Question Set 6: Concrete and Timber Questions with Comments and Answers

Question 1

Find values for the coefficient of thermal expansion of concrete, steel reinforcing bars and epoxy.

Answer (from Granta):
Concrete: 5-12 microstrain per degree C
Low-carbon steel: 11.5 – 13 microstrain per degree C
Epoxy: 81 – 117 microstrain per degree C

Comment on the values you find and their consequences for the thermal behaviour of reinforced concrete.

Answer:
The coefficients for concrete and the low-carbon steel used in reinforcement are similar. Therefore (somewhat dependent on the precise values for the materials in use) they will not develop substantial internal stresses due to temperature change.

Fibre-reinforced polymers with an epoxy matrix are used in rehabilitation of reinforced concrete structures by bonding them to the face of the concrete. Based on the values you found, what should designers consider when designing this form of rehabilitation?

Answer:
The coefficient of thermal expansion is very different, and this can lead to large stresses developing between the bonded materials with temperature change. This can be a big issue, particularly in cases where the concrete and fibre-reinforced polymers are in direct sunlight, where even in the UK, surface temperatures can reach 50 degrees C.

Question 2

What does “embodied” carbon mean for a material, and what are its units?

Answer:
Embodied carbon is a phrase for the anthropogenic carbon emissions associated with producing a material and getting it into the situation where we’re using it. It depends on the whole process of producing that material and getting it into a particular application, so is very difficult to calculate. I gave them this reference in the course materials: https://www.designingbuildings.co.uk/wiki/Embodied_carbon

Embodied carbon is commonly given in kgC/kg [kg carbon per kg of material]

What are the main sources of embodied carbon in concrete?

Answer:
The energy input to the kiln in production of cement clinker.
The carbon released by decarbonation (or calcination) of the lime when clinker is produced.

It has been proposed that crushed concrete from buildings after demolition is spread over fields and left there to reduce its net carbon emissions. How would this reduce the net carbon emissions? Do you think it is a good idea?

Answer:
Concrete carbonates once it has hardened. This is a slow process which occurs over many years and absorbs carbon dioxide from the atmosphere, taking back in some of the carbon released in the kiln. The higher the surface area, the higher the rate of carbonation: hence crushing the material and spreading it out to speed up the process. I find it hard to imagine this could ever be the best use of land for absorbing CO_2 from the atmosphere, but I'd be interested to hear arguments the other way!

Question 3

A concrete mix uses aggregate with Young's modulus 140GPa and a cement matrix with Young's modulus 22GPa. The concrete comprises 0.3m^3 of aggregate (including course and fine), and 0.2m^3 of hardened cement matrix. Using the rule of mixtures, estimate the Young's modulus of the concrete.

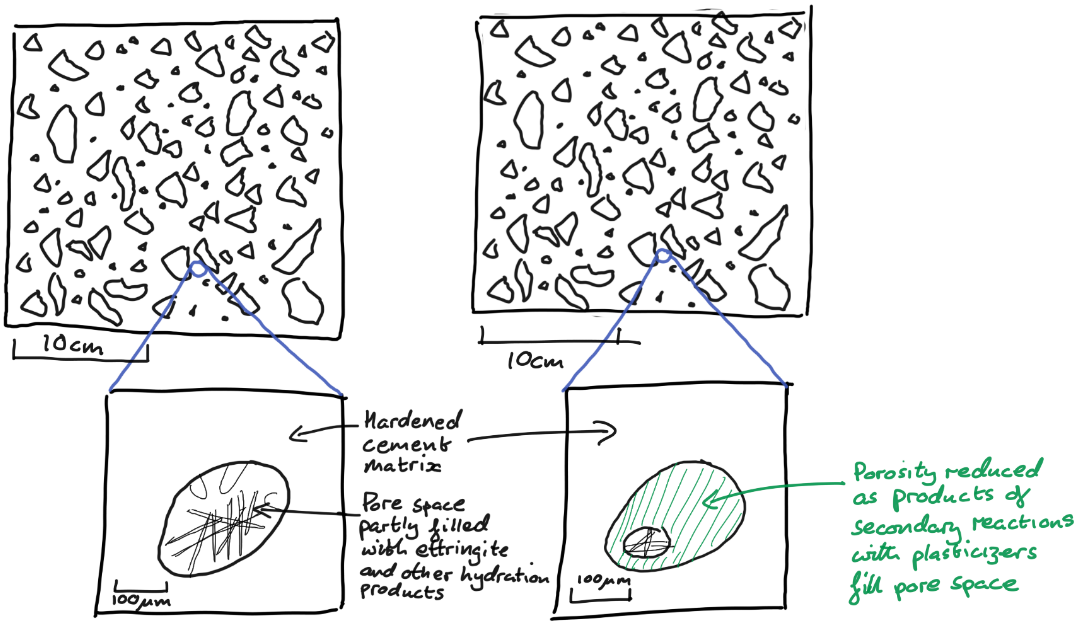
Answer:

The rule of mixtures (lower bound) says:
Ec=1/(Va/Ea+Vm/Em)=1/(0.3/(0.3+0.2)/140+1/(0.2/(0.3+0.2)/22)=44.5GPa

Note the Young's modulus of the aggregate is really high, but this was taken from a text-book example.

Using sketches at appropriate scales, indicate the effect of plasticizers on the microstructure of concrete.

Answer: see my sketch overleaf



Question 5

Because timber grows rather than being manufactured, we need to have ways of estimating its mechanical properties before it is used. This process is called "grading" and requires us to use observations and measurements we can make from the timber without damaging it to estimate properties that we can only really know by breaking it (such as strength).

Based on what you've heard and seen in the timber videos, what observations and measurements do you think could be used for grading?

Answer:

There are a big range of different observations and measurements that are used, with a range of different levels of technology. Here are some:

- Weighing boards to measure density
- Counting knots per m2 (and also the severity of the knots: loose "black" knots reduce strength more than well bonded "green" knots)
- Measuring stiffness by bending under small loads
- Measuring the speed of acoustic waves through the wood
- Computed Tomography (CT) scanning of the wood to look for defects

Question 6

Table 1 shows the embodied carbon and the global production rate of three major construction materials. If the total global anthropogenic carbon emissions are 14.1GT per year, estimate the percentage of those emissions due to each material.

Concrete 0.035 x 19/14.1 = 4.7%
Steel 0.482 x 0.98/14.1 = 3.4%

Timber 0.125 x 2.1/14.1 = 1.9%

You plan to use both concrete and timber in a construction project. Suggest two methods to reduce the embodied carbon of the material you use.

Concrete: use efficient design to minimise the concrete required; use recycled aggregate, from local demolition if available; use admixtures to achieve high concrete strength with the same cement usage.

Timber: use timber that has had minimal processing (avoid kiln drying if possible, and avoid gluing if possible); use efficient design to minimise the timber required.

Table 1: Embodied carbon and production rate of construction materials

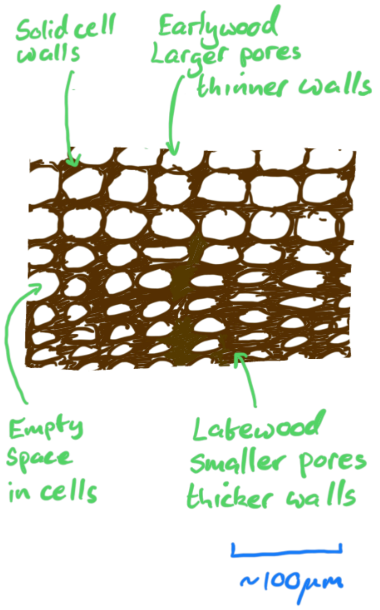
Material	Embodied Carbon (kgC/kg)	Annual Global Production (Tonnes)
Concrete (as generally used in low-rise buildings)	0.035	1.9 x 10^{10}
Steel (including 42.3% recycled content)	0.482	9.8 x 10^{8}
Timber (wood, pulp and paper)	0.125	2.1 x 10^{9}

Question 7

Sketch the cellular structure of wood.

If the solid cell wall material in wood has a Young's modulus of 40GPa, and makes up 30% of the volume of the wood, use the rule of mixtures to estimate the Young's modulus of the wood parallel to the grain.

Answer:



Parallel to grain:

Upper bound rule of mixtures:

$E_m = E_1 V_{f1} + E_2 V_{f2}$
E(parallel)=40 x 0.3 +0 x 0.7=12GPa

What about perpendicular to grain?

Lower-bound rule of mixtures?

$E_m = 1/(V_{f1}/E_1 + V_{f2}/E_2)$
E(perpendicular)=1/(0.3/40+0.7/0) … doesn't work (actually there are still load paths through the solid material in this direction, so the lower bound isn't appropriate)