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Project Summary: A Biologically-Enabled and Inspired Self-Healing Cementitious Composite

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1 Background

Concrete is the most used man-made material in the world. Concrete is an amazing and versatile building material which allows us to construct buildings, bridges, roads, and even magnificent structures like shard. However, since concrete is used in such large quantities, this means that the concrete industry has a massive carbon footprint which makes up 8% of overall global emissions.

Figure 1. Some impressive concrete structures.

Sometimes, due to different reasons like changes in temperature or carrying heavy weights, cracks can appear in concrete. These cracks must be repaired, which is very expensive and time consuming. At times, cracked concrete structures must be replaced, meaning more concrete is used, which is bad for the environment. If concrete could repair these cracks by itself, this would lead to longer-lasting structures, reduced maintenance costs, and lower emissions.

2 Bacteria-based self-healing concrete

This is where special bacteria in self-healing concrete come to the rescue. Bacteria are mixed into concrete as it is being made. When a crack appears in the concrete, the bacteria wake up and start to eat the food that’s available in the concrete. As they eat, they produce a substance called calcium carbonate which acts like a glue to seal the crack in the concrete. Just how our bodies can heal cuts and bruises, bacteria self-healing concrete has the power to repair itself when it gets cracked or damaged.

Hydrogels have recently been investigated as bacterial carriers. The bacteria are protected inside the hydrogel material before mixing the hydrogel in concrete. Hydrogels are materials which can absorb a lot of water, just like a sponge. The bacteria can drink this water as they produce calcium carbonate, improving the crack healing action.

3 Project methods

This project looked at using agarose and alginate hydrogel fibres as a carrier for *Spororscarcina pasteurii* bacteria. The idea is that the hydrogels provide a structural template for the calcium carbonate glue precipitated by bacteria to grow in and around. Taking inspiration from nature, this project aimed to show that the morphology and general alignment of bacterial precipitates could be modulated inside hydrogel fibres to yield a composite healing material with enhanced material properties. The aim was to cause the calcium carbonate material to be formed inside the hydrogel fibres in an anisotropic (directional) manner.

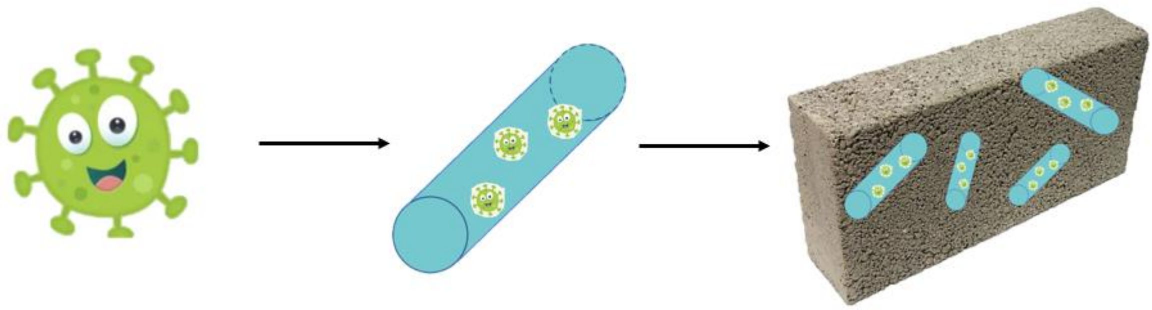

Figure 2. Hydrogel fibre-encapsulated, bacteria-based self-healing concrete concept: Bacteria are first encapsulated in hydrogel fibres and then distributed throughout a concrete matrix along with a food source for the bacteria.

3.1 Anisotropy

Anisotropy is a term that describes how things can be different in different directions. Isotropic, which is the opposite to anisotropic, means 'the same in all directions'. An anisotropic structure in many natural materials (e.g. bone, seashells, teeth) gives these materials improved material properties. Imagine bricks used to build houses. Bricks are always arranged in the same way, as this allows for building walls to be as strong as possible (Figure 3a). A natural material with a clear anisotropic structure is nacre seashell as you can see in Figure 3b below. Nacre has very impressive properties, such as toughness and strength. This project aimed to mimic nature by producing the calcium carbonate material inside the hydrogel fibres in an anisotropic fashion, to allow for a stronger and tougher crack healing material to be formed.

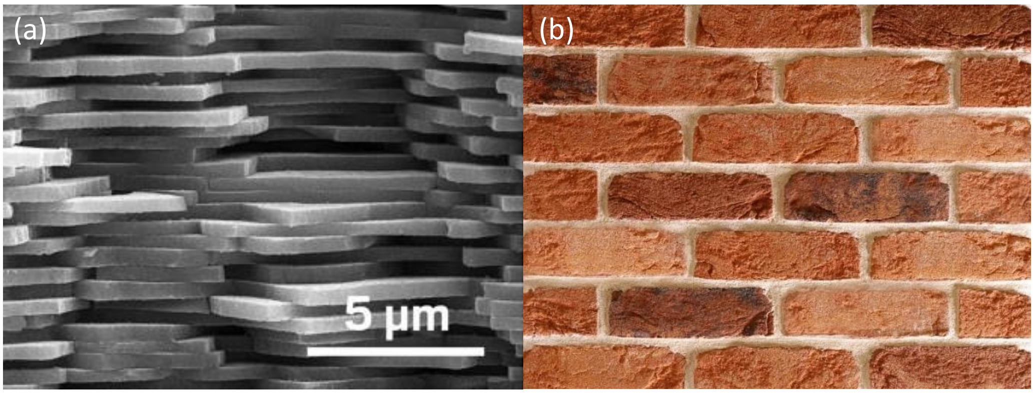

Figure 3. Anisotropic structures: (a) nacre seashell, and (b) a brick arrangement

3.2 Fibre making

I made hydrogel fibres by drying fibres under tension (Figure 4). This drying process stretched out the network inside the hydrogel fibre, making the fibre anisotropic, as we wanted.

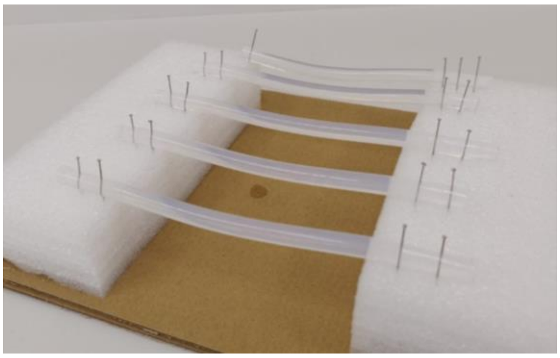

Figure 4. Drying hydrogel fibres under tension.

3.3 Crystal precipitation

Next, I looked at different ways of forming calcium carbonate crystals inside the hydrogel fibres. In Figure 5 below, you can see how the crystals formed in an anisotropic hydrogel fibre grow differently to in an isotropic fibre.

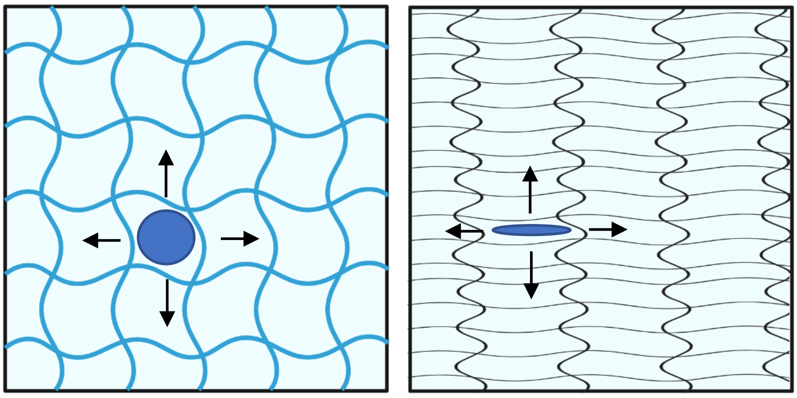

Figure 5. Crystal growth in an isotropic (left) and anisotropic (right) hydrogel structure.

4 Results

Looking at the fibres under the microscope, you could clearly tell that the hydrogel fibre changed the shape of the crystals formed. In isotropic fibres, rhomboidal/diamond-shaped crystals were formed, but, in anisotropic fibres, the crystals aligned to the dried fibre network structure, with a more rounded shape (see Figure 6).

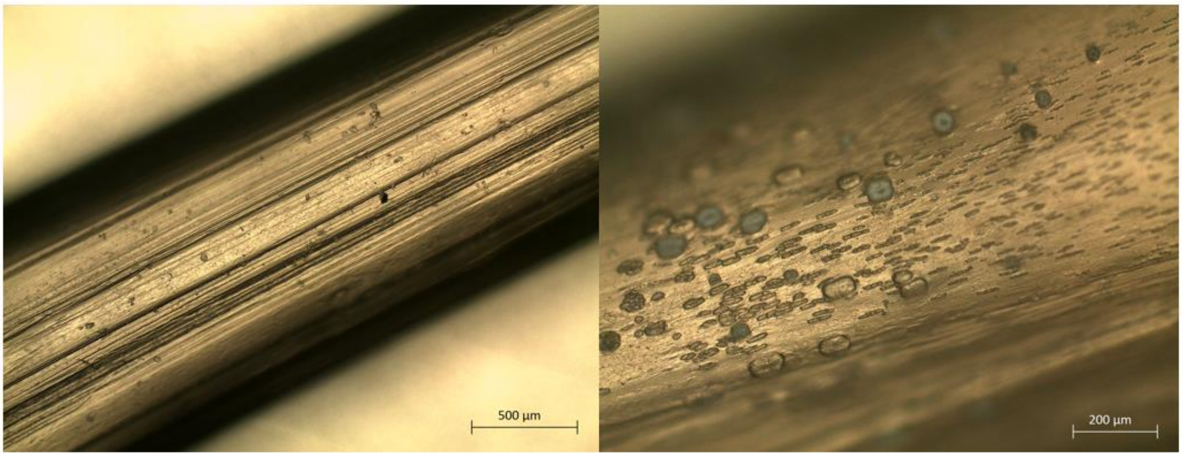

Figure 6. Light microscope images of crystal precipitation in dried anisotropic hydrogel fibres.

Finally, to test the mechanical properties of concrete with hydrogel fibres mixed into it, I made mortar specimens with and without hydrogel fibres, and tested them in compression and flexion with the apparatus shown below (Figure 7). This tested how much the concrete resisted being crushed, and how much the concrete resisted being bent and cracked.

Figure 7. Mortar specimen making and testing: (a) Hydrogel fibres are mixed into the mortar to make fibre-reinforced specimens, (b) Testing under compression, (c) Testing under flexion.

Although we had expected the hydrogel fibres to improve the mechanical properties of the sample, the opposite result was found, with the fibre-reinforced specimens performing worse in both compression and tension. However, in tension, the fibres effectively bridged the crack formed, stopping the crack from growing. This prevented the specimen from failing catastrophically, improving the structural integrity and toughness of the sample.

5 Conclusions

Throughout this project, vegetative bacterial cells were used. However, in concrete, it would be better to use spores. Just how polar bears can hibernate for long periods of time during winter, spores are dormant forms of vegetative bacteria, which hibernate until a crack is formed. The use of spores would allow for self-healing events over longer time periods.

Although there are still many aspects of the bio-inspired hydrogel-fibre encapsulated bacterial precipitation method that still need to be improved and investigated, altogether, these findings demonstrate the potential of using anisotropic fibres to modulate bacterial precipitation and control crack growth, while forming an enhanced crack healing material. Improved crack healing would boost structural durability, increasing the service life of structures and reducing maintenance requirements, as well as decreasing the detrimental effect of such extensive concrete use on the environment.