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The influence of the number of injections of bio-composite cement on the properties of bio-sandstone cemented by bio-composite cement

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HIGHLIGHTS

- Ingredients and microstructure of the bio-sandstones have been analyzed.
- Defect volume of the bio-sandstones was characterized under different number of injections.
- The wind erosion rate of bio-sandstone has been tested.

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ABSTRACT

Using bio-composite cement, loose sand particles can be aggregated into bio-sandstone with good mechanical strength. The average compressive strength, hydraulic conductivity, and porosity of bio-sandstone made with 6 injections of bio-composite cement were 1.33 MPa, 2.03×10^{-2} cm/s, and 25.15%, respectively. The ingredients of the bio-sandstone, as determined through X-ray diffraction (XRD) analysis, were mainly quartz sand, $MgNH_4PO_4(H_2O)_6$, and $Mg_5(CO_3)_4(OH)_2{\cdot}4H_2O$. Scanning electron microscopy (SEM) images of the bio-sandstone showed that the cementation products have an irregular flake morphology. The maximum defect volume of the bio-sandstone creating using 2, 4, and 6 injections of bio-composite cement was 1401 mm^3, 930 mm^3, and 738 mm^3, respectively. The internal microstructure of quartz sand, as observed by SEM, was found to be irregular spheres of 100–300 μm. The wind erosion rate of bio-sandstone created by spraying bio-composite cement on quartz sand 1 or 3 times was 0 $g/m^2/h$, after 1 h of wind erosion.

1. Introduction

Sandstorms are meteorological events that occur frequently in many regions of the globe, resulting in serious air pollution [1–4]. To prevent this pollution, loose particles can be cemented using bio-carbonate cement, which has been widely studied by materials scientists, chemists, and biologists [5–27]. Urease bacteria produce bio-calcite crystals that can form bridges between loose particles. Urea can be rapidly hydrolyzed by urease bacteria, producing ammonia and carbonate ions [28–30]. Based on stoichiometry, two moles of ammonia can be produced by urease bacteria hydrolyzing one mole of urea. Ammonia/ammonium (NH_3/NH_4^+) can be converted into the environmentally friendly struvite and carbonate precipitation when *Sporosarcina pasteurii* contained HPO_4^{2-} ions [28]. Therefore, ammonia/ammonium effluent does not need to be handled [31]. Loose particles can be cemented using struvite [28].

The properties of the bio-sandstone were characterized using energy-dispersive X-ray spectroscopy (EDS), X-ray diffraction (XRD) analysis, scanning electron microscopy (SEM), shore hardness testers, and X-ray computed tomography (XRCT). The evolution and distribution of 3D defect volumes was also analyzed. This microbial method can be applied to the improvement of sandy soil foundations by cementation, and has potential applications in the suppression of sand-dust emission.

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2. Experiments and methods

2.1. Materials

Sporosarcina pasteurii was cultured and used in experiments for binding loose sand. One mole of urea and two moles of $MgCl_2$ were dissolved in 1 L of water, producing a solution containing a mixture of urea (1 mol/L) and $MgCl_2$ (2 mol/L). The bacterial solution (1 mol/L of $K_2HPO_4{\cdot}3H_2O$) was prepared by dissolving 1 mol of $K_2HPO_4{\cdot}3H_2O$ in 1 L of *Sporosarcina pasteurii*. The quartz sand particles ranged from 212 to 425 μm.

2.2. Sand cementation

Loose quartz sand was added to PVC pipe (internal diameter = 5.0 cm, length = 15.0 cm), and then 100 mL of bacterial solution (1 mol/L of $K_2HPO_4{\cdot}3H_2O$) was injected into the sand column. Next, 100 mL of the urea/$MgCl_2$ solution was injected into the sand column. After standing for 6 h, 100 mL of bacterial solution (containing 1 mol/L of $K_2HPO_4{\cdot}3H_2O$) was injected into the sand column, and then 100 mL of the urea/ $MgCl_2$ mixture was injected 2, 4, or 6 times. The cementation solution cannot be injected more than 6 times. Fig. 1 shows a schematic diagram of the bio-grouting process. After casting, specimens were maintained at 30 ± 2 °C for 21 days.

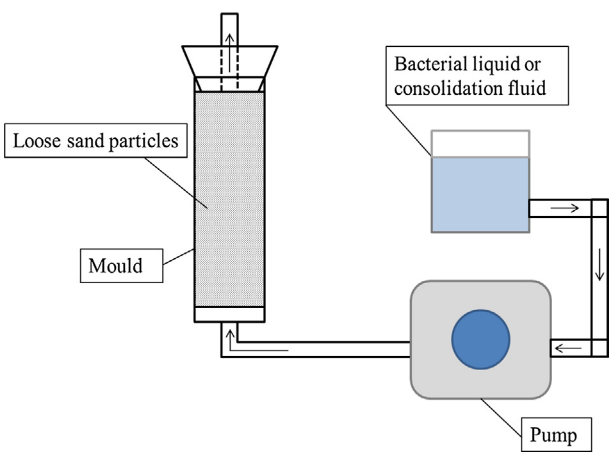

Fig. 1. Schematic diagram of bio-grouting process.

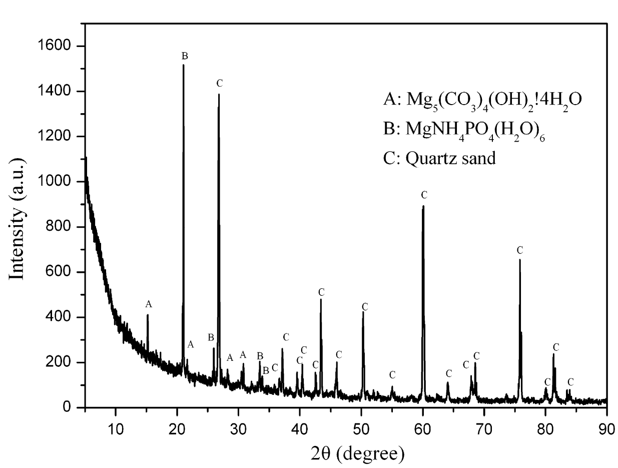

Fig. 2. X-ray diffraction of the bio-sandstone.

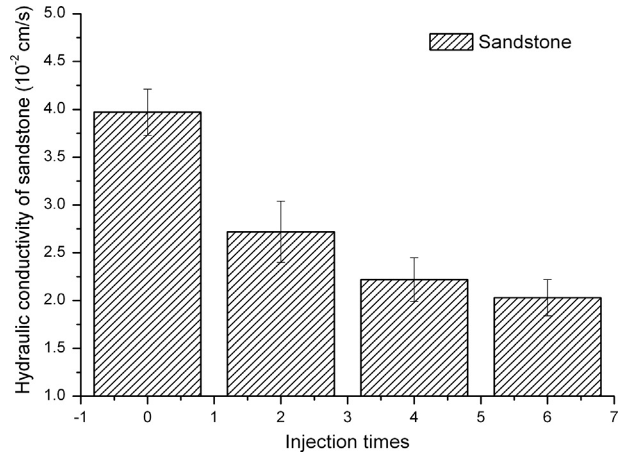

Fig. 3. Effect of the number of injections on the hydraulic conductivity of the bio-sandstone.

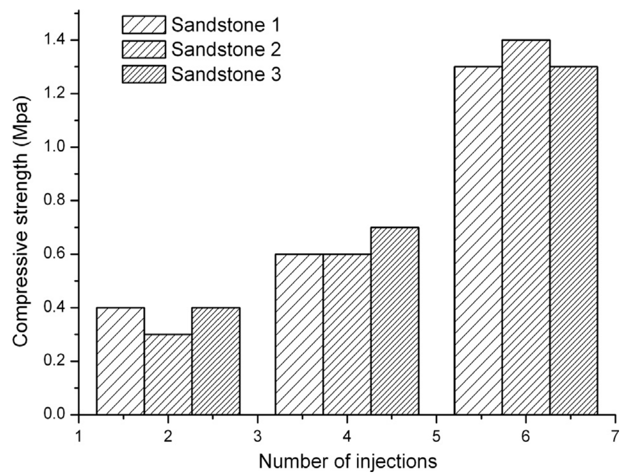

Fig. 4. Effect of the number of injections on the compressive strength of bio-sandstone.

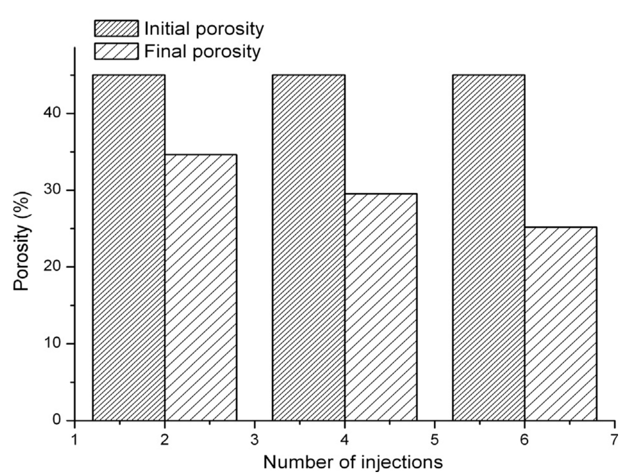

Fig. 5. Effect of the number of injections on the porosity of bio-sandstone.

Loose quartz sand was solidified by spraying the urea/$MgCl_2$ mixture and the bacterial solution 1or 3 times. Finally, sand cakes were dried at 30 ± 2 °C for 14 days.