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Durability of superhydrophobic engineered cementitious composites

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HIGHLIGHTS

- SECC demonstrate reduced water absorption and permeability.
- SECC possess improved mechanical behavior.
- SECC provide exceptional freeze–thaw resistance.

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ABSTRACT

Key elements of infrastructures throughout the United States are displaying poor durability, especially in northern regions where freeze–thaw damage is prevalent. One main factor leading to the early deterioration of concrete is related to the infiltration of water into the porous structure of the concrete matrix. To account for this, sealers or water repellant coatings are often applied on the surface of cementitious materials to reduce the ingress of water into the material. However, when the material develops micro-cracks, which is unavoidable, water can easily penetrate and saturate the bulk of the material. By incorporating a hydrophobic admixture within the concrete mix, water is restricted to enter the capillary voids and porous space, where, upon freezing, damage occurs. This type of modification is achieved in superhydrophobic engineered cementitious composites (SECC) designed with hydrophobic or superhydrophobic air voids evenly distributed throughout the cementitious matrix, providing effective protection against water infiltration. Moreover, SECC incorporates fiber reinforcement tuned to limit the crack opening. The reported research demonstrates the improved durability in fiber reinforced cementitious materials by creating a 3-dimensional hydrophobization to reduce the water absorption and permeability as well as to improve the freeze–thaw performance.

1. Introduction

The infrastructure facilities in the United States are in desperate need of repair. This is especially evident in northern regions that are exposed to harsh climate change and severe conditions such as water infiltration, de-icing salts, and freezing and thawing cycles. Cementitious materials undergo accelerated deterioration when high quantities of water and dissolved chemicals are seeping through the material. To reduce this effect, sealers are often used to prevent detrimental aqueous systems from entering the concrete. However, this approach has disadvantages. The sealer often wears off after only a short period. Additionally, if a crack on the surface of the concrete occurs, the sealer loses its ability to resist the ingress of water. When either of these occurs, water can easily infiltrate the cementitious matrix accelerating the deterioration process.

To account for this, the use of a 3-dimensional (volume) hydrophobization [1] is used to construct the water repellant structure capable of protecting the material from detrimental effects that could occur when water and other elements unavoidably enter the cementitious matrix (Fig. 1). This can be achieved by the use of polyethyl hydrosiloxane (PEHSO) or polymethyl hydrosiloxane (PMHS) based admixtures, which when incorporated into a cementitious mix, release small quantities of hydrogen to form small internal air voids [1] with a superhydrophobic or water repellant surface (Fig. 2).

Since the air voids can be well dispersed and engineered for a specific size, they result in a material with adequate air bubble distribution while showing only minimal reductions in compressive strength. The air voids can also serve as artificial flaws to initiate

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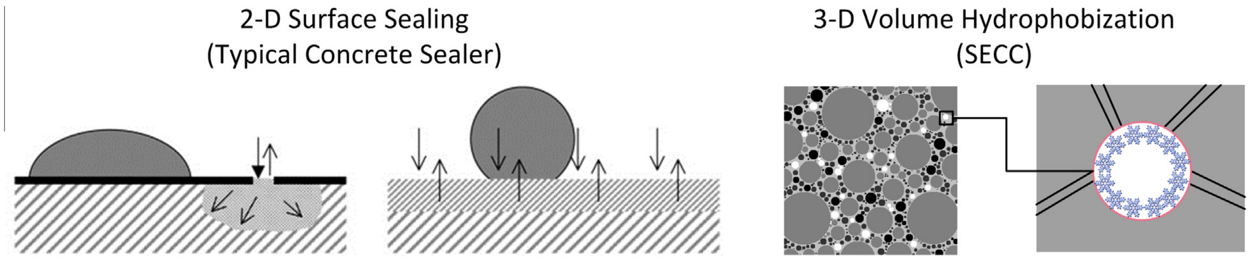

Fig. 1. Typical concrete sealers (left) and 3-D volume hydrophobization (right).

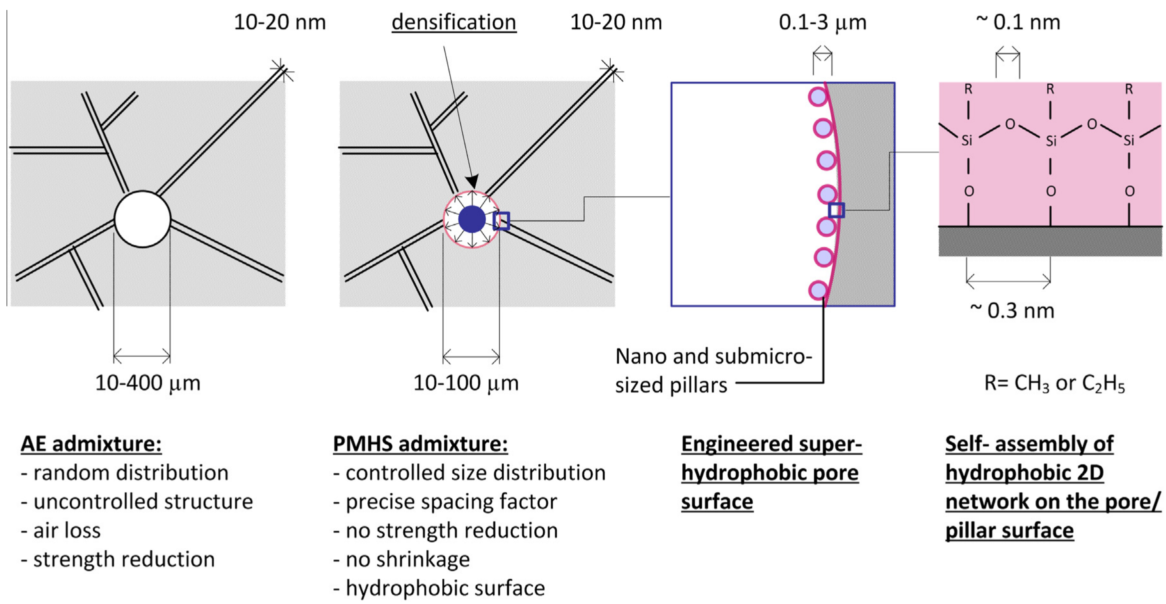

Fig. 2. How the concept of superhydrophobization works.

cracking and provide multi-cracking and strain hardening behavior in fiber reinforced composites [2,3].

The concept of superhydrophobic hybridization incorporates biomimetics (lotus effect), chemistry (use of siloxane polymers), and nanotechnology (the use of nano-SiO_2 particles) to improve concrete durability [1,4–6]. Superhydrophobic surfaces have gained much attention as of late due to their potential for industrial applications such as self-cleaning [7–9]. To manufacture an air void structure with superhydrophobic surfaces, emulsions are produced with hydrogen-containing siloxane compounds (e.g., polymethyl hydrosiloxane, PMHS) and combined with small quantities of submicro- and nano-sized particles (Fig. 2). The PMHS admixture (used at a dosage of 0.01–0.1% of cement weight) releases hydrogen and forms small voids in the range of 10–100 μm within the cement paste [10]. The submicro- and nano-sized particles then coat the surface of the voids to create the roughness required for a superhydrophobic effect [11]. The submicro- and nano-sized particles also help to create preferred distribution of droplet sizes within the emulsion (Fig. 3). The size and distribution of the air voids within the hardened cementitious matrix can be correlated with the droplet size [1]. For optimal performance, more than 70% of the droplets must be dispersed to a size of less than 10 μm [1]. The addition of the nano-sized particles also improves the stability of the emulsion, ensuring a good distribution without coalescence [12].

Commonly, water that infiltrates concrete occupies entrapped air voids and capillary voids; upon freezing, water expands, resulting in internal stresses and cracking of concrete [13]. To reduce the

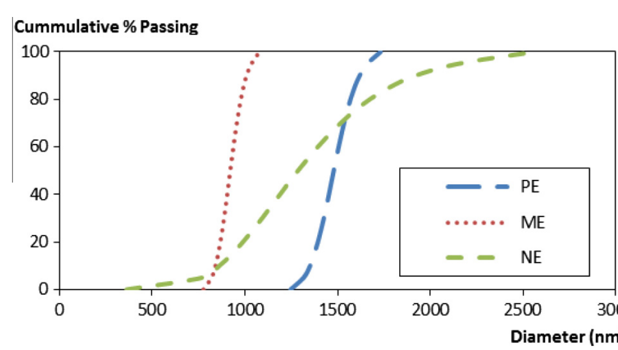

Fig. 3. Droplet size distribution of emulsions containing PVAS only (PE), PVAS and metakaolin (ME), and PVAS, metakaolin and nano-SiO_2 (NE).

internal pressure caused by the formation of ice, air-entraining (AE) admixtures are used. However, many AE admixtures that are used in concrete have several downfalls. There is typically a significant reduction in compressive strength of concrete due to air entrainment. Additionally, there is often a loss of intended air during mixing, transportation, placement, and compaction [14]. Another downfall of typical air entraining admixtures is that large, unevenly spaced, and, sometimes non-spherical voids are created (Fig. 2). These properties are not ideal to resist against severe freezing and thawing cycles.

The use of randomly oriented fibers also improves the durability of cementitious materials [15,16]. The addition of polyvinyl