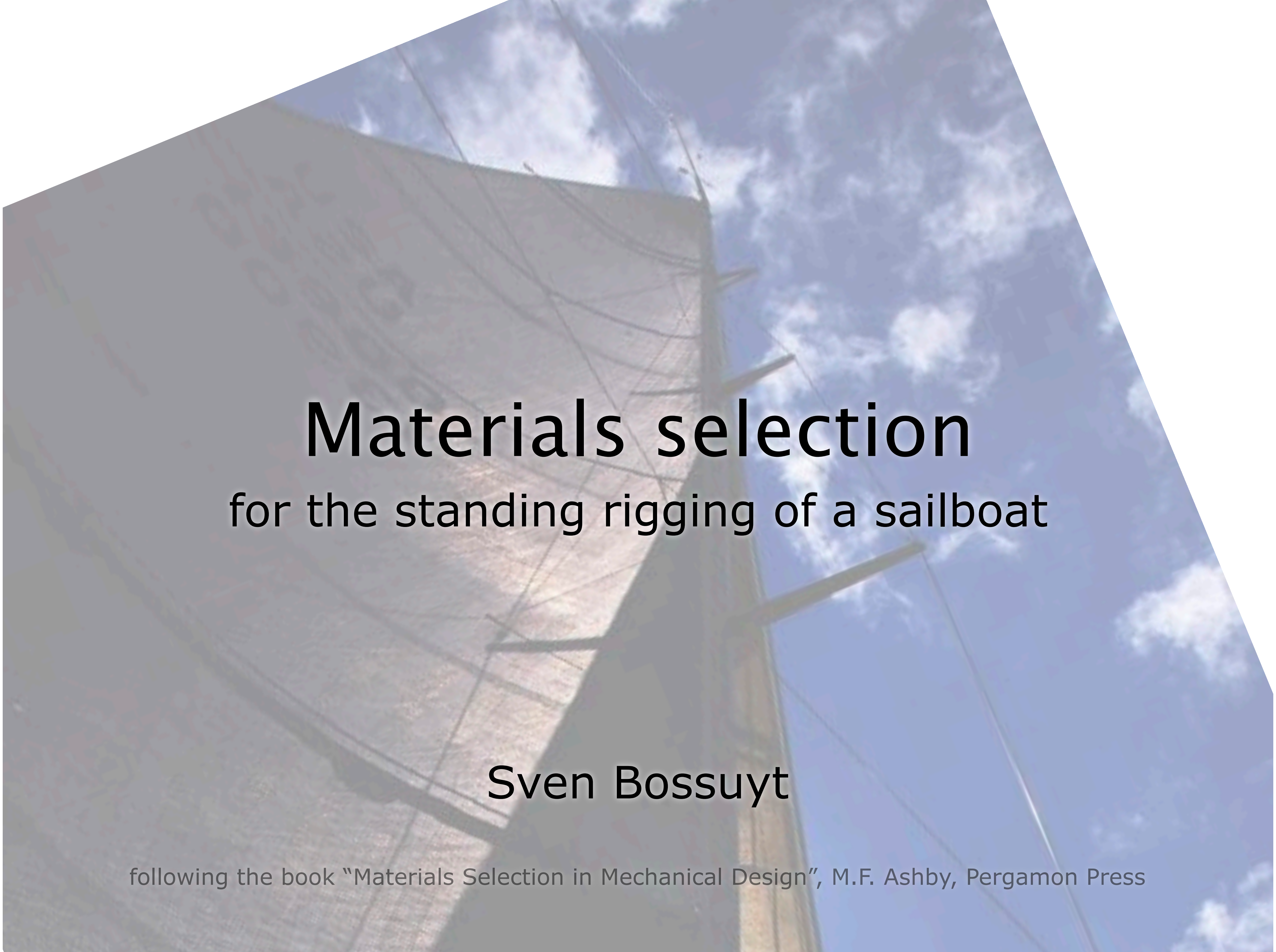


Materials selection

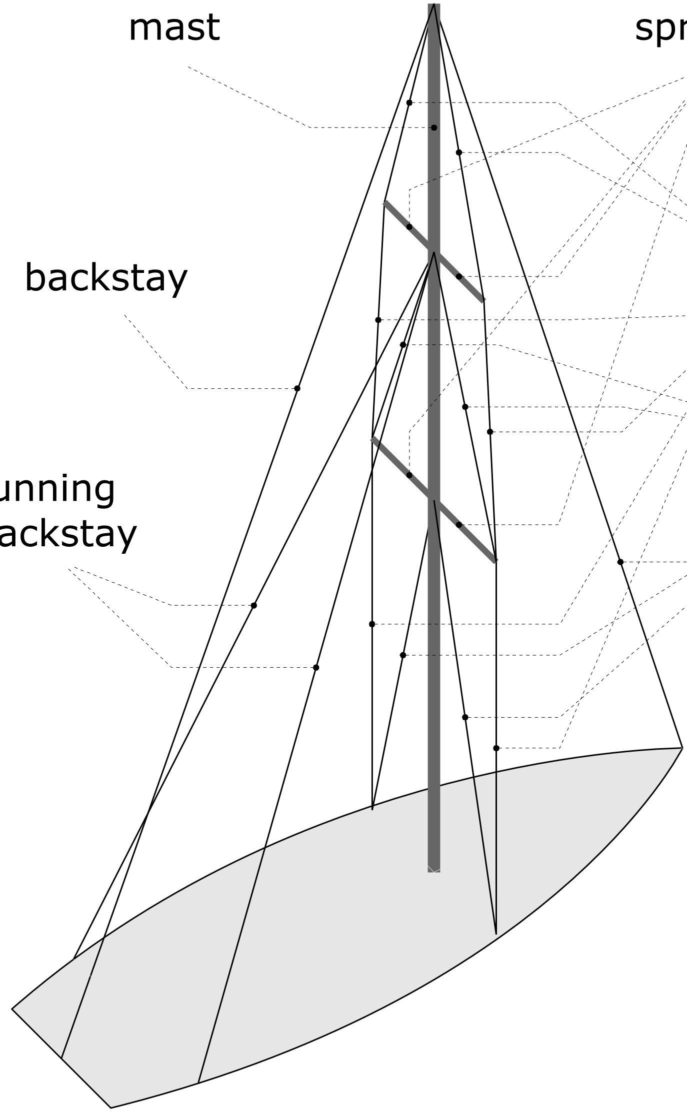
for the standing rigging of a sailboat

Sven Bossuyt

following the book “Materials Selection in Mechanical Design”, M.F. Ashby, Pergamon Press

standing rigging of a sailboat

rigging |ˈrɪɡɪŋ|
noun [mass noun]
1 the system of ropes or chains employed to support a ship's masts (standing rigging) and to control or set the yards and sails (running rigging). *I'm listening to the wind in the rigging.*



Function of the standing rigging

- keep the mast upright
  - resistance to the forces (wind and pre-tension)
  - rigidity
- constraints
  - minimum weight
  - minimum surface to the wind
  - marine environment
  - price

Performance index
for a slender and strong tie rod

area A necessary to support a force F:

$$\sigma_f \, A = F$$

to minimise the area

$$A = F \cdot (1/\sigma_f)$$

we must choose the material with the highest strength

$$\sigma_f$$

Performance index for a light and strong tie rod

mass m of a rod with length l:

$$m = \rho A l$$

area A necessary to support a force F:

$$\sigma_f A = F$$

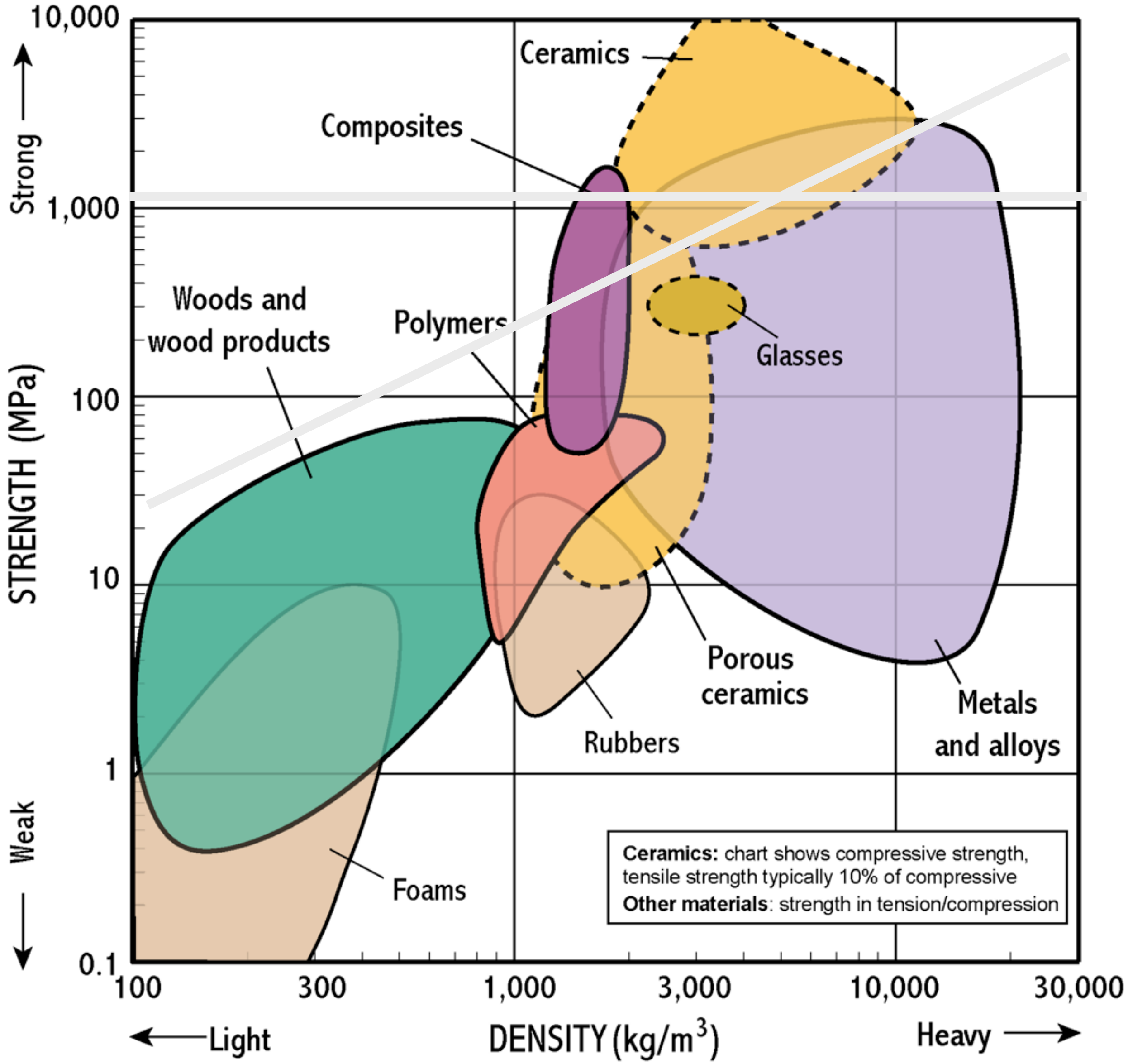
elimination of the area gives:

$$m = \rho (F/\sigma_f) l = F \cdot l \cdot (\rho/\sigma_f)$$

to minimise the mass, we maximise the specific strength of the material

$$\sigma_f/\rho$$

Selection chart strength - density



Performance index
for a slender and stiff tie rod

elasticity modulus of the material

$$F/A = E\,\Delta\ell/\ell$$

spring stiffness k:

$$k = F/\Delta\ell$$

elimination of the elongation $\Delta\ell$ gives:

$$A = F\,\ell/E\,\Delta\ell = k \cdot \ell \cdot (1/E)$$

thus to minimise the area, we maximise the material's elasticity modulus

$$E$$

Performance index
for a light and stiff tie rod

mass m of a rod with length l:

$$m = \rho A l$$

spring stiffness k:

$$k = F/\Delta l \quad \text{where} \quad F/A = E \, \Delta l / l$$

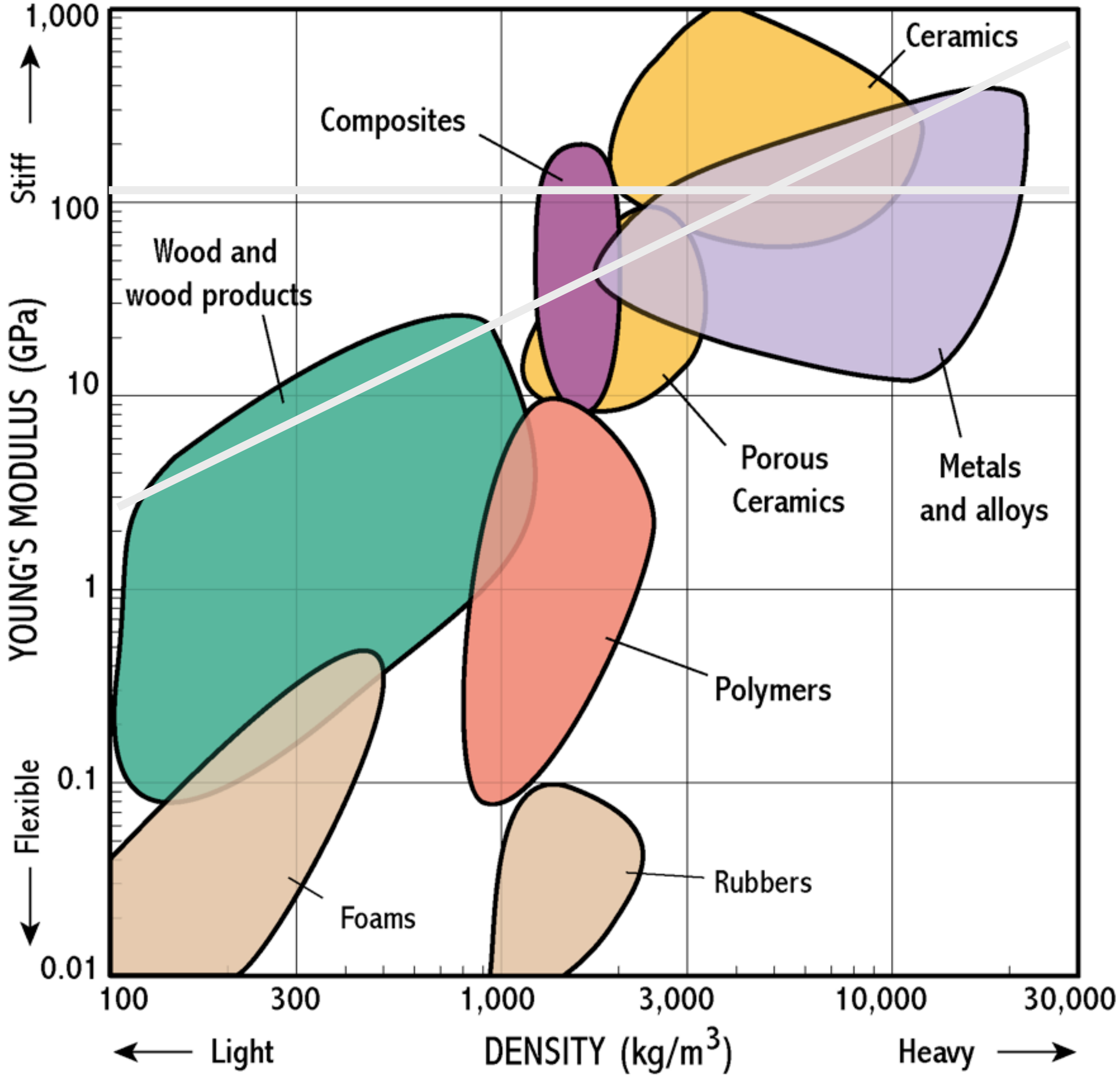
elimination of the area A and the elongation Δl gives:

$$m = \rho \, (F \, l / E \, \Delta l) \, l = \rho \, (k l / E) \, l = k \, l^2 \, (\rho/E)$$

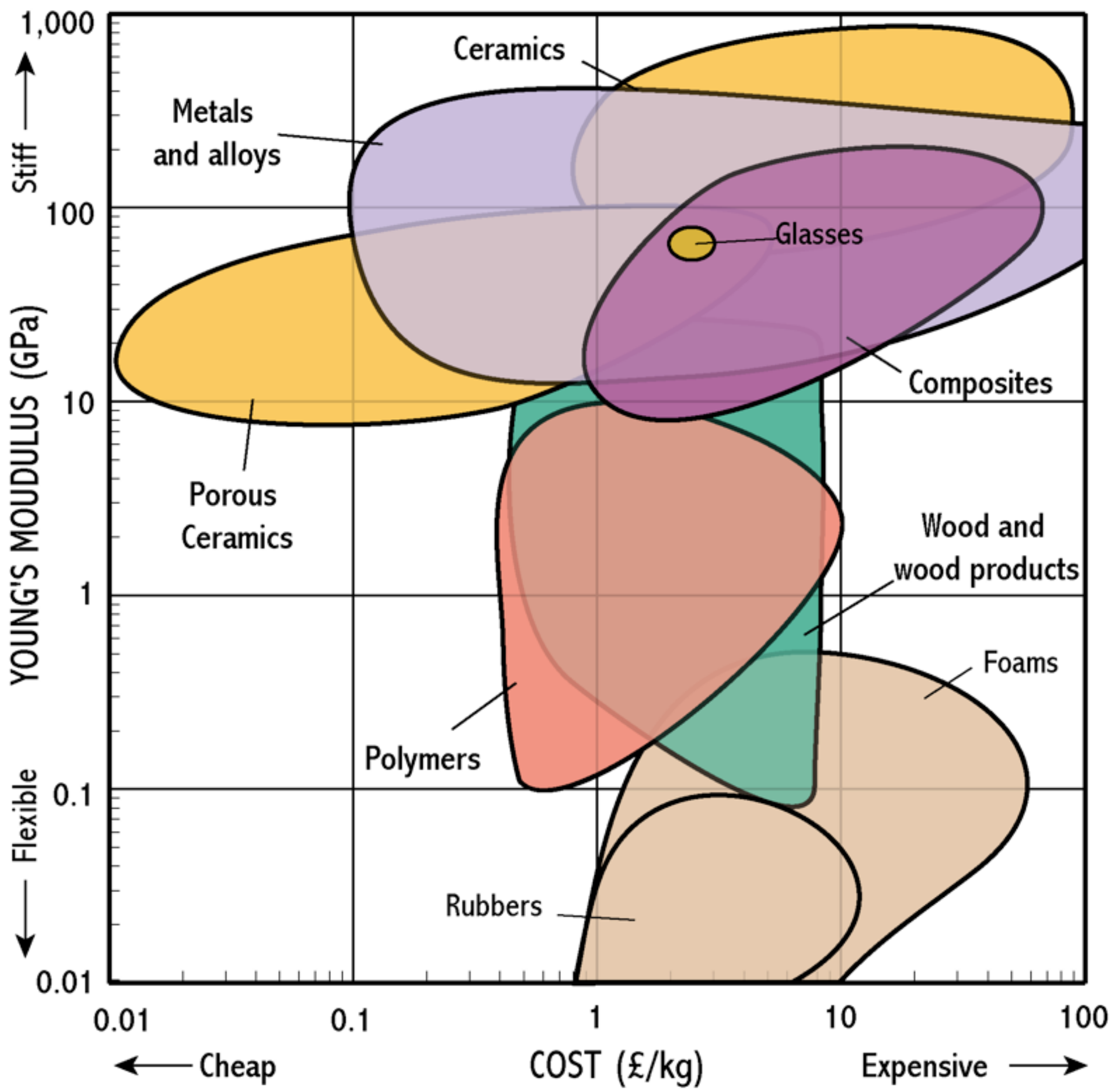
minimise the mass by maximising the material's specific modulus

$$E/\rho$$

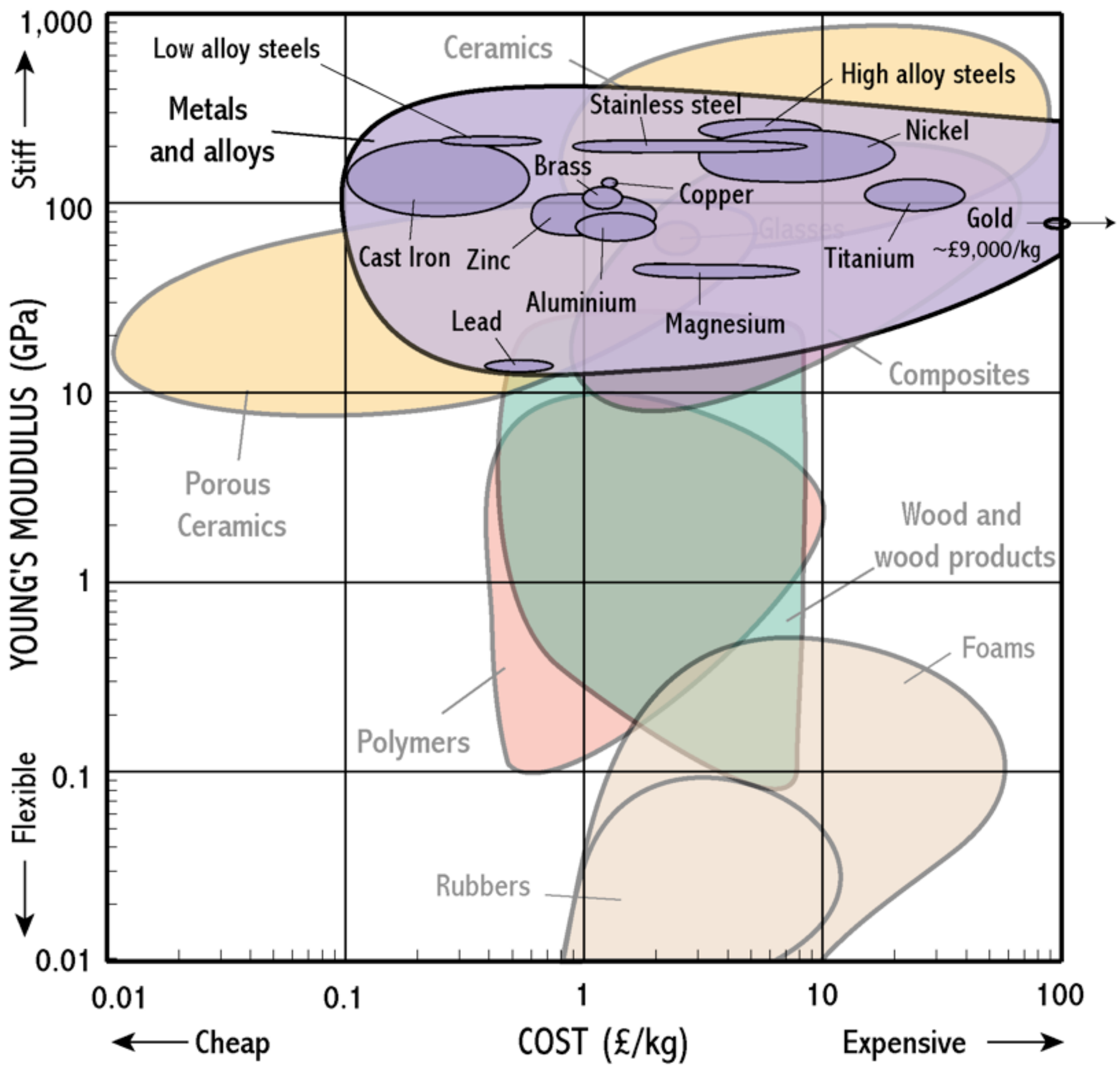
Selection chart stiffness - density



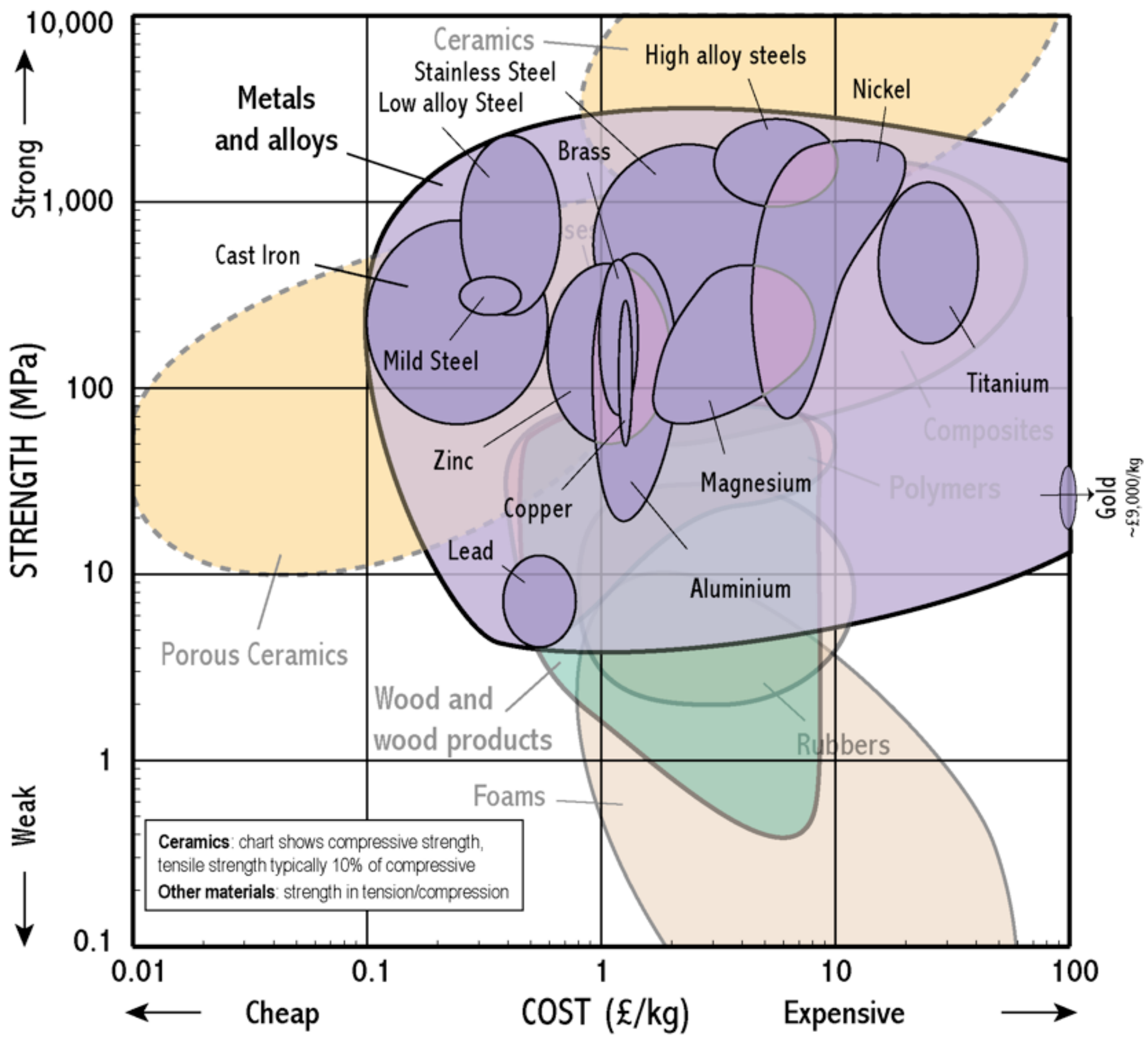
Selection chart
stiffness - cost



Selection chart stiffness - cost



Selection chart strength - cost



Conclusion: materials selection for standing rigging

- performance indices
  - strength: σ_f
  - specific strength: σ_f / ρ
  - stiffness: E
  - specific stiffness: E / ρ
- constraints
  - marine environment
  - price
- results
  - historical: hemp cord
  - conventional: stainless steel cable
  - high performance: stainless steel rods, carbon fibre composites

Performance index for a light column in compression

mass m of a column with length l:

$$m = \rho A l$$

buckling load:

$$F_{eul} = n\pi^2 E I / l^2$$

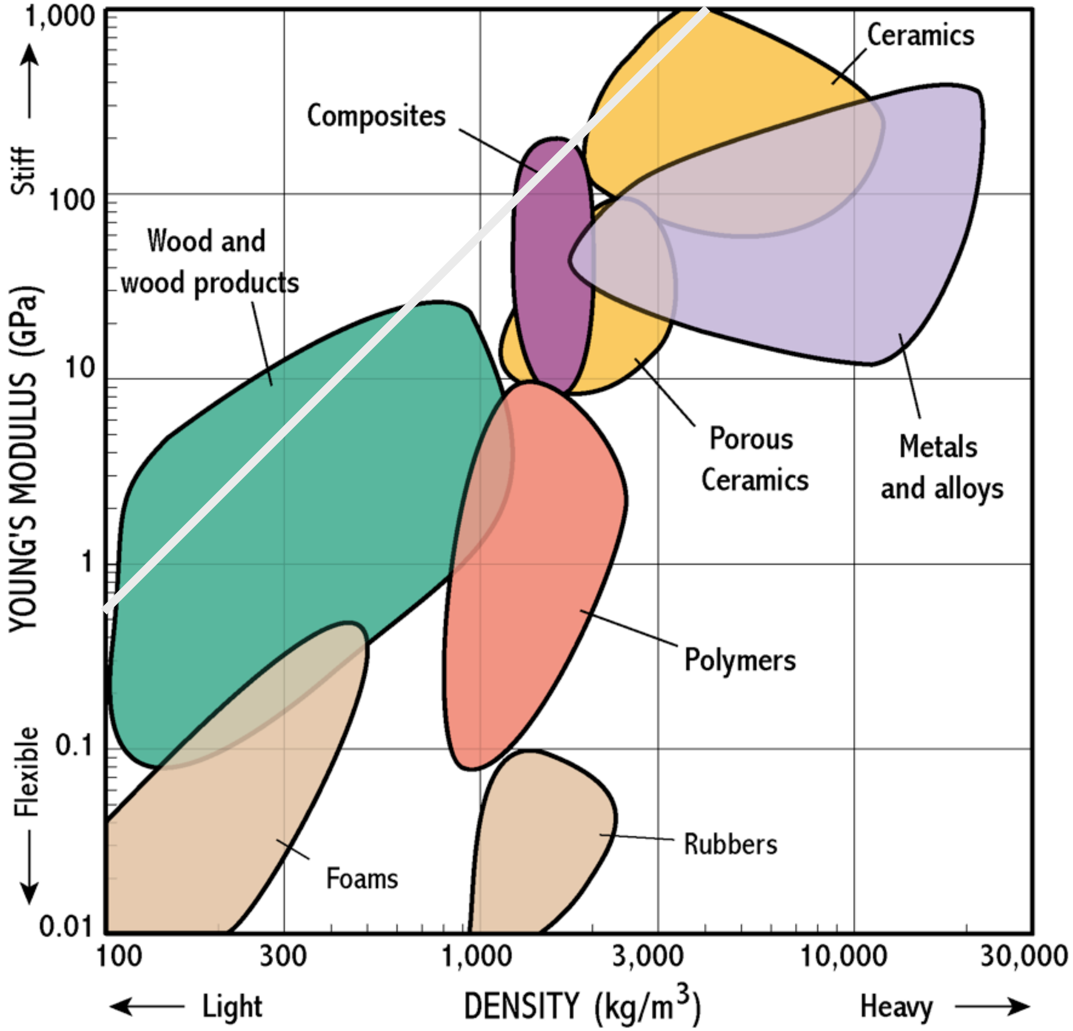
for a circular section $I = \pi r^4/4 = A^2/4\pi$ which gives:

$$m^2 = \rho^2 4\pi I l^2 = \rho^2 4\pi (F l^2/n\pi^2 E) l^2$$

$$= 4/n\pi F \cdot l^4 \cdot (\rho^2 / E)$$

performance index: $\sqrt{E}/\rho$

Selection chart stiffness - density



materials selection including the shape of the mast of the sailboat

for other than circular sections, let's define

$$\Phi_{el} = 4\pi \cdot I / A^2$$

in the performance index for buckling

$$m^2 = \rho^2 \, 4\pi \, I / \Phi_{el} \, l^2$$

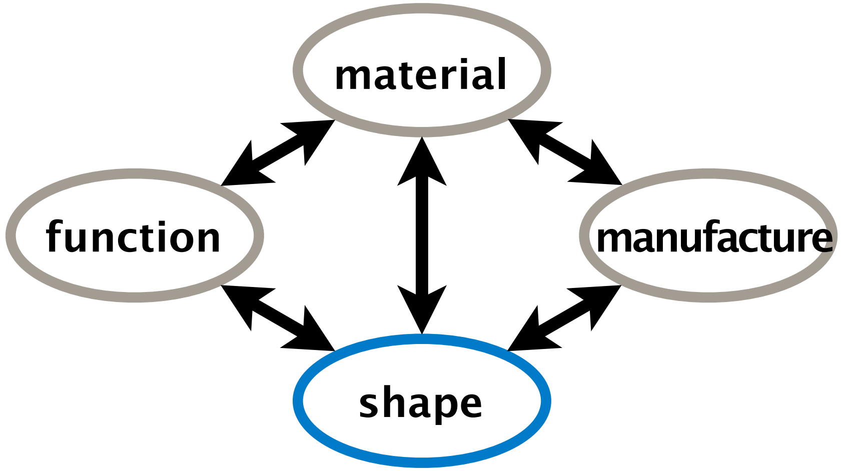
$$= \rho^2 \, 4\pi \, (F l^2 / n\pi^2 \, \Phi_{el} \, E) \, l^2$$

- $= 4/n\pi \; F \cdot l^4 \cdot (\rho^2 / \Phi_{el} \, E)$

for each performance index, we can find a form factor this way

for hollow sections $\Phi_{el} \approx r/t$

the wall thickness t is limited by the manufacturing process, for each material



Selection chart stiffness - density