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Short communication

# Carbonation assessment in concrete by nonlinear ultrasound

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ABSTRACT

The carbonation process results in a change in the elastic properties of concrete, resulting in a variation of standard acoustic indicators such as wave speed. However, this evolution is too low to ensure an efficient carbonation assessment. The present communication focuses on the feasibility of carbonation assessment in concrete by applying Nonlinear Resonant Ultrasound Spectroscopy (NRUS). The results show that the nonlinear parameter is significantly affected by the presence of carbonation, which is interpreted with respect to the evolution of concrete microstructure in the presence of this pathology.



Carbonation is a chemical reaction in concrete between the calcium hydroxide ($Ca(OH)_2$) contained in cement and the carbon dioxide ($CO_2$) in the air. The following chemical reactions can be identified:

- Dissolution of carbon dioxide in water:

$$CO_2 + H_2O \rightarrow H_2CO_3$$

$$H_2CO_3 + H_2O \rightarrow HCO_3^- + H_3O^+$$

$$HCO_3^- + H_2O \rightarrow CO_3^{2-} + H_3O^+$$

- Reaction of carbonic acid with calcium hydroxide $Ca(OH)_2$, after its dissolution:

$$H_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3 + 2H_2O \quad (1)$$

One of the consequences is the decrease of the pH due to the liberation of ions $H_3O^+$. The pH value of concrete ranges from 12 to 13 and after carbonation, the pH drops to 9 for fully carbonated concrete. It was observed that the ability of carbon dioxide to be fixed by calcium hydroxide depends on the quantity of alkalis (NaOH, KOH) contained in the cement because the alkalis decreases the solubility of calcium hydroxide. But once the alkalis are carbonated higher amounts of calcium hydroxide can be carbonated [1].

Carbonation also affects the other hydrates of the cement paste (silicates and aluminates). Particularly, it was observed that the C–S–H can be carbonated following the reaction:

$$1.7H_2CO_3 + 1.7CaO.SiO_2.2.5H_2O \rightarrow 1.7CaCO_3 + 1.7SiO_2.2.5H_2O + 1.7H_2O$$

Nevertheless it must be noticed that the carbonation of calcium hydroxide is faster than for the other hydrates. The speed of carbonation essentially depends on the humidity of concrete and is maximal for values about 65%.

After carbonation it was observed that the porosity of concrete decreases due to a highest molar volume of carbonation products in comparison to the volume of hydrates. For instance, the molar volume of $Ca(OH)_2$ is about 33.2 $cm^3$/mol while the molar volume of $CaCO_3$ is about 36.9 $cm^3$/mol which corresponds to an increase of 11%. The consequence of this difference was observed on cement pastes [2] and on concrete [3], essentially by Mercury Intrusion Porometry (MIP). For concrete, the difference of porosity between non carbonated and carbonated concrete is higher for concrete with low porosities and can attain 10% [3]. The same studies emphasized that carbonation also modifies the size distribution and it was generally observed a coarsening of the pore structure after carbonation. For instance, it was observed an increase of the volume of capillary pores after full carbonation of cement pastes mixed with different cements [2]. For the authors the coarsening of the pore structure may be associated with the formation of additional silica gel due to the decomposition of the C–S–H gel in the matrices following prolonged exposure to $CO_2$. Another study aiming to compare the effect of $CO_2$ concentration on the carbonation process demonstrated that the carbonation of C–S–H is significantly enhanced when high concentration is used (50% of $CO_2$ in this study) [4]. This consideration again supports the assumption that the reduction of porosity is due to the carbonation of C–S–H, but specifically at high pressure of $CO_2$.

The most important consequence of carbonation for reinforced concrete structures is the decrease of pH. In fact, it will lead to a destruction of the passive film which is formed by non-carbonated concrete around the reinforcing steel [5]. Then, in presence of oxygen and water the corrosion process can be initiated. Such corrosion products are expansive, so very quickly the concrete is mechanically damaged and a spalling of cover can be observed with the reinforcement

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