Cork

- Romans used cork for soles of shoes, to seal bottles (also sealed with pitch over cork)
- Benedictine monks in 1600s perfected stopping bottles with clean, unsealed cork
- cork is the bark of the cork oak tree (Quercus suber)
- grows in Portugal, Spain, Algeria, California
- all trees have a layer of cork in their bark
- Q. suber unusual in that cork layer is several cm thick

- can cut bark off Q. suber + it regrows
- cell walls of cork covered in unsaturated fatty acid - suberin - impervious
- cork still used to seal bottles, as gaskets, for soles of shoes.

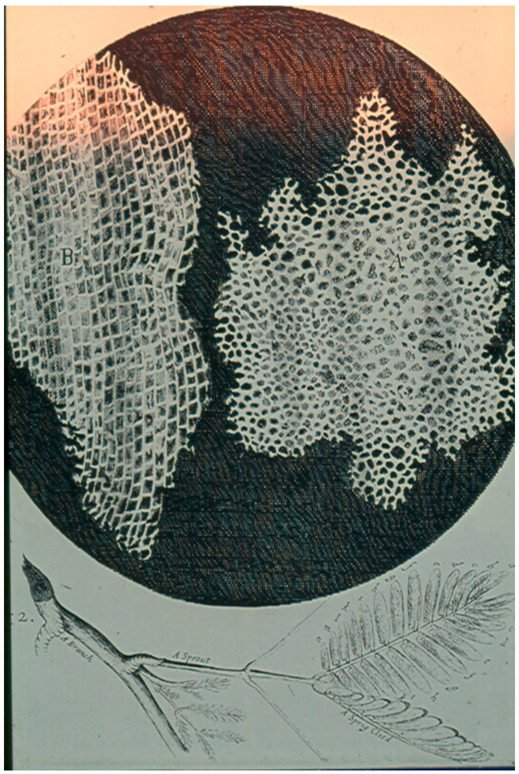
Structure

- Hooke's drawings, SEM: one plane, roughly hexagonal cells; other 2 - box-like cells, corrugated walls
- axisymmetric - hexagonal cells normal to radial direction
  - x_1 = tangential x_2 = axial x_3 = radial
- cell size ~ 30-40 μm (smaller than most engineering foams)
- density ~ 170 kg/m³ $\rho_s \sim 1150$ kg/m³ $\rho^*/\rho_s \sim 0.15$ typically.

Cork

Quercus suber

Cork microstructure



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Hooke, 1665

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Cork microstructure

Cork microstructure

Mechanical behavior

Modelling: 1-2 directions – honeycomb loaded in plane
(tang. / axial)

	Measured	
$E_1^* = E_2^* = 0.5\, E_s (\rho^*/\rho_s)^3 = 15\text{ MPa}$	13 MPa	
$G_{12}^* = 0.13\, E_s (\rho^*/\rho_s)^3 = 4\text{ MPa}$	4.3 MPa	
$\nu_{12}^* = \nu_{21}^* = 1$	0.25-0.50	(constraint of end membranes)
$(\sigma_{el}^*)_1 = (\sigma_{el}^*)_2 = 1.5\text{ MPa}$	0.7 MPa	

Modelling: radial direction (x_3)

- need to account for corrugations
- if walls straight – axial deformation
- corrugated walls – also have bending

$$E_3^* = \frac{0.7\, E_s (\rho^*/\rho_s)}{1 + 6(a/t)^2} = 20\text{ MPa}$$

Measured: 20 MPa

- $\nu_{31}^* = \nu_{32}^* = 0$ (corrugations fold up)

$\nu_{13}^* = \frac{E_1^*}{E_3^*} \nu_{31} = 0\,;\ \nu_{23}^* = 0$

} measured: 0 - 0.1

Stress-strain

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Table 12.2 Comparison between calculated and measured properties of cork†

	Calculated	Measured
Moduli		
E_1^*, E_2^* (MN/m^2)	15	13 ± 5
E_3^* (MN/m^2)	20	20 ± 7
G_{12}^*, G_{21}^* (MN/m^2)	4	4.3 ± 1.5
$G_{13}^*, G_{31}^*, G_{23}^*, G_{32}^*$ (MN/m^2)	—	2.5 ± 1
$\nu_{12}^* = \nu_{21}^*$	1.0	0.25[a]–0.50
$\nu_{13}^* = \nu_{31}^* = \nu_{23}^* = \nu_{32}^*$	0	0–0.10[a]
Compressive collapse stress		
$(\sigma_{el}^*)_1, (\sigma_{el}^*)_2$ (MN/m^2)	1.5	0.7 ± 0.2
$(\sigma_{el}^*)_3$ (MN/m^2)	1.5	0.8 ± 0.2

†Data from Gibson *et al.* (1981), except for (a) Fortes and Nogueira (1989).

Uses of cork

- stoppers for bottles: excellent seal due to elastic moduli $\nu = 0$, low E, K
  - compare with rubber stoppers: low E but high K ($\because \nu \to 0.5$)
  - also note orientation of still wine / champagne corks - in champagne corks, axis of symmetry aligned with bottle axis
- gaskets: cork makes good gaskets for same reason (plus closed cells - impervious)
  - also used as gaskets for musical instruments (woodwinds)
    - sheet cut with prism axis normal to sheet; when sections of instruments are mated $\nu = 0$ sheet gasket doesn't spread + wrinkle

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- floor coverings, shoes: friction
  - cork has high loss coefficient $\eta = \frac{D}{2\pi U} = 0.1 - 0.3$
  - when deform, dissipates energy
  - results in high coefficient of friction, even when wet & soapy
  - damping also exploited in tool handles.

Stoppers for bottles

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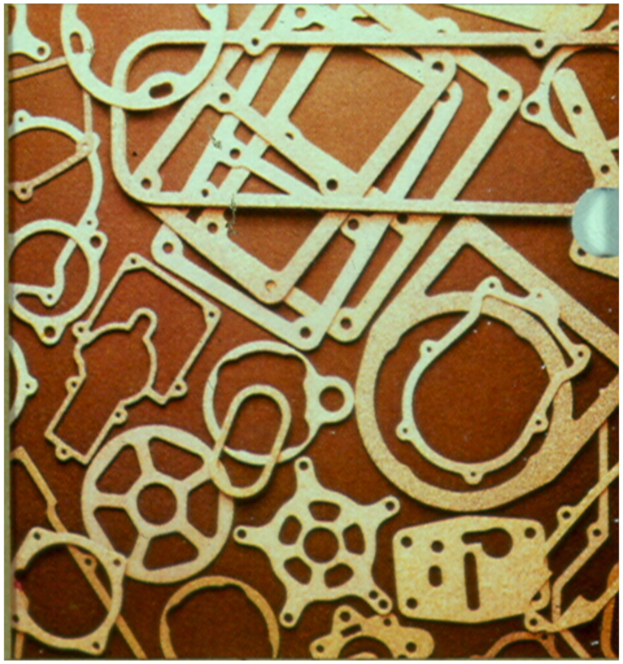
Gaskets

Clarinet



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Cork flooring

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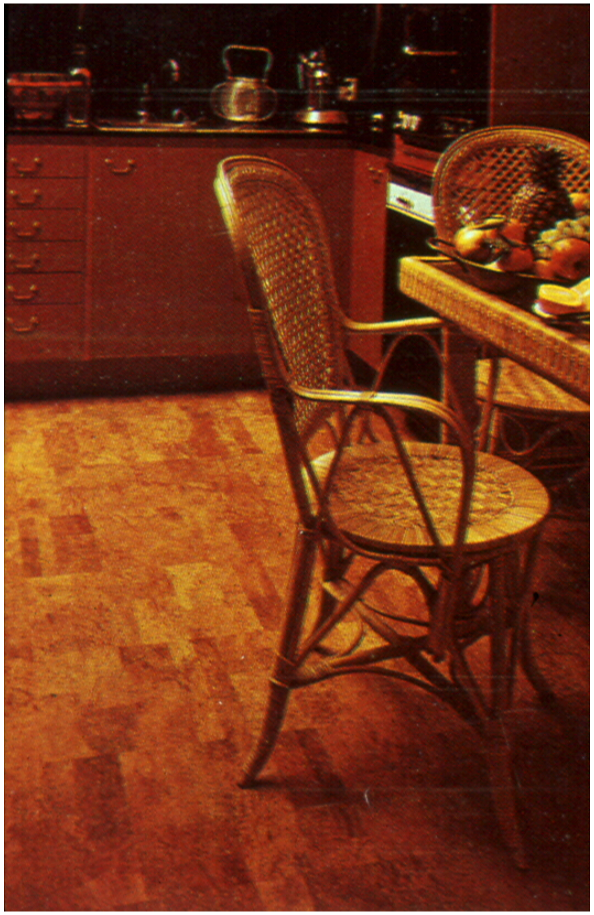

insulation

- small cell size decreases thermal conductivity
- hermit caves in Portugal lined with cork
- cigarette tips - originally cork

indentation/bulletin boards

- cork densifies when indented; $def^{\underline{n}}$ highly localized
- $def^{\underline{n}}$ elastic - hole closes up again when pin removed.

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Indentation

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