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Effect of entrained air voids on the microstructure and mass transport properties of concrete

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ABSTRACT

The effects of entrained air on microstructure and transport properties of concrete with up to 11.5% air at different w/c ratios, curing and conditioning regimes were investigated. It was found that air voids disrupt the packing of cement and increase the heterogeneity of the microstructure. The width of the affected interface is around 30 μm. Gaseous diffusivity and permeability are increased by up to a factor of 2–3 at the highest air contents. This effect is similar to that due to increasing w/c ratio from 0.35 to 0.50 when samples are conditioned at 52% r.h or 50 °C. The effect on sorptivity is less consistent, while the effect on electrical conductivity is influenced by the moisture condition of the air voids. It is estimated that every 1% increase in air content increases transport by 10% or decreases it by 4%, depending on whether the air voids act as conductors or insulators.

1. Introduction

A typical concrete contains around 1-2% vol. of air voids that are inadvertently entrapped because of incomplete compaction. Air voids may also be deliberately incorporated by means of a suitable surfactant, i.e. an air entraining admixture. It is well established that air entrainment enhances the resistance of concrete to damage by repeated exposure to freeze-thaw cycles and salt scaling, by providing a system of discrete, small and closely spaced spherical voids that are well dispersed throughout the cement paste. The size of the entrained air voids is generally between ten and hundreds of microns. To ensure adequate frost protection, the spacing of the air voids should be smaller than a critical distance, typically 200–250 μm [1,2]. However, for simplicity and convenience, most standards prescribe the total air content by assuming that the spacing factor is inversely proportional to air content. For example, the recommended air content according to ACI 201.2R-01 [3] ranges from 3–7.5% depending on the maximum aggregate size and severity of the exposure, with a tolerance of ± 1.5% allowed for field concretes. The volume and size of the entrained air voids depend on many factors, including the type and amount of air-entraining agent, materials and mix composition, mixing and placing techniques. These issues and concepts relating to freeze-thaw damage and the beneficial effects of air entrainment have been reviewed elsewhere [2–5].

Because concrete contains around 65–75% vol. aggregate and all of the air voids reside in the cement paste, a small amount of air entrainment causes a significant change to the microstructure of the paste, and to its pore structure in particular. This in turn may have a significant effect on the properties of the hardened concrete. A well known example is strength loss that accompanies air entrainment. As a general rule of thumb, one-percentage increase in air content results in about 5% decrease in the compressive strength of concretes at equal water-to-cement (w/c) ratios. However, a more significant reduction in strength has been reported particularly when the air avoids cluster at the aggregate-paste interface [6,7]. Air entrainment also increases workability, improves consistency and reduces the bleeding and segregation tendency of fresh concrete [2,5].

Whereas there is an extensive body of work on characterising the air void system and determining its requirements for frost protection, very little research has been carried out on understanding the effects of entrained air on other aspects of hardened concrete such as mass transport processes and resistance to other forms of deterioration. Air voids are penetrable, but because they appear isolated in the microstructure and do not form a continuous flow channel, they are often assumed to make little or no contribution to the bulk transport properties of concrete. Thus, air voids are treated as inert inclusions similar to aggregate particles. Air voids may disturb the packing of cement grains and the distribution of porosity, but this effect could be negligible due to their small size relative to aggregates. Some studies suggest that air entrainment decreases the permeability of concrete, but this is often a result of a lower w/c ratio in the air-entrained mixes to take advantage of its improved workability [2,8]. Increasing the air content is accompanied by a change in other variables, such as the cement and aggregate content, that may have a larger influence on transport. For example, increasing the air content decreases the aggregate content if the cement content and effective w/c ratio are

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