Lecture 6, Cork notes, 3.054

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 is unusual in that cork layer is several cm thick
- Can cut the bark off Q. suber and it regrows
- Cell walls of cork covered in unsaturated fatty acid — suberin — impervious
- Cork still used to seal bottles, as gaskets, and for soles of shoes

Structure

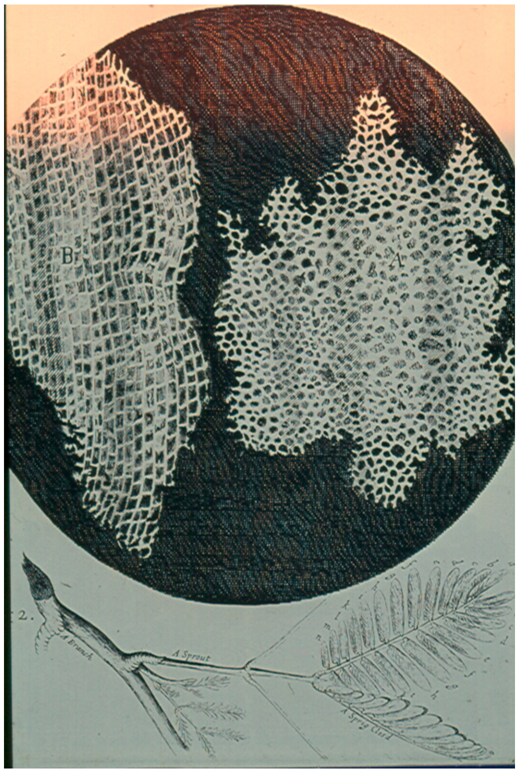
- Hooke's drawings, SEM: one plane, roughly hexagonal cells; other two, box-like cells, corrugated walls

- Axisymmetric
  - hexagonal cells normal to radial direction
  - x_1 = tangential; x_2 = axial; x_3 = radial
- Cell size: 30-40μm (smaller than most engineering foams)
- Density $\sim 170\ kg/m^3$, $\rho_s \sim 1150\ kg/m^3$, $\rho^*/\rho_s \sim 0.15$ typically

Cork

Quercus suber

Cork microstructure



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Hooke, 1665

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Cork microstructure

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Cork microstructure

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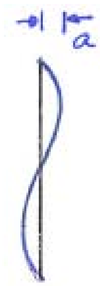
Mechanical behavior

Modeling: 1-2 directions — honeycomb loaded in plane (tangential/axial)

Model	**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

Modeling: 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)

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

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 ($\therefore\ \upsilon \to 0.5$)
  - Also note orientation of still wine/champagne corks — in champagne corks, axis of symmetry aligned with bottle axis
- **Gaskets:** Cork makes good gaskets for some 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 and wrinkle
- **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 and soapy
  - Damping also exploited in tool handles

Stoppers for bottles

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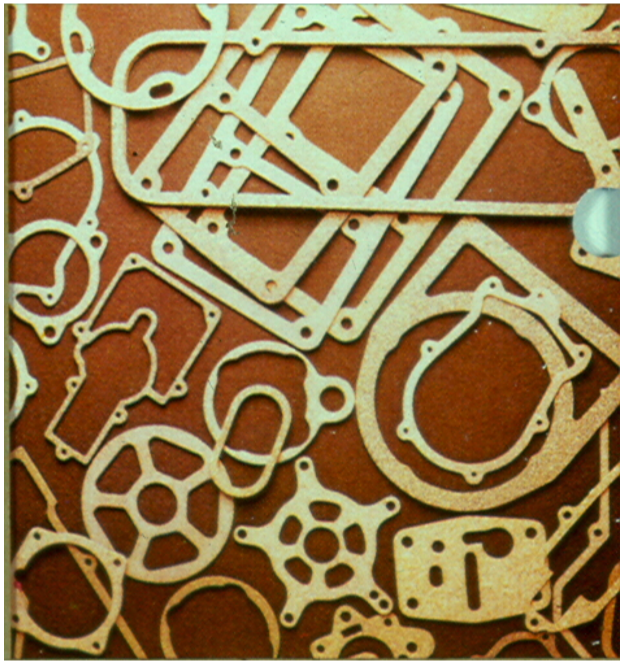
Gaskets

Clarinet



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Cork flooring

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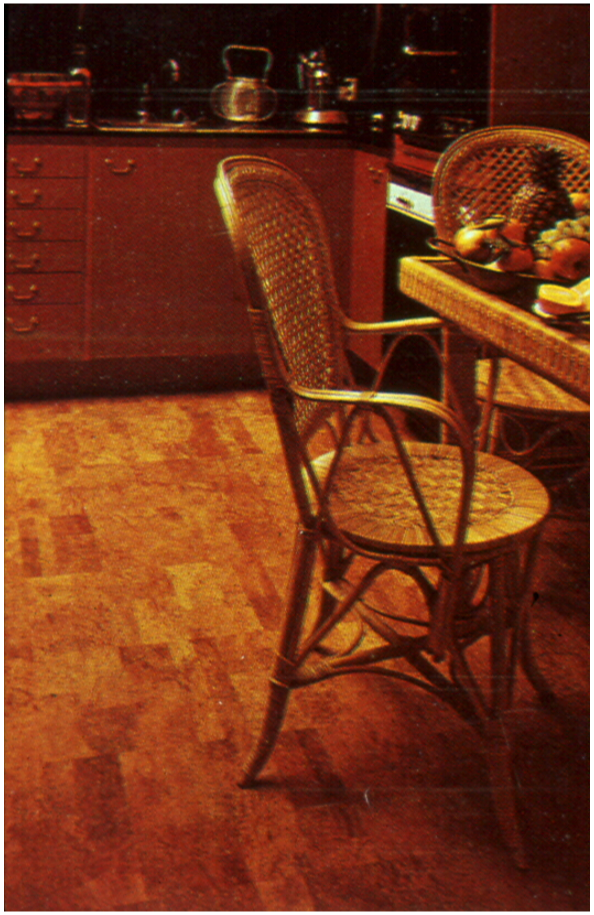

Insulation

- Small cell size decreases thermal conductivity
- Hermit caves in Portugal lined with cork
- Cigarette tips — originally cork

Indentation/Bulletin boards

- Cork densifies when indented; deformation highly localized
- Deformation elastic — hole closes up again when pin removed

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Indentation

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