Material Selection for Precision Telescope Mirror

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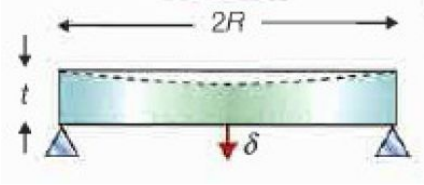
Problem Definition

- Precision telescope mirrors are made out of glass for its mechanical and thermal properties
- Goal: determine if there is a better material
- Mirror must not deflect under its own weight more than a wavelength of light (1 micrometer maximum)
- No creep and low thermal expansion
- Must use a material that is available in bulk (because such large quantities may be required) and minimize the total mass



Translating Constraints

- Given equation for deflection and mass, the thickness free variable in both can be solved for and plugged in to determine FGM equation for mass
- First CES plot will show density vs. the cubed root of Young's modulus, which is the proportionality that is important
- Second CES plot is required thickness and mass to limit deflection

$$deflection: \delta = \frac{3mgR^2}{4\pi E t^3}$$

$$mass: m = \pi R^2 t \rho$$

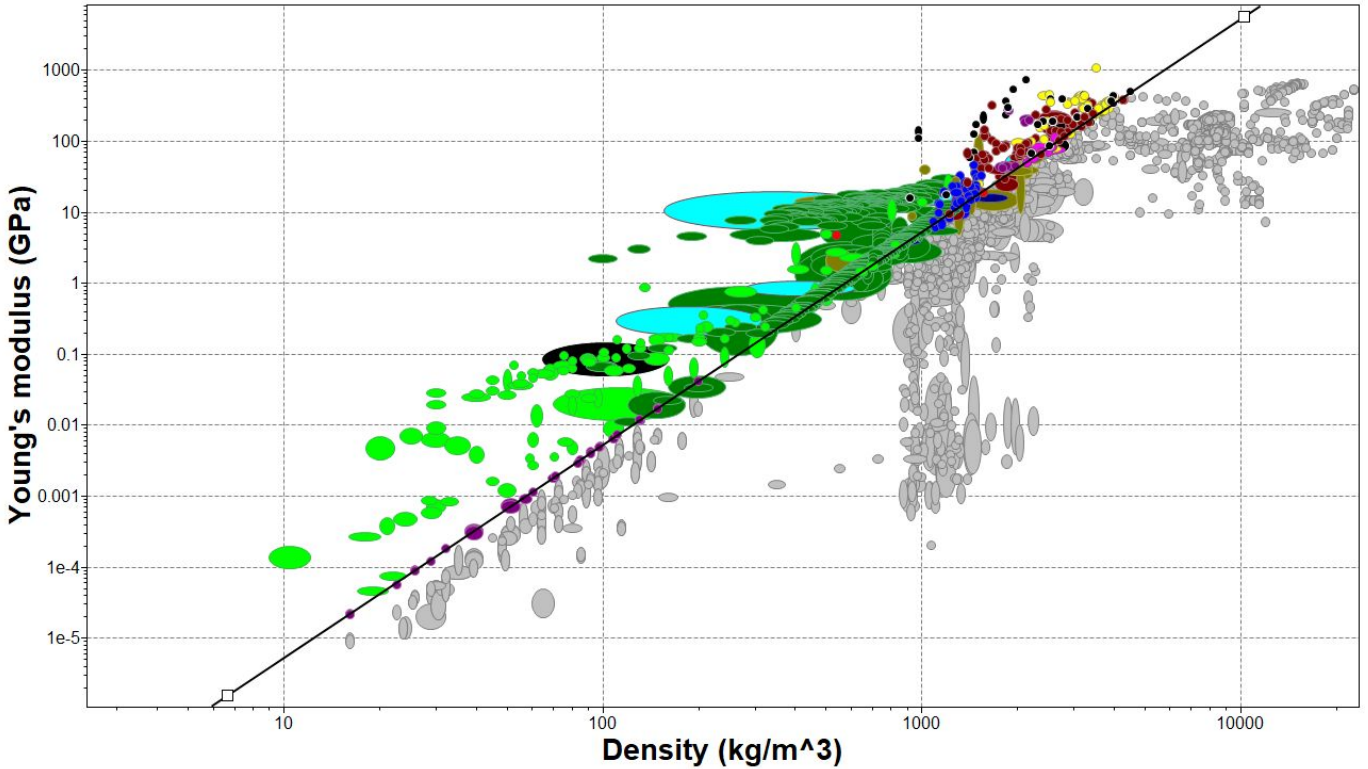
$$solve\ for\ t\ from\ \delta\ and\ plug\ into\ m$$

$$m = \left(\frac{3g}{4\delta}\right)^{\frac{1}{2}} (\pi R^4) \left(\frac{\rho}{E^{\frac{1}{3}}}\right)^{\frac{3}{2}}$$

Where $\left(\frac{3g}{4\delta}\right)^{\frac{1}{2}}$ is the functionality term, (πR^4) is the geometry term, and $\left(\frac{\rho}{E^{\frac{1}{3}}}\right)^{\frac{3}{2}}$ is material term.

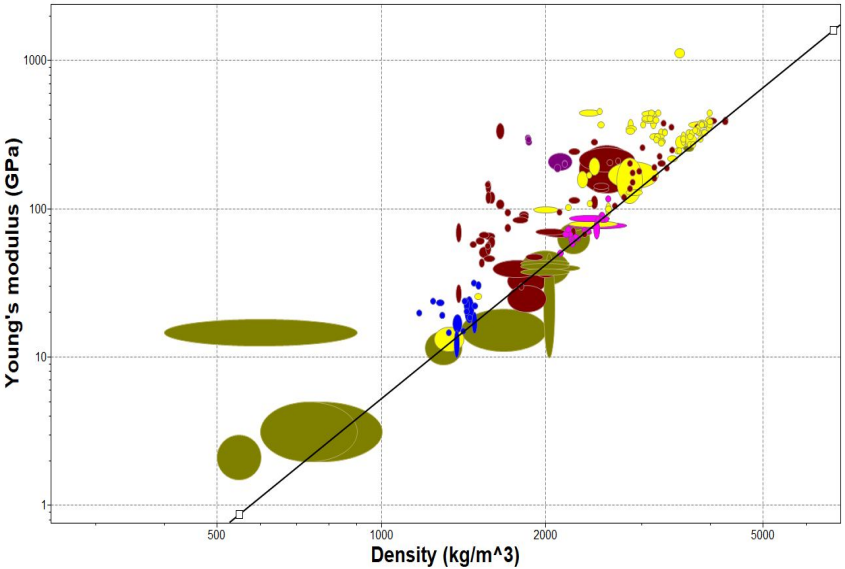
Initial Screening

The first screen that is done (shown in the plot) is the log of density vs. the log of Young's modulus, with the line limiting to only the top half of materials as a starting point.

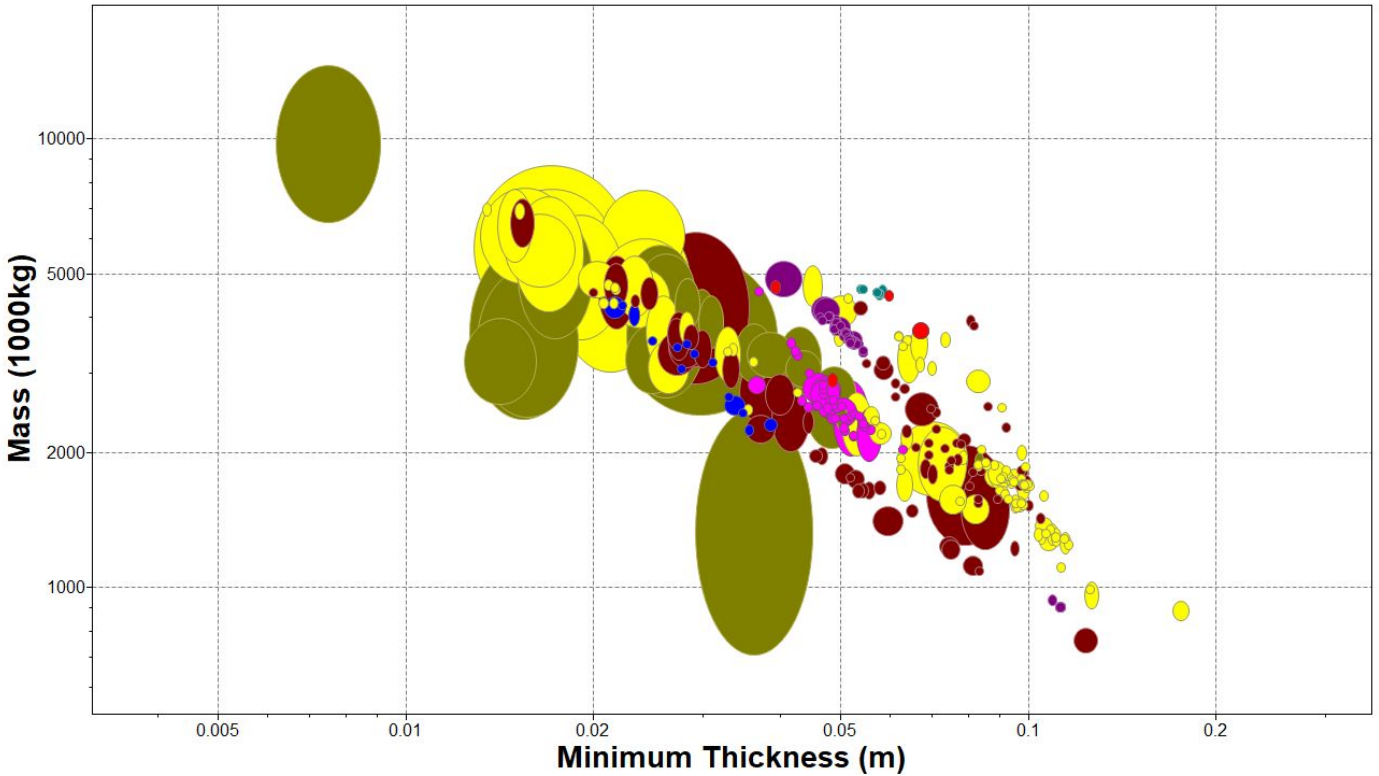


Further Screening Steps

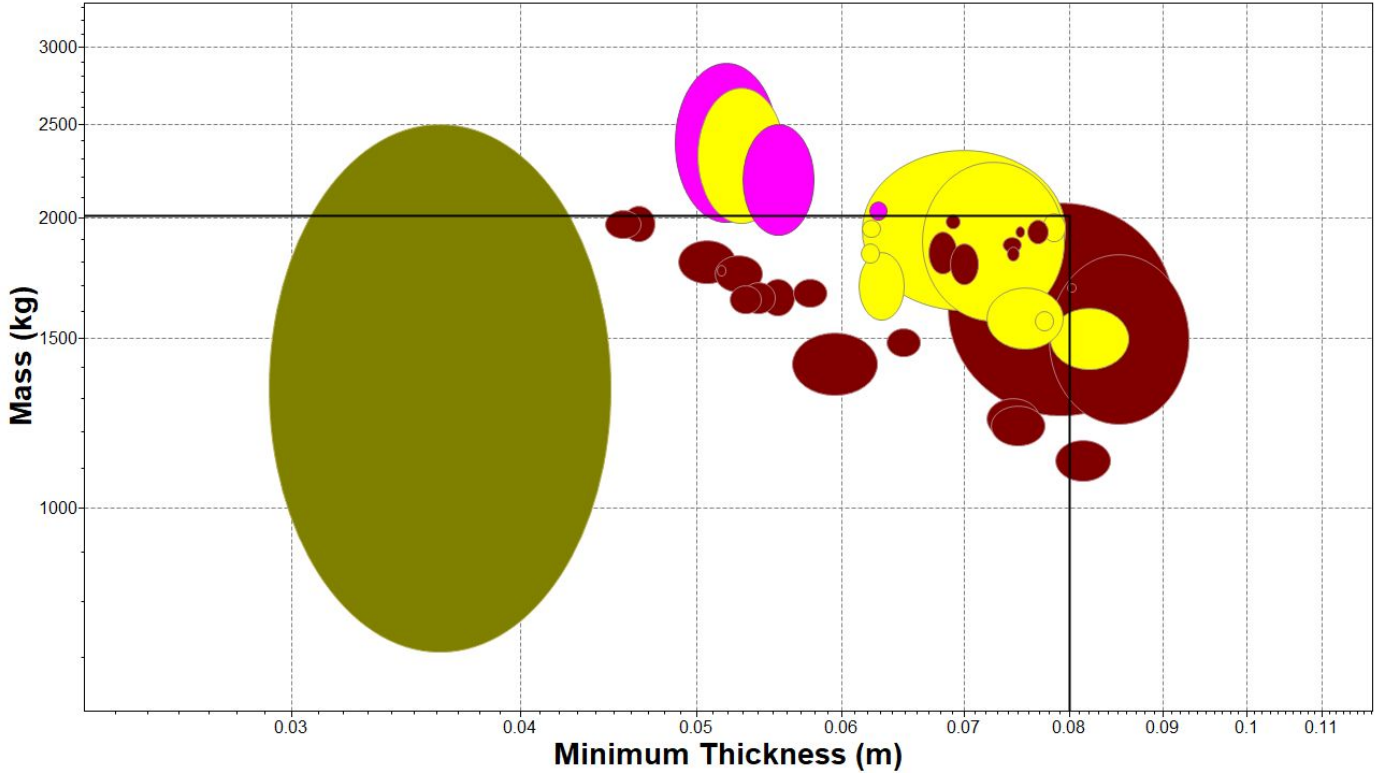
- Materials must be available in bulk, as large quantities may be needed depending on telescope size
- Thermal expansions is limited to 5 microStrain/C
- Service temperature is limited between -50 degrees C and 100 degrees C, to accompany a wide range of environments and reduce creep
- There are now 379 materials remaining



Screening: Mass vs. Thickness for R=1m Mirror



Screening: Limit Overall Size



Ranking Materials

There are 21 remaining materials, ranked by material index below (showing top 5). A majority of the materials are carbon fiber composites, but only the best are choosen and all categories are listed for comparison. Prices and weights are calculated for a mirror with radius 1m.

Name	Price (k$)	Weight (kg)	Thickness (m)
Glass Ceramic (N11)	4 - 36	1980 - 2890	0.048 - 0.055
Silicon Carbide (nitride bonded)	29 - 57	1980 - 2730	0.050 - 0.056
Epoxy/HS Carbon Fiber, UD prepreg+layup	40 - 49	1070 - 1180	0.079 - 0.084
PEEK/IM Carbon Fiber, UD prepreg, QI layup	184 - 215	1750 - 1790	0.051 - 0.052
SiC fiber, 35-45Vf - quasi isotropic laminate	3825 - 10070	1230 - 1830	0.078 - 0.093

Final Elimination

- Although cost was not a major constraint in the problem, the SiC fiber, 35-45Vf - quasi isotropic laminate will be eliminated because of its exorbitant price compared to the other materials; the material also requires one of the thickest mirrors (0.078m - 0.093m)
- PEEK/IM Carbon Fiber, UD prepreg, QI layup is only of average required thickness and mass, and is (without the SiC fiber) also an outlier when it comes to cost; it also would be difficult to form this composite into such a thick sheet, and will be removed
- Silicon Carbide (nitride bonded) offers a inexpensive and thin option for the mirror, but will be removed because of its extremely low toughness and fracture toughness, which could lead to failures in case of small accidental impacts

Options

Glass Ceramic (N11)
(cheap, heavy, thin option)

Price (k$): 4 - 36
Weight (kg): 1980 - 2890
Thickness (m): 0.048 - 0.055
Note: opaque, extremely durable, non-machinable, average fracture toughness

Epoxy/HS Carbon Fiber, UD prepreg+layup
(more expensive, light, thick)

Price (k$): 40 - 49
Weight (kg): 1070 - 1180
Thickness (m): 0.079 - 0.084
Note: opaque, high fracture toughness / impact strength

Further thought should be put in to determine the characteristics of the support structure, and if a thicker/lighter or thinner/heavier mirror would be ideal for the scenario