

## Effect of Surface Water Proofing Admixture on Carbonation of Concrete

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### Abstract

Carbonation is the reaction of carbon dioxide in the environment with the calcium hydroxide in the cement paste. This reaction produces calcium carbonate and lowers the pH to around 9. At this value the protective oxide layer surrounding the reinforcing steel breaks down and corrosion becomes possible. The reaction of carbon dioxide and calcium hydroxide only occurs in solution and so in external or internal isolated concrete carbonation will be slow. In this study, rapid carbonation test was performed on internal isolated concrete. In most structures made with good quality concrete, carbonation will take several (or many) years to reach the level of the reinforcement. Concrete members were produced in standard curing and they were coated with water proofing materials. They exposed to rapid carbonation for 1, 5 and 10 days in carbonation test cabinet. After test, samples were splitted and solution was poured on the concrete surface. At the same time, electrical resistivity of series was determined. Carbonation dept was measured on the concrete sample. It was found that carbonation dept decreased on external isolated concrete. For concrete with standard curing, it was found that the electrical resistivity measurement was the most reliable parameter in predicting the resistance of concretes to carbonation.

**Keywords:** Carbonation, concrete, water proofing

## INTRODUCTION

Concrete is the most widely used construction material in the world and its production is expected to increase in the coming years. Concrete has high alkaline properties. This property of concrete protects reinforcements from corrosion by the formation of a passive oxide film. However, alkalinity of concrete decrease with time due to carbonation. Carbonation is a big problem to cause structure deterioration for reinforced concrete. This process is the reaction of the hydration products dissolved in the pore water with the carbon dioxide (CO<sub>2</sub>) in the air which find atmosphere around 0.03-0.3%. The reaction reduces the pH of concrete pore solution from about 12 to less than 9. Therefore, the passive oxide film of reinforcement decomposes.

The one of the most important factors is pore system in carbonation occurring. Pores take place along hardening of concrete. Excess water evaporate and create pore in concrete while some of water in concrete mixing consumed in hydration of cement. The pore size of concretes is between nano to micrometer range (10 nano to 50 micro meter). These pores allow water and dangerous substance for concrete to penetrate the structure leading to degradation. Several studies [1], [2] and [3] on concrete to produce high performance have been interested in water permeability.

It is assumed that one of the best economic solutions is to use mineral admixtures for durability of concrete [4], [5] and [6]. Numerous studies have been published about concrete durability with and without mineral admixtures. There are conflicting published data concerning the performance of concrete containing mineral admixture. For instance, Toutanji, 2004 [7] have reported that durability of concrete against freezing and thawing on the control samples (without FA and SF) is much better than the concretes with SF and FA. However, Hooton, 1993 [8] and Song 2007 [9] concluded that incorporation of Silica Fume (SF) in concrete produces higher strength and durability. Because of vary fineness and chemical features of FA according to power plants which are produced, their performances in concrete may also differ from each other. Similarly, there are conflicting published paper concerning the carbonation. Carbonation was argued that mineral admixtures was decreased in some of studies [10] and [11] and while increased other [12], [13] and [14]. Since fineness and chemical features of mineral admixtures vary according to power plants which are produced, their performances in concrete may also differ from each other.

Another way to produce impermeable concrete is to use waterproofing admixtures in concrete mixing. It is obvious that long term performance of concrete will increase with to

prevent water pass to concrete interior. Instead of forming a barrier on the positive or negative side of concrete, water proofing admixture turn the concrete itself into a water barrier. Internal concrete waterproofing systems can be water repellents or crystalline admixtures [15]. It can be observed that studies on using waterproofing admixtures in concrete mixing. study was carried out by Kumar, 2009 [16] to find the role of water proofing admixture during hydration of portland cement. Coppola, 2018 [17] evaluated the performance of an innovative carboxylic acid-based admixture to improve concrete water tightness and self-sealing ability of the cement matrix. In the present investigation, study was carried out to find the role of waterproofing admixture effect to carbonation.

## MATERIALS AND METHODS

### Materials

In the experimental study, crushed sand and crushed limestone has been used as fine and coarse aggregate. Specific gravity of crushed sand and crushed limestone is 2.67 and 2.70, and the maximum grain sizes are 4 mm and 11.2 mm. In the experiments, CEM I 42.5 R ordinary Portland cement which is suitable to TS EN 197-1 [18] standards have been used.

### Concrete production

Amount of cement in concrete was 350 kg/m<sup>3</sup> and water/cement ratio is 0.65 for concretes. The 25 L capacity mixer was used. Crushed sand and crushed limestone were used as half and half. Unit volume components of concrete have been shown in Table 1. Initially for the mixture of concrete, crushed sand, crushed limestone and cement were mixed for 1 min in order to have dry mixture. Then almost 2/3 of mixture water was added to the dry mixture. Finally, the rest of water (1/3) was put into the mixture and the process of mixing was continued for 5 min. Liquid water proofing admixture (Sika-1) was added to the batching of concrete in ratio of 0%, 1%, 2% and 3% by weight of cement. In the experiments, 4 different series were designed. Prepared concretes were put into plastic moulds whose sizes are

10x10x10 cm by shake table. After casting, the specimens were kept in mould for 1 day, and they were cured in water-pool for 28 days after de-moulding.

### Carbonation test

Accelerated carbonation tests carried out on the specimens. As shown in Fig. 1, the accelerated carbonation test was performed in accelerated carbonation apparatus. Constant relative humidity value (55%) was considered during the carbonation test. The concrete specimens were placed inside the carbonation test vessel (Fig. 1) and the lid of the vessel was tightly closed. In experiment, samples were exposed to 40% of CO<sub>2</sub> during periods of 1, 6 and 10 days. After testing period, the specimens were taken from the chamber and their compression strength was measured according to TS EN 12390-3 [19] (Turkish standard code) in a hydraulic press on three samples (100 mm cubes).



Figure 1. Carbonation test cabinet

Table 1. Materials content of concrete for per cubic meter

Mixture	Cement,	Water, l/	W a t e r	Crushed	C r u s h e d
M1	350	243	0	841	858
M2	350	239.5	3.5	841	858
M3	350	236	7.0	841	858
M4	350	232.5	10.5	841	858

The carbonation depth of the specimens was determined by the phenolphthalein method recommended by RILEM CPC18 on a vertical section of the splitted specimen, after being removed from the carbonation environment. Phenolphthalein solution is prepared as a 1% solution in 70% ethyl alcohol was sprayed onto the concrete surface which has been cleaned of dust and loose particles. Phenolphthalein is a colorless acid indicator which turns red when the pH is above a value of 9.5, that is, when the concrete is alkaline. If no coloration occurs, carbonation has taken place and the depth of the carbonated surface layer can be measured.

Each result reported is the average depth carbonation “D” measured at three points perpendicularly to three faces of the splitted concrete cube and repeated on three specimens (Fig. 2). At the same time, carbonation test procedure was applied on the non-carbonated concretes that waited in laboratory.

The concrete specimens with various water proofing admixtures were cooled down to room temperature after they had been dried in the oven at about 105 °C until constant mass. The specimens were exposed to the water from bottom face by placing on a pan. The water in the pan was maintained at about 5 mm above the base of the

specimens during this experiment. The upper areas on the sides of the specimens were coated with paraffin to achieve unidirectional flow. At certain times (25 min), the mass of the specimens was measured using a balance, then the amount of water absorbed was calculated and normalized with respect to the cross-section area of the specimens. Therefore, capillarity coefficient was obtained for each series in experimental study by Eq. (1), as follows

$$q = k\sqrt{t}$$

where,  $k$  is capillarity coefficient ( $\text{cm}^2/\text{min}$ );  $q$  is water absorption quantity in cross-section of specimens ( $\text{cm}/\text{s}0.5$ ); and  $t$  is time (min).

Specific porosity and water absorption were determined on the produced paving blocks aged 28 days according to Archimedes principle by the weight measurements of saturated specimens in air and in water, and dry weight (oven drying at  $105^\circ\text{C}$  to constant weight). Schmidt hammer test was also performed on the carbonated and non-carbonated concrete specimens. Twelve readings were carried out on different points of concrete that under 7 MPa pressure. The compressive strength was defined by hydraulic compressive machine with a rate of loading controller.

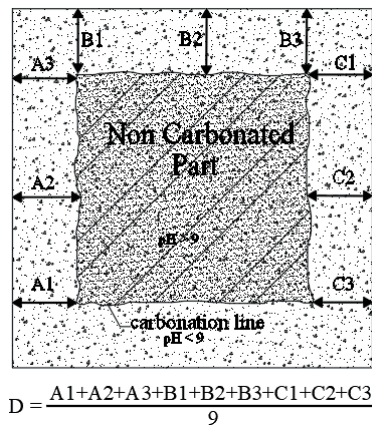


Figure 2. Schematic representation of carbonation depth measurement on concrete sample

## EXPERIMENTAL RESULTS

Figure 3 shows the carbonation depth of water proofing admixture blended concrete. Water proofing admixture which is active chemical material permeate to the interior of concrete via percolating water, catalyze silicate of concrete to generate water immiscible crystals, fill in capillary pores and tiny fissures to make concrete compact, enhance penetration and waterproofing functions. Hence, carbonation depth of concretes was decreased considerably by using of water proofing admixture. While the highest carbonation depth was measured on plain concrete, the lowest carbonation depth was in water proof admixture blended concrete for each carbonation duration. For example, at the end of 10 days carbonation, carbonation depth of concretes was reduced in ratio of 32.8%, 46.8% and 50% for water proof admixture content of 1%, 2% and 3%, respectively.

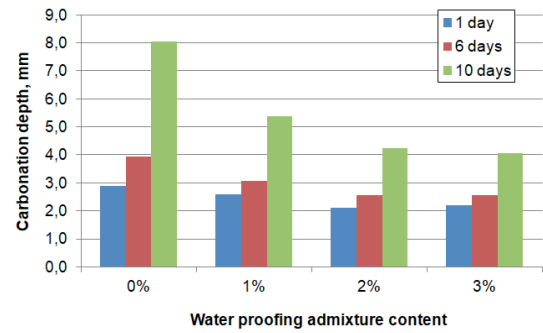


Figure 3. Carbonation depth of water proofed concretes

In general, the specific porosity (SP) of concretes decreased with increasing water proofing admixture (Fig. 4). Maximum SP was obtained at control series for carbonated and non-carbonated samples. On the other hand, it can also be noted that the SP of concretes showed a considerable decrease after carbonation depending on increase of water proofing admixture. Carbonation begins at the concrete surface and slowly penetrates deeper [20]. Accelerated carbonation decreases total porosity by 8.4% in the case of water proofing admixture content of 3%. When water proofing admixture is reduced porosity is also reduced this results in reduction of depth of carbonation by filling the pores [21].

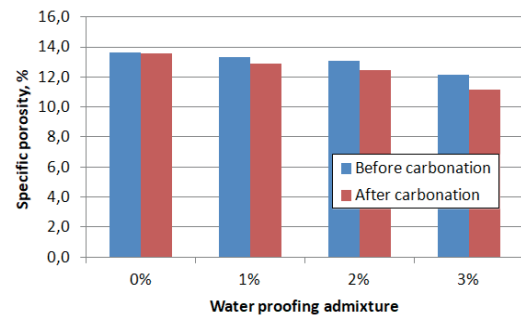


Figure 4. Specific porosity of concretes depending on carbonation

Water absorption in concretes with water proofing admixture was lower than the reference concretes for all the curing types evaluated (Fig. 5). This behavior is associated to the porosity decrease of concretes with admixture in function of the filling of pores. Water absorption of concrete was also reduced by carbonation during some periods. This decreasing effect may be caused by saturation of the pores by the diffusion of  $\text{CO}_2$  into the paste.

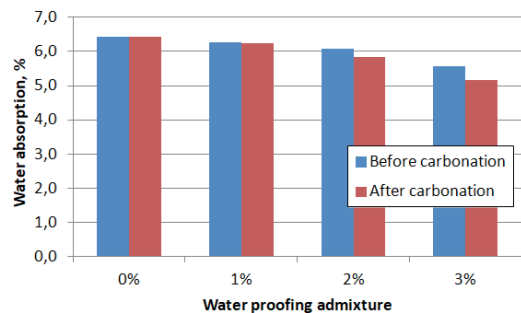


Figure 5. Water absorption of concretes depending on carbonation

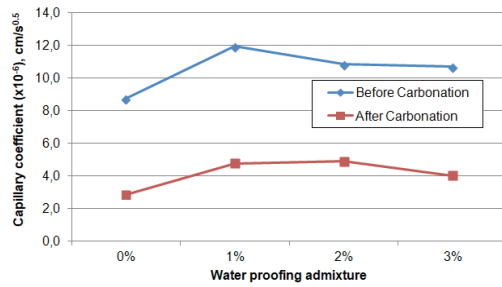


Figure 6. Capillary coefficient of concretes depending on carbonation

Capillarity coefficient of concretes was presented in Fig.6 by comparatively of before and after carbonation process. Regardless of the specific porosity of the concrete, the capillary coefficient increased with the addition of water proofing admixture. This is probably because of reduction of pore size with chemical reaction products of water proofing admixture [22]. On the other hand, carbonation process plays important role on the reduction of capillary coefficient. The diffusion of  $\text{CO}_2$  into the capillary pores of concrete resulted with filling of pores by  $\text{CaCO}_3$  products [23].

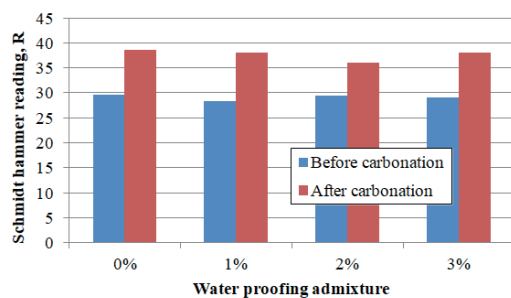


Figure 7. Schmidt hammer values on concrete versus admixture content

Surface hardness of concrete samples before and after carbonation was determined by using Schmidt hammer. As expected, surface hardness values increased after carbonation in all the concrete series. Admixture content did not effected the hardness values. It changed between 28 and 29 for non carbonated concrete while it ranged between 36-39 for carbonated concrete depending on water proofing admixture content. However, Schmidt hammer values were increased in ratio of 22.4%-30% depending on admixture content. In general, Schmidt hammer values are related with compressive strength for existing structure as non destructive method. If the open air concrete structures are evaluated by Schmidt hammer, it would be give about 30% higher results [24]. Therefore, Schmidt hammer readings will not reliable on open air concrete structures.

## CONCLUSION

In this study, rapid carbonation test was performed on internal isolated concrete by using of water proof admixture. Following results can be drawn:

- Carbonation depth of concretes was decreased

considerably by using of water proofing admixture. While the highest carbonation depth was measured on plain concrete, the lowest carbonation depth was in water proof admixture blended concrete for each carbonation duration.

- Carbonation depth of concretes was reduced in ratio of 32.8%, 46.8% and 50% for water proof admixture content of 1%, 2% and 3%, respectively.
- Accelerated carbonation decreases total porosity by 8.4% in the case of water proofing admixture content of 3%.
- Water absorption of concrete was also reduced by carbonation during some periods. This decreasing effect may be caused by saturation of the pores by the diffusion of  $\text{CO}_2$  into the paste.
- The capillary coefficient increased with the addition of water proofing. However, carbonation process plays important role on the reduction of capillary coefficient.
- After carbonation, Schmidt hammer values were increased in ratio of 22.4%-30% depending on admixture content.

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