Detailed Observation of Air Bubble Generation by Water Flow Hydrodynamics in Narrow Gaps such as Concrete

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ABSTRACT

Self-healing technologies are still under development and therefore careful understanding of the mechanisms involved is critical in developing efficient self-healing/self-sealing materials. Water permeation induced self-healing mechanisms in cementitious materials have the potential for sustainable concrete infrastructure. However, recent direct observation of water flow in the narrow gaps showed growth of air bubbles. This research thus examines the water flow mechanisms that lead to air bubble generation in narrow gaps. By using a transparent glass plane bound to a study surface, water flow in the narrow cracks was imitated. Gap sizes of 0.1 and 0.2mm were studied for specimen dimensions of 10 x 17 cm, with a constant water head of 8.5cm in continuous water permeation condition. Video observations, photography and use of coloured water, plus tracer powder revealed water flow profiles before and after air bubble formation and growth. Air bubble growth was observed right from the immediately observable sub-micro size to the large sub-centimetre sizes; and also how this growth shapes water flow profiles within the narrow gaps of two surfaces. At a relatively longer time scale (5 hours), the effect of air bubble creation in terms of gap constriction was observed to cause water flow reduction. Direct observations also revealed that air bubbles could be formed at pore points (surface imperfections of study surface) and are anchored to these points or may be released into the crack where they may remain stable and continue to grow to up several millimetres.

1. INTRODUCTION

Water permeation self-healing testing methods usually rely on water leakage reduction to determine extent of self-healing for a given type of concrete, crack size, or applied pressure head [1],[2],[3], etc. Direct observation of water flow condition through narrow concrete cracks has been characterised by formation of air bubbles, Ikoma (2014) [4]. In this research, the air bubble generation mechanisms are investigated. The methodology adopted involves direct visual observation of water flow through a narrow opening (0.1~0.2mm) between two parallel surfaces. One surface is an observation transparent plane glass and the other is the study material. It is natural that dissolved air will escape out of bulk water depending on the balance of temperature, solubility and pressure factors. Also, free floating bubbles will tend to rise out of water [5]. In micro cracks/openings and under slow water flowing conditions, and different inter-surface material characteristics, air (dissolved and free micro bubbles) may be caused to come out of water. The phenomenon is similar to cavitation but differs by the absence of large pressure differences and high flow speeds [6]. It is thus reasonable at the moment to infer that the same mechanisms, by which bulk water releases air, are achieved in these slow flowing water micro channels. In the bulk, water contains dissolved air, about 2~3% air and of this 30% exists as free air with bubble sizes from 5micro to a one millimetre [5].

2. EXPERIMENTAL SET-UP

To study air bubble creation phenomenon in in micro size channels, several cementitious materials of different surface characteristics were used. Surfaces of machine cut concrete, mortar and cement paste surfaces were studied with gap widths of 100~200 microns and 17x10cm specimen. Specimen fabrication is similar to that adopted by Ikoma (2014). A study surface is bound to plane glass surface leaving a clearance dictated by Teflon sheet thickness *w* (100 or 200 micron). Once ready, the specimens are rid of any air by vacuum soaking under water for 12 hours. After achieving total water saturation as an initial condition, the test set-up then involves continuous supply of tap water to the specimen via an 8.5cm high pipe attached to the top of the specimen. The water head is maintained at 8.5cm. Video recording is started to observe the evolution of air bubbles at any instant. Coloured water was added to clearly observe any air bubbles at given intervals.

3. OBSERVATION AND DISCUSSIONS

3.1 Air bubble growth and development

Based on careful observation, air bubbles in the narrow gaps don’t just appear suddenly. They start small at almost non observable sizes to the naked eye and then steadily increase in size with the passing of time and continuous supply of water. Air bubbles grow freely from the point of nucleation at their point of attachment (on the study surface) and once a bubble touches the surface of the glass, growth becomes only limited to radial extents (Figure 1ⓒ).

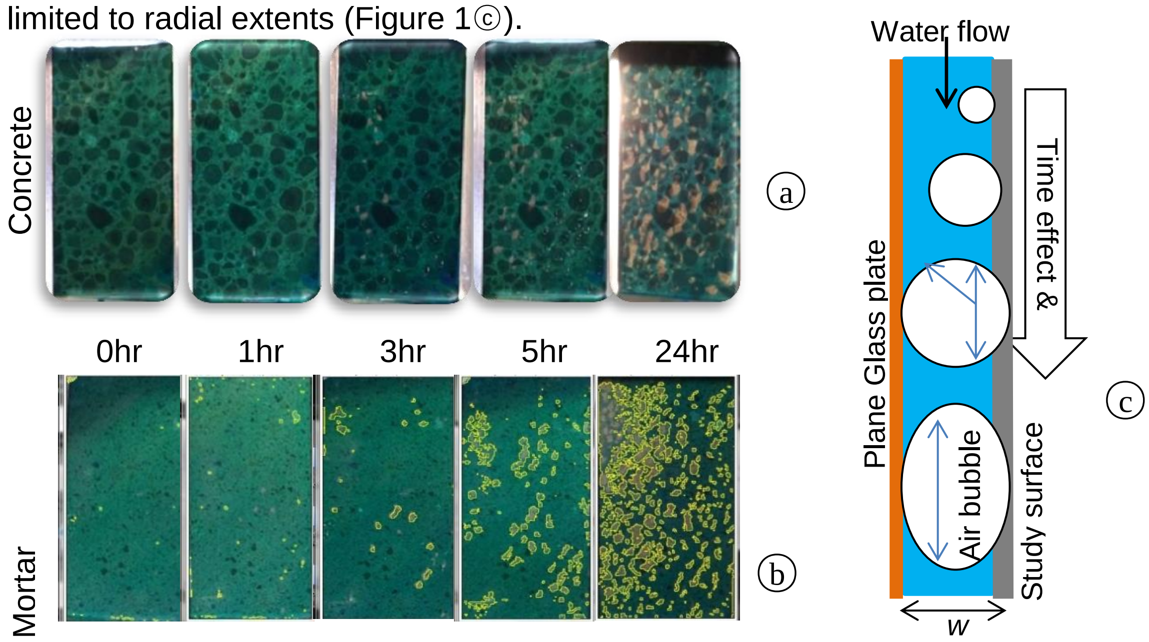

Figure 1: Air bubble development over the entire specimen surface

Bubble growth involves mass transfer (of gases) at the bubble - water interface, and is usually from water into the air bubble [6]. The opposite occurs when bubbles burst, and air re-dissolves into water. Figure 1 shows the growth of air bubbles over the entire specimen surface within a few hours, whereas figure 3ⓒ shows the growth of a single air bubble from almost zero to a relatively larger size. Initially, it is difficult to actually see any significant air bubble across the entire surface. One hour later, sizeable air bubbles become more visible and their density across the entire surface starts to increase. In the first few hours of air bubble generation, a single bubble can grow separately by feeding off the air supply from water; or if two bubbles are adjacent, they may fuse together to form one larger bubble. A dislodged air bubble may travel downstream and either get flushed out or get attached to downstream stable air bubbles. Magnified observations reveal several micro bubbles that once created, disappear either by flushing effect of flowing water or re-dissolving into water.

3.2 Initial specimen condition and water type

Observations of micro channel water flow with de-aired water showed no air bubble generation. De-aired water has not the necessary nuclei for air bubble growth; though it is difficult to rid water of all contained air. Figure 1 shows result with tap water supplied continuously over the entire testing period. The initial condition is one of de-aired water saturation for all specimens. On the other hand Figure 2 compares two initial conditions of specimens, in terms of air bubble evolution.

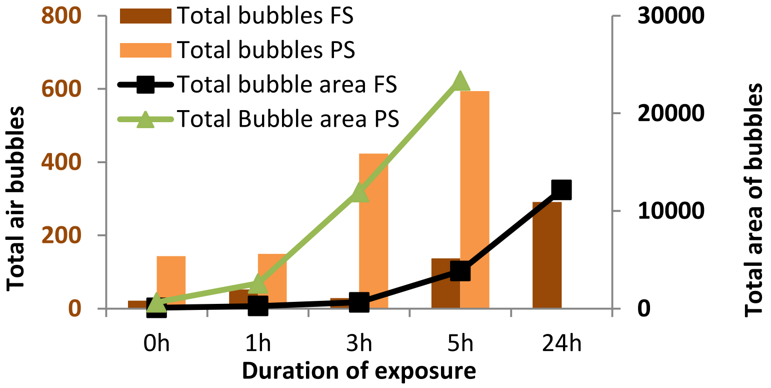

Figure 2: Effect of initial condition: fully saturated (FS) & partially saturated (PS)

In the partially saturated condition, specimen contains some trapped air while in the fully saturated condition it's fully water saturated by vacuum soaking. It is clear from the results in Figure 2 that initial air content in specimens acts as nuclei and contributes to faster growth of air bubbles. For fully saturated specimens, all the nuclei that are needed for air bubble growth are supplied from the flowing water; and as it flows, they are replenished by new incoming water. This is one of the main inputs to air bubble growth. Figure 1ⓑ shows air bubble mapping using image analysis to compute overall air bubble growth and development (Figure 2).

3.3 The effect of surface imperfections

Observations of water flow and air bubble creation revealed that air bubbles utilise surface imperfections as anchorage points. Figure 3ⓐ shows correlation between location of pores and air bubbles. Significant correlation between the two was observed. Thus concrete pores act as nucleation points for air bubble growth [6]. Concrete pores/pocket/crevices could be the source of heterogeneous nucleation and can persist indefinitely on the surfaces. At some points, it was observed that an air bubble is formed, grows and once released another one starts to grow at the same place. It is likely that even at their micro and sub micro level, surface imperfections are able to cause air release from water. At such pore pockets static pressure reduces, not below water vapour pressure, but to extents sufficient to cause gaseous diffusion which promotes the growth of submicron bubble nuclei.

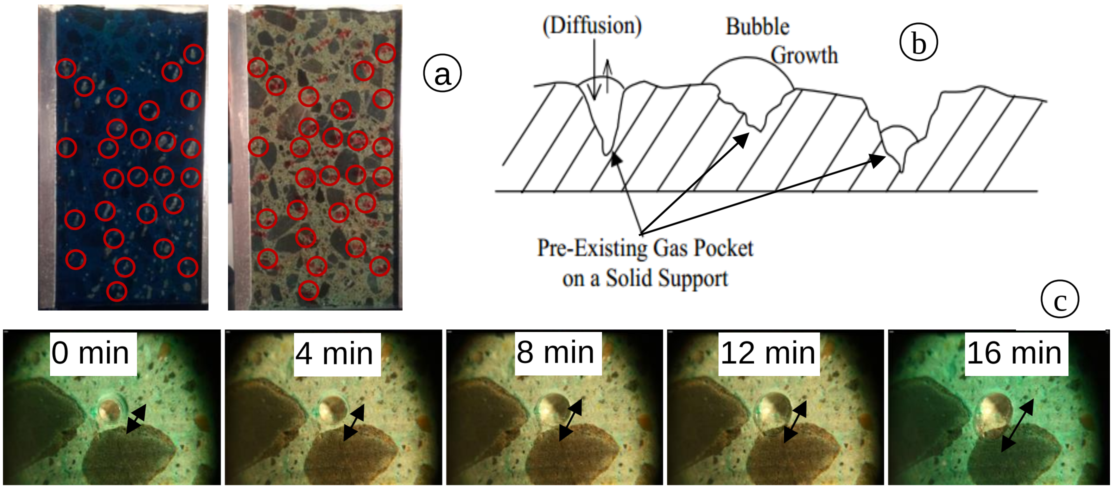

Figure 3: Magnified air bubble growth and effect of surface imperfections

The presence of any surface imperfections within the micro channels also creates varying water flow profiles at those locations. In such a closed channel, these changes affect flow speed and cause micro pressure reductions, all of which are hypothesised to contribute to the release of air from water.

4. CONCLUSIONS

Detailed observation of air bubble generation reveals intriguing aspects about air bubble growth, characterised by random spatial distribution across a material’s surface. Air bubbles once formed are mostly anchored at the different surface imperfections such as pores of cementitious materials. In narrow gaps, air bubbles by steady growth, touch the two parallel surfaces and stay anchored and stable as long as water exists in the channel. Air bubbles after growth influence water flow profiles.

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