Abstract

Microbial-Induced Calcium Carbonate (CaCO3) Precipitation (MICP) is a biological process in which microbial activities alter the surrounding aqueous environment and induce CaCO3 precipitation. Because the formed CaCO3 crystals can bond soil particles and improve the mechanical properties of soils such as strength, MICP has been explored for potential engineering applications such as soil stabilisation. However, it has been difficult to control and predict the properties of CaCO3 precipitates, thus making it very challenging to achieve homogeneous MICP-treated soils with the desired mechanical properties. This PhD study investigates MICP at both micro and macro scales to improve the micro-scale understandings of MICP which can be applied at the macro-scale for improving the homogeneity and mechanical properties of MICP-treated sand. A microfluidic chip which models a sandy soil matrix was designed and fabricated to investigate the micro-scale fundamentals of MICP. The first important finding was that, during MICP processes, phase transformation of CaCO3 can occur, which results in smaller and less stable CaCO3 crystals dissolving at the expense of growth of larger and more stable CaCO3 crystals. In addition, it was found that bacteria can aggregate after being mixed with cementation solution, and both bacterial density and the concentration of cementation solution affect the size of aggregates, which may consequently affect the transport and distribution of bacteria in a soil matrix. Furthermore, bacterial density was found to have a profound effect on both the growth kinetics and characteristics of CaCO3. A higher bacterial density resulted in a quicker formation of a larger amount of smaller crystals, whereas a lower bacterial density resulted in a slower formation of fewer but larger crystals. Based on the findings from micro-scale experiments, upscaling experiments were conducted on sandy soils to investigate the effect of injection interval on the strength of MICP treated soils and the effects of bacterial density and concentration of cementation solution on the uniformity of MICP treated soils. Increasing the interval between injections of cementation solution (from 4 h to 24 h) increased the average size of CaCO3 crystals and the resulting strength of MICP-treated sand. An optimised combination of bacterial density and cementation solution concentration resulted in a relative homogeneous distribution of CaCO3 content and suitable strength and stiffness of MICP-treated sand. This thesis study revealed that a microfluidic chip is a very useful tool to investigate the micro-scale fundamentals of MICP including the behaviour of bacteria and the process of CaCO3 precipitation. The optimised MICP protocols will be useful for improving the engineering performance of MICP-treated sandy soils such as uniformity and strength.