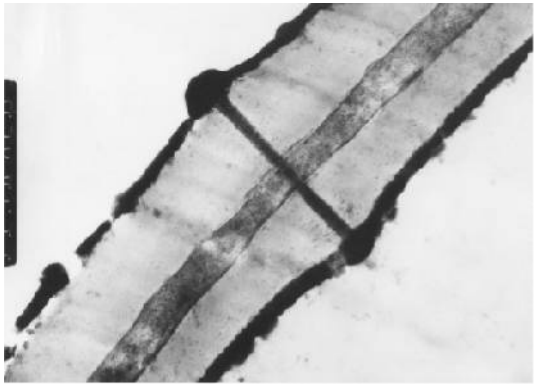
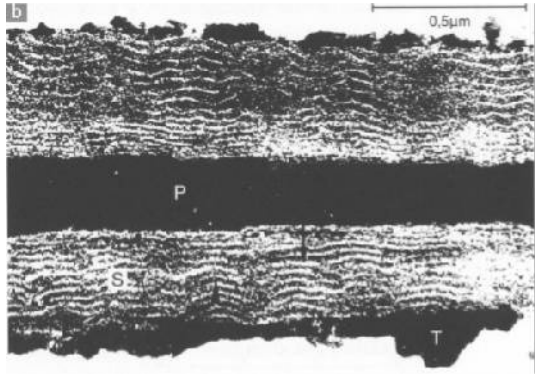
Transmission electron (TEM) micrographs of cork cell walls





⇨A plasmodesmata can be observed in the cell wall (not very frequently)

⇨Layering in the secondary wall can be observed

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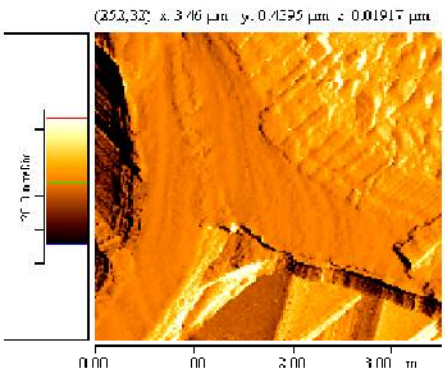
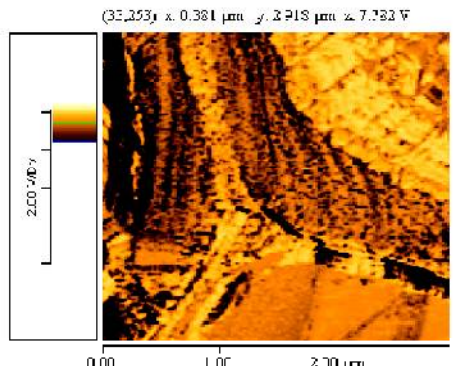
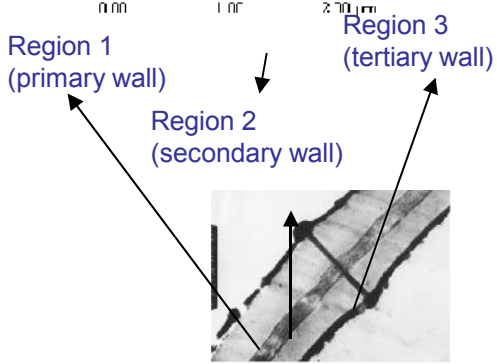
Atomic Force Microscope Observations

Topographic image



Phase shift image





Note that:

- **Suberine** (secondary wall) is a pasty viscoelastic material
- **Cellulose** (primary and tertiary walls) is a crystalline (stiffer) material

ϕ_0

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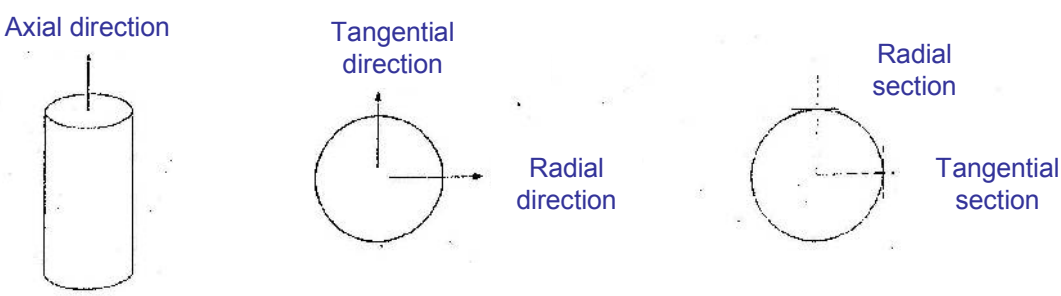
Orientation of natural cork stoppers

⇨ Transverse section of stopper Ξ Tranverse section of cork



Height: 38 – 45mm
Diameter: (18)24 – 26mm

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Stopper/Cork properties

- Initial diameter of stopper ϕ_0
- Bottling
  - Diameter reduction $\phi_0 \rightarrow \phi_m < \phi_g < \phi_0$
    - **Compression** (radial and tangential)
  - Introduction into bottle neck $\phi_m \rightarrow \phi_g > \phi_m$
    - **Recovery of dimensions + Contact**
- Stopper into bottle neck $\phi = \phi_g$
  - **Stress relaxation + Contact/Sealing**
- Introdution of cork-screw
  - **Fracture**
- Removal from bottle neck $\phi_g \rightarrow \phi' \qquad \phi_g < \phi' < \phi_0$
  - **Friction + Recovery of dimensions**

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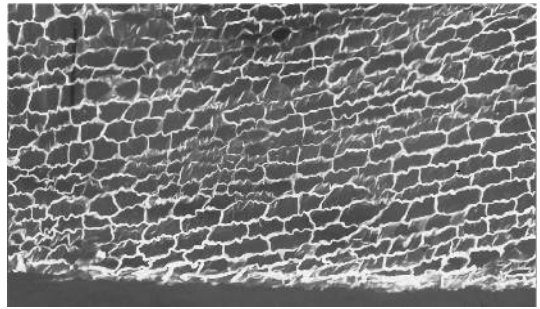
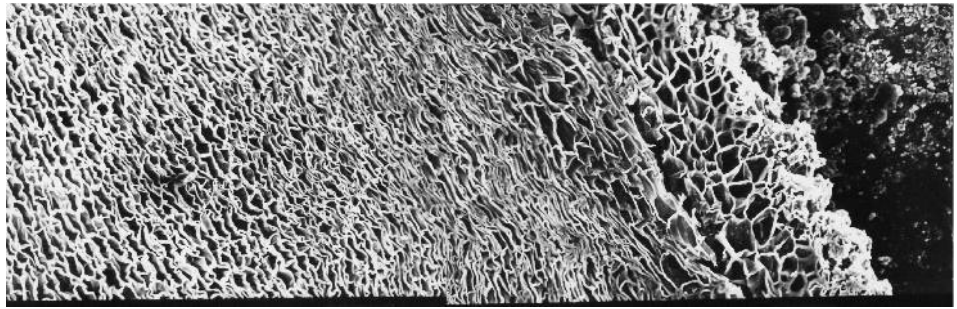
Transverse section of natural cork stopper

⇨ Before introduction into bottle neck



⇨ Introduced into bottle neck



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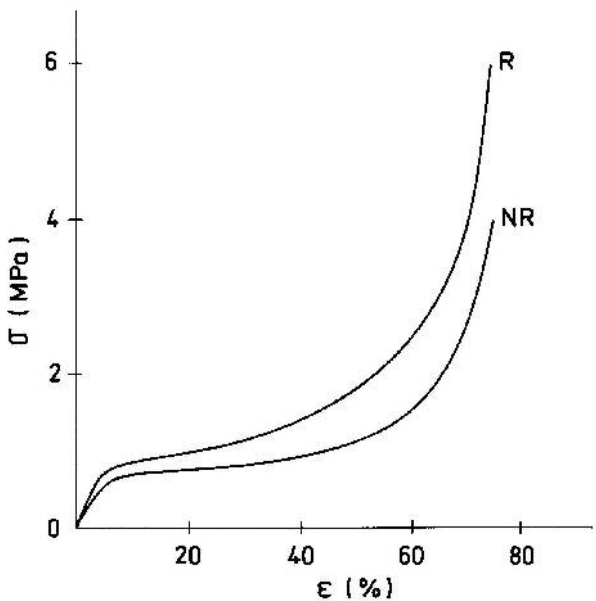
Compression curves of cork



R – radial
NR – non-radial (axial/tangential)

Stress: $\sigma = \frac{F}{A_0}$

Strain: $\varepsilon = \frac{\phi_0 - \phi}{\phi_0}$

Example: $\phi_0 = 24\text{mm}$

$\phi_m = 16\text{mm}$ $\quad \varepsilon_m \cong 33\%$

$\phi_{gt} = 18{,}5\text{mm}$ $\quad \varepsilon_{gt} \cong 23\%$

$\phi_{gb} = 20\text{mm}$ $\quad \varepsilon_{gb} \cong 17\%$

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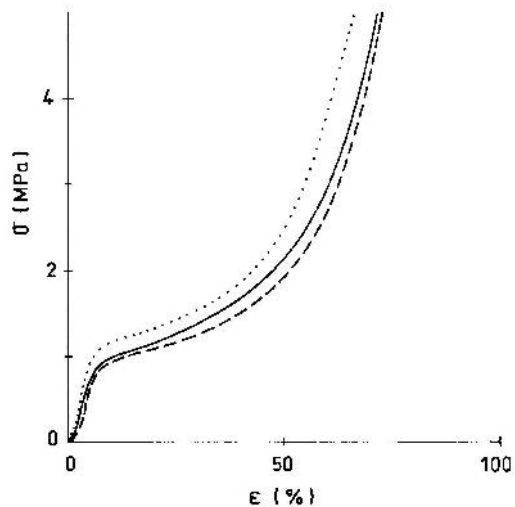
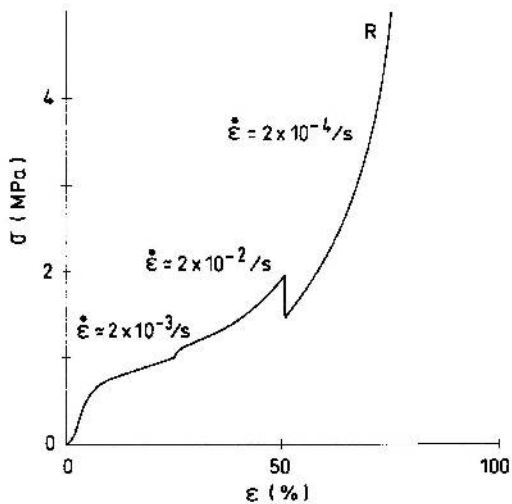
Effect of strain rate

Radial compression Strain rate ≈ 0,0002-0,002-0,02/s

m = 0.08





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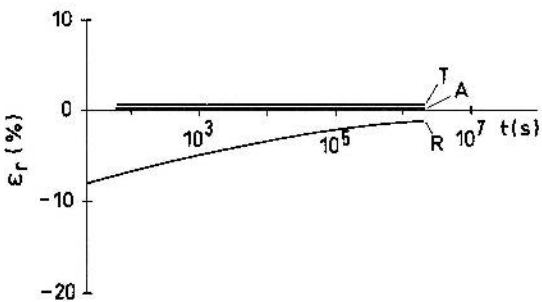
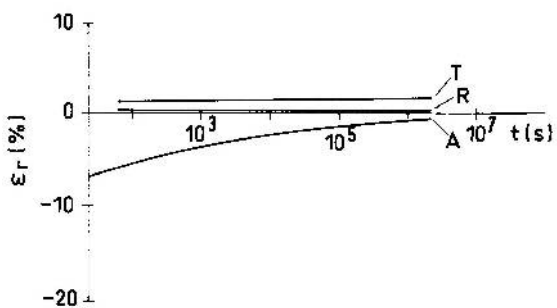
Recovery of dimensions





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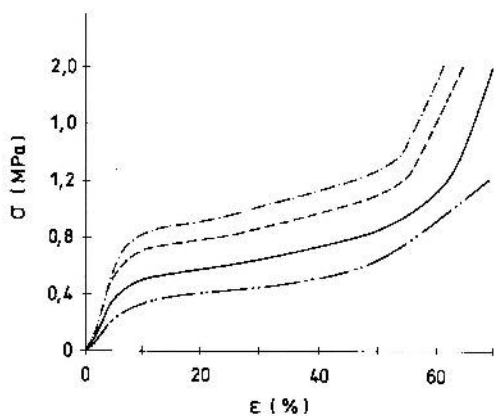
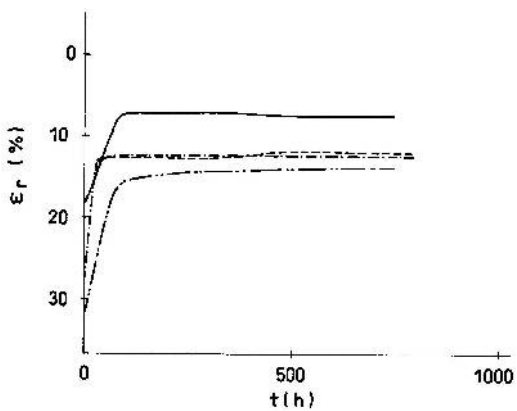
Effect of moisture content

Radial compression

Moisture content = 6-9-12-33%





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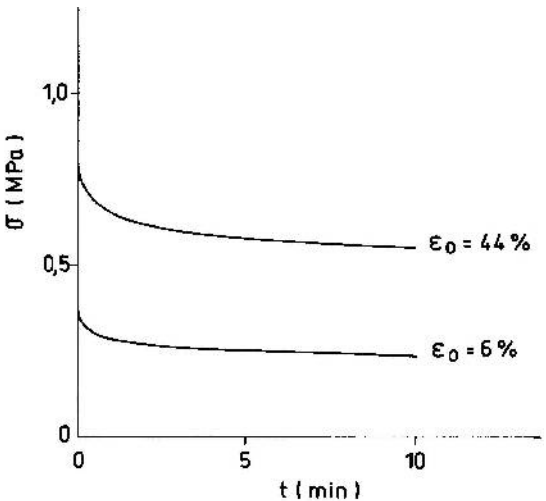
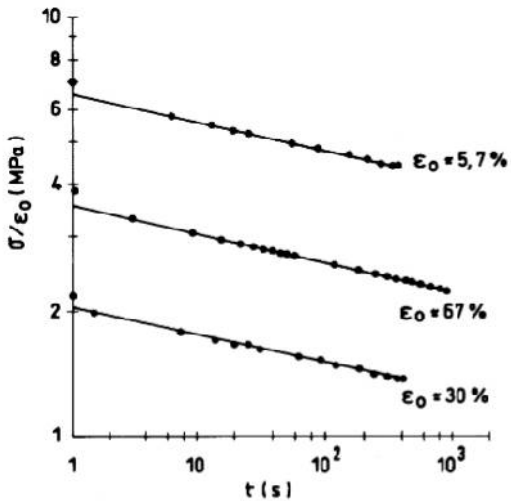
Stress relaxation

$$\phi(t) = \phi_g \rightarrow \varepsilon(t) = \varepsilon_g \qquad F(t) \rightarrow \sigma(t)$$





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Sealing power

⇨ **Pression** on bottle neck

⇨ Stopper **strain**

⇨ **Contact area** between stopper and bottle neck

↳ **Sealing power** of stopper

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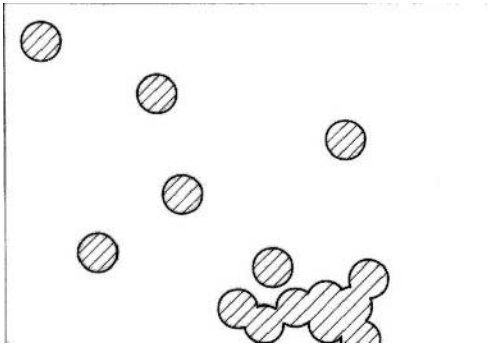
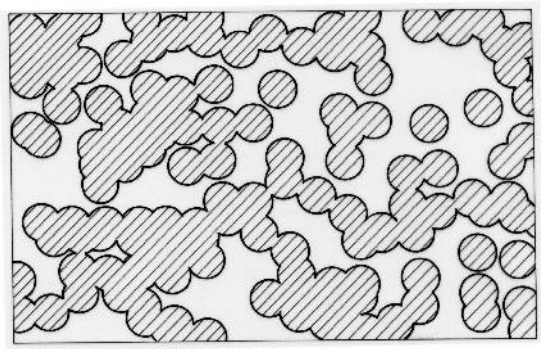
Sealing power/Contact stopper-bottle neck



Top

Bottom



Perfect sealing: $f > 0{,}65$

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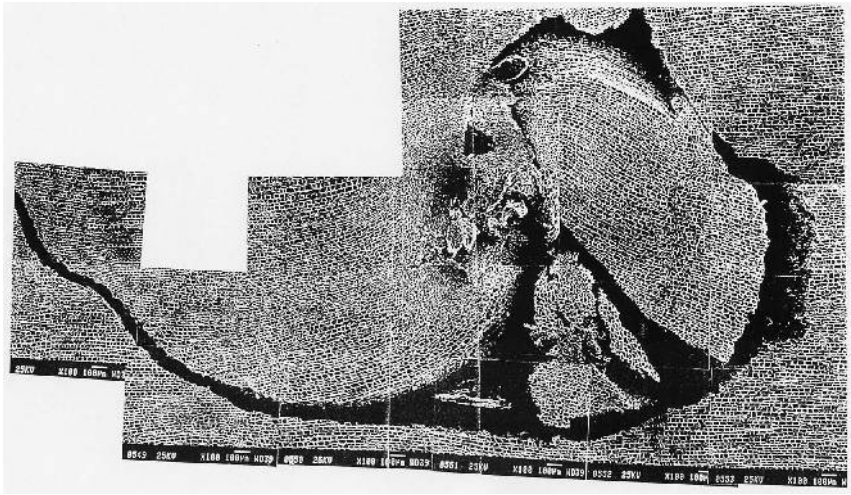
Introduction of a cork-screw

Transverse section of stopper



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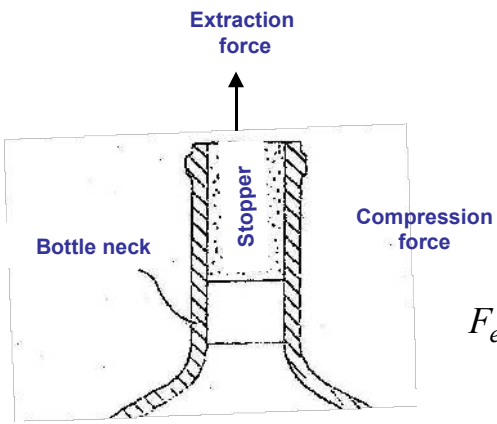
Extraction force

Friction coefficient μ

$$\mu = \frac{\text{Extraction force}}{\text{Compression force}}$$

Extraction force $(F_{ext}) = \mu \times$

$\times$ Compression force (F_{ap})



$\mu_{\text{cork-glass}} = 0.6$

F_{ext} = 20 – 40daN F_{ap} =30 – 60daN

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Other properties

- Liquid absorption
- Permeability to gases
- Chemical inertia
- Aspect
- Price

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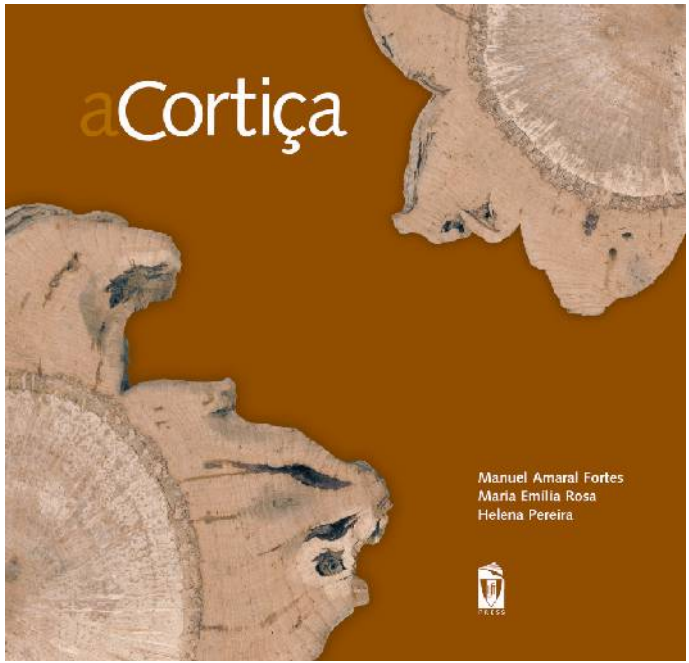

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