PhD Final Examination

Nano-modification for High Performance Cement Composites with Cellulose Nanocrystals and Carbon Nanotubes

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ABSTRACT

One of the new engineering frontiers is the exploration of infrastructure materials with novel combinations of properties that break traditional paradigms. The goal of this study is to utilize two different nano-fibers, cellulose nanocrystals (CNCs) and carbon nanotubes (CNTs) to modify the nanoscale structures of cement composites and thereby improve the performance at the macro-level. This study also evaluates the mechanism behind the modification, since fiber bridging, the most common reinforcing mechanism for fiber-reinforced composites, cannot be simply applied because CNCs are too short to bridge cracks in cement composites.

The mechanical tests show an increase in the flexural strength of cement paste with modest CNC concentrations. It is found that the degree of hydration (DOH) of the cement paste is increased when CNCs are used, which is the fundamental reason for the strength improvement. Two mechanisms are confirmed for the increased DOH: steric stabilization and a new theory referred as short circuit diffusion (SCD), which is more dominant. SCD increases DOH by increasing the transport of water from the pores to the unhydrated cement core through the high density CSH shell. This study evaluates the agglomeration of CNCs at high concentration and it is found the strength of the cement paste with CNCs decreases when the agglomerates start prevailing. The ultrasonication is employed to effectively reduce the agglomerates and the strength of the cement paste is improved significantly with ultrasonicated CNCs. Due to the hygroscopic and hydrophilic nature of CNCs, the agglomerates may lead to larger and more pores around them. It is found that the elastic modulus at the high density CSH is increased when raw CNCs are added, and is increased even more with ultrasonicated CNCs. The porosity study shows CNCs can reduce the total porosity of cement pastes, while after ultrasonication the porosity reduction is even greater.

The CNTs are successfully dispersed with a combined approach of ultrasonication and surfactant and the degree of dispersion is evaluated with SEM imaging and impedance spectroscopy (IS). The flexural and compressive strength of the cement paste increase significantly with the dispersed CNTs. It is verified that the fiber bridging is the mechanism for the strength improvement. The IS curve for cement paste with CNTs shows a dual-arc behavior, which is consistent with the frequency-switchable coating model.

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