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'Microbial Mortar'- restoration of degraded marble structures with microbially induced carbonate precipitation

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Ancient stone relics and historic buildings are often subject to significant degradation. The protection and restoration of these monuments is extremely urgent. Here, a method of building repair based on microbial induced carbonate precipitation (MICP) has been tested on marble stone. In previous research, microbial mortar (stone powder treated by MICP) was tested as a filling material to repair cracks within stone. In this paper, the effect of microbial treatment on degraded marble consisting of larger particle sizes is studied. In the experiment, we focus on altering the permeability and porosity of crushed marble grains and show that the porosity and the permeability of the sample are notably decreased by carbonate precipitation.

MICP treatment is carried out in a column filled with marble grains with the injection of six batches over six days. A white CaCO3 precipitate is produced which matches the original marble colour and is sufficiently strong to cement the marble sand together from the inlet up to a depth of 150 mm into the column. To understand the micro-scale distribution of the CaCO3 precipitation within the column, and its effect on flow and transport properties, we analyse the MICP-treated column using X-ray CT with a resolution of around 3 microns. The X-ray CT scan data, support the macro-scale observations of a gradient in the degree of cementation along the direction of liquid flow, indicating that producing an evenly solidified sample is a problem that needs to be resolved.

We use the core-scale experimental data to derive cm-scale fluid transport properties using tracer breakthrough curves taken, prior to, and after MICP treatment. The fitted transport properties show that the fraction of pores containing mobile water decreases with increasing cycles of MICP. Pore-scale modelling using the X-ray CT data supports these findings, showing that cementation leads to a change in the pore network structure, with flow increasingly focussed into a smaller number of faster moving open channels.

Our experiments show that CaCO3 precipitation is greatest at the inlet. It is reasoned that this could be avoided by modification to the injection strategy. Prevention of re-agent mixing outside the marble grains, careful choice of marble grain size distribution, and tailored injection flow rates could deliver re-agents deeper into the media and take advantage of the formation of stable flow pathways to maximise seal uniformity. MICP is a promising technique for the restoration of marble structures and monuments.

References

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