20. Adhesives

We use adhesives to hold things together.

For optical applications, we can define several classes of adhesives:

Optical adhesives
Transparent. Optical qualities are important.

Structural adhesives
Strength is most important

Elastomers
Use rubbery properties for sealing and to provide compliance

Cyanoacrylates
Superglue
Quick staking,
Beware: outgassing can ruin coatings

Issues:

- **Choice of materials, bond thickness, bond area**
- **Strength of the bond**
- **Stability**
- **Stiffness**
- **Thermal stresses**
    - **Can thermal effects cause the bond to fail?**
    - **Can thermal effects cause distortion in the optics**
- **Ease of assembly**
    - **Surface preparation**
    - **primers**
- **Ease of disassembly**
    - **Solvents**
    - **Mechanical cutting**

Elastomeric bonds

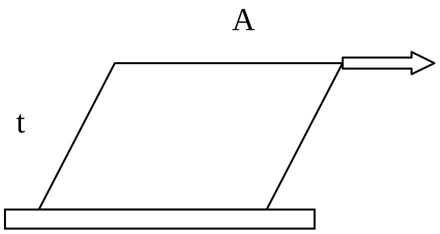
Rubber and RTV (ν ~= 0.5) behave strangely as an elastic material.

G (Shear modulus)	~ 100 psi	(~1 MPa)
E_0 (Young's modulus)	~ 3 G = 300 psi	(~3 MPa)
E_B (Bulk modulus)	~ 100,000 psi	(~1000 MPa)

Shear stiffness, where thickness < width

Shear stiffness K_s is

$$K_s = \frac{\delta F_{shear}}{\delta y} = \frac{GA}{t}$$

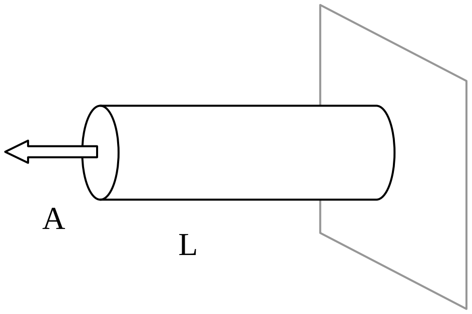


<u>Very compliant</u>

Axial stiffness, for tensile elongation where axial length >> width

Axial stiffness K_1

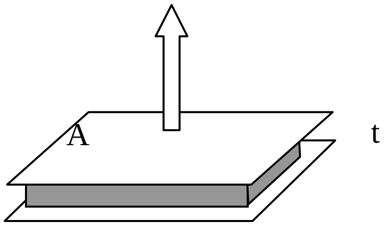
$$K_1 = \frac{\delta F_{axial}}{\delta z} = \frac{E_0 A}{L}$$



<u>Very compliant</u>

In compression, this buckles and behaves non-linearly

For thin rubber , thickness << width, transverse strain is constrained, use the <u>bulk modulus</u>

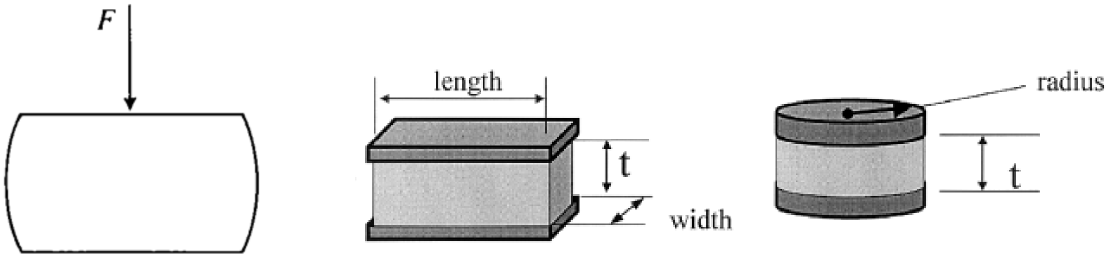


$$K_2 = \frac{\delta F_{axial}}{\delta z} = \frac{E_B A}{t}$$

<u>Very stiff!</u>

What about compression for a more general case?

The dominant axial compliance for this case is due to shape change, not material strain.



<u>Axial stiffness – depends on shape</u>

Axial stiffness K_z is $K_z = \frac{\delta F_{axial}}{\delta z} = \frac{E_C A}{t}$

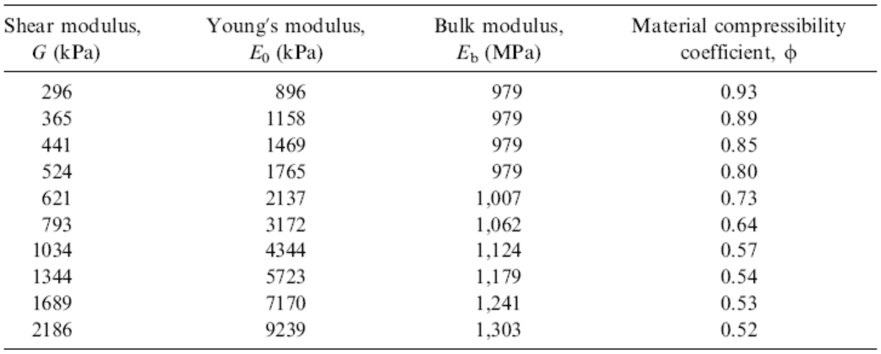
Where E_C is the *compression modulus*, which depends on geometry

$$E_C = E_0\left(1 + \phi S^2\right)$$

***E_0* = Young's modulus**
***S* = Shape factor**
***ϕ* = material compressibility coefficient (=0.64 for RTV)**

The shape factor S is defined as

$$S = \frac{Load\ area}{Bulge\ area} = \frac{A}{perimeter \times thickness} = \frac{l \times w}{(2w + 2l) \times t}$$



Shear modulus, G (kPa)	Young's modulus, E_0 (kPa)	Bulk modulus, E_b (MPa)	Material compressibility coefficient, ϕ
296	896	979	0.93
365	1158	979	0.89
441	1469	979	0.85
524	1765	979	0.80
621	2137	1,007	0.73
793	3172	1,062	0.64
1034	4344	1,124	0.57
1344	5723	1,179	0.54
1689	7170	1,241	0.53
2186	9239	1,303	0.52

For small S, $E_C = E_0$ as above

For large S, E_c blows up. Take the maximum value of E_c to be the bulk modulus E_b

<u>For 2 mm thick RTV pad 20 x 20 mm</u>
E_0 = 3MPa
G = 1 MPa
ϕ =0.64
S = (20x20)/4x(2x20) = 2.5

E_C = 3 MPa (1 + 0.64*2.5^2) = 15 MPa

K_Z = E_cA/t = 3000 N/mm
K_S = GA/t = 200 N/mm

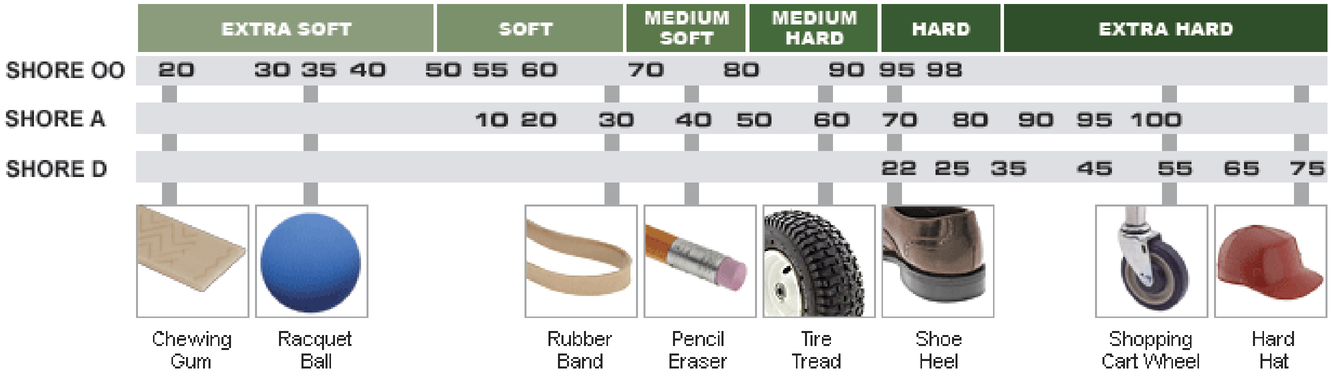
K_z/K_s = 15

Reference:

P. M. Sheridan, F. O. James, and T. S. Miller, “Design of components,” in *Engineering with Rubber* (A. N. Gent, ed.), pp. 209{Munich:Hanser, 1992)

Hardness

Defined as resistance to indentation, according to specific tests:



(McMast Carr)

Viscosity

A fluid’s resistance to flow. The “thickness” of the fluid.

10 poise = 1 Pa s

MATERIAL APPROXIMATE VISCOSITY (in centipoise)

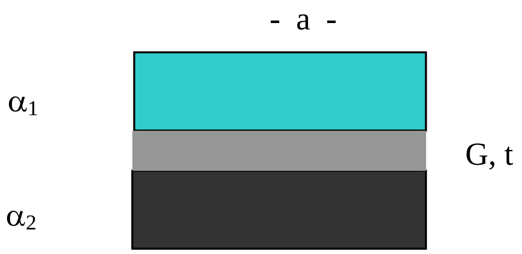
Water @ 70 F	1
Blood or Kerosene	10
Anti-Freeze or Ethylene Glycol	15
Motor Oil SAE10 or Corn Oil	50 to 100
Motor Oil SAE30 or Maple Syrup	150 to 200
Motor Oil SAE40 or Castor Oil	250 to 500
Motor Oil SAE60 or Glycerin	1,000 to 2,000
Corn Syrup or Honey	2,000 to 3,000
Molasses	5,000 to 10,000
Chocolate Syrup	10,000 to 25,000
Heinz Ketchup or French's Mustard	50,000 to 70,000
Tomato Paste or Peanut Butter	150,000 to 250,000
Crisco Shortening or Lard	1,000,000 to 2,000,000
Caulking Compound	5,000,000 to 10,000,000
Window Putty	100,000,000

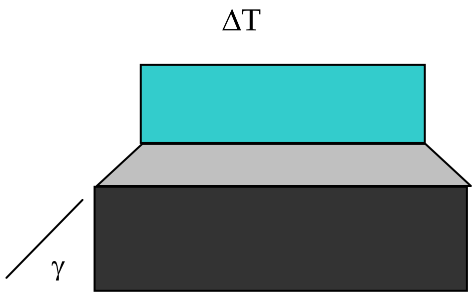
Thermal stress

Usually, thermal mismatch is accommodated by the adhesive, because it has most compliance.

Also, the thermal expansion of the adhesive is usually less important than that of the substrates

For bond with dimension a, thickness t





Adhesive goes into pure shear.

Maximum shear strain = γ
$$\gamma = \frac{\frac{a}{2}\alpha_1 \Delta T - \frac{a}{2}\alpha_2 \Delta T}{t} = \frac{a}{2t}\left(\alpha_1 - \alpha_2\right)\Delta T$$

Shear stress τ

$$\tau = G\gamma = \frac{Ga}{2t}\left(\alpha_1 - \alpha_2\right)\Delta T$$

This approximation will work most of the time. It is conservative. Actual stress is reduces by additional compliance of substrates. For cases where the substrates are thick compared to the glue:

$$\frac{Substrate\,compliance}{Epoxy\,compliance} \approx 0.1\frac{a}{t}\frac{G_{epoxy}}{E_{substrate}}$$

For epoxy, G ~= 150 ksi.
Bonding metal to glass. Approximation is only valid for size/thickness: $a/t < 100$

A more complete relationship is given in Yoder p.802 and Vukabratovich p 123. (Note L is the bond ***radius***, not the overall size. (Chen and Nelson 1979).

Example

Bond Glass to Aluminum

For 3M 2216,

G = 342 MPa at 24°C, 1500 MPa at 0° C

CTE = 100 ppm/°C

Shear strength of 2216 = 2 ksi = 14 MPa

Nominal bond is 0.1 mm thick.

For 5 mm bond, strength @ 14 MPa is 274 N (62 lbs)

for $\Delta T = 20° C$, $\Delta a/2$ is (20°C)(5 mm)/2*(23 – 7)ppm/°C = 0.8 μm

$\gamma = \Delta a/2 / t)=0.8/100$

$\gamma = 0.008$

Using G@24°C of 342 MPa

τ = 2.8 MPa (
safety factor = 14/2.8 = 5

If cooled 20°C, use G = 1500 MPa

τ = 12 MPa
This is close to the strength of the epoxy

Taking into account deflection of 6 mm thick aluminum, 25 mm thick glass. Use relation on p 123 of Vukabratovich (L is the bond RADIUS) the stress is reduced from 12 MPA to 11 MPa.

To survive this temperature:

1. Use an epoxy with lower modulus at temperature
2. Use thicker adhesive layer
3. Prepare the glass surface (fine ground and acid etched) to provide > 2000 psi (14 MPa) strength. At this point the epoxy is the weakest link.
4. Use smaller bond area
5. Use mechanical design with flexures to allow thermal expansion.