Effect of Vacuum Dewatering Application on the Chemical Corrosion and Mechanical Properties of Concrete

Emre Sancaık
Department of Construction Education, Faculty of Technical Education, Suleyman Demirel University, Bati Kampus-Çümür, Isparta, 32260, Turkey

Abstract: In this study, reference concrete slab, which its height is 15 cm and size is 200×600 cm, a concrete slab to be exposed to vacuum for 35 min (full vacuumed) with size of 300×400 cm and a concrete slab vacuum-processed for 18 min (semi-vacuumed) with size of 300×400 cm were produced. Compressive strength tests were performed on core specimens taken from these three concrete slabs on 7th, 28th and 1080th (36th month) days and tensile strength test was performed on 1080th (36th month) day. Carbonation depth test was performed on the core specimens produced was investigated. Carbonation depth and Cl− ion determination were tested on powder samples from these core specimen. Test results have shown that vacuum dewatering to concrete increased its resistance to long term chemical corrosion and also improved its mechanical properties.

Keywords: Concrete, vacuum dewatering, compressive strength, carbonation depth, chloride penetration

INTRODUCTION

The hardening process (hydration reaction) is complex and continues over many months if not years, depending on the amount of water in the mix. There must be excess water for workability and a pore network therefore develops as it dries out. It is this pore network and the solutions it contains that are critical to the durability of the concrete (Broomfield, 1994).

Stiffening, setting and hardening are caused by the formation of a microstructure of hydration products of varying rigidity which fills the water-filled interstitial spaces between the solid particles of the cement paste, mortar or concrete. Finally, due to growing crystals, the gap between the cement particles is increasingly bridged. During further hydration, the hardening steadily increases, but with decreasing speed. The density of the microstructure rises and the pores fill. the filling of pores causes strength gain. In principle, the strength continues to rise slowly as long as water is available for continued hydration, but concrete is usually allowed to dry out after a few weeks and this causes strength growth to stop (Mehta and Monteiro, 2006; Popovic, 1992).

During consolidation, the densification and subsequent volume shrinkage of the fresh concrete forces entrapped air voids and excess water out of the cementitious matrix. The water tends to migrate upward due to a density differential and become bleed water. Also, that harmful substances introduce these places in the course of time affects negatively strength of the concrete. Although capillary pores are filled with water at early ages, water will be depleted by hydrating cement or leaks outside of the pore with time. General experience indicates that a concrete mixture with a w/c of 0.45 or less may give a relatively high resistance against chloride penetration, e.g., a low chloride diffusivity (Gery, 2003). Accordingly, ACI Building Code 318 specifies a maximum 0.4 water/cement ratio for reinforced normal-weight concrete exposed to deicing chemicals and seawater (Mehta and Monteiro, 2006).
Rate of carbonation generally increases with an increase of w/b. The existence of microcracks in the transition zone at the interface with steel and coarse aggregate is the primary reason that concrete is more permeable than the corresponding hydrated cement paste or mortar (Dhir et al., 1989; Güneyisi et al., 2005). Furthermore, the number of pores may increase in case of very low w/c ratios because placement and compression of the concrete become more difficult. It is certain that carbonation rate increases as permeability of concrete increases (Neville and Brooks, 1990).

Vacuum dewatering may be applied on top surface or side surfaces of the concrete. More water can be drained if vacuum is applied on top surface. Its rate for acquiring strength will increase and the required curing time will decrease. This application gives positive results on the concretes having large surface area and not too high in thickness (Neville, 1995).

Vacuum dewatering lowers the water content of a freshly placed concrete slab by 15-25% over a depth of 150 to 300 mm. Since fresh concrete contains a continuous system of water-filled channels, the application of a vacuum to the surface of the concrete results in a large amount of water being extracted from a certain depth of the concrete. In other words, what might be termed water of workability is removed when no longer needed. Vacuum treatment increases the density, strength and frost resistance of the slab and decreases the slab’s absorption, abrasion and shrinkage (Neville, 1995; Pickard, 1981).

Ozdemir (1999) examined reference and vacuumed concretes as full-size and half-size in his study by using CEM II A-P type cement and aggregate with maximum 32 mm diameter. In the study, cylindrical samples with 300 mm height and 150 mm diameter were employed. Compressive strength test were performed on 1, 3, 7, 14 and 28th days on full-size samples and bottom, intermediate and top regions of half-size samples.

In this study, it was aimed to determine the effect of vacuum dewatering on strength and durability of concrete in field. For this purpose, three different concrete slabs, reference (without vacuum dewatering), full-vacuum (35 min) and semi-vacuum (18 min) were produced. Compressive strength tests were performed on core specimens taken from these three concrete slabs on 7th, 28th and 1080th (36th month) days and tensile strength test was performed on 1080th (36th month) day. The effects of vacuum period and the vacuum, which was applied, on compressive and tensile strengths along the thickness of the concrete, carbonation depth and chloride content were examined on the samples.

MATERIALS AND METHODS

Ready-mixed concrete was used in this experimental study. Concrete with nominal compressive strength of 20 MPa (according to ASTM C 94, 2000) was cast into the molds with sizes of 3×4 m for full-vacuum and semi-vacuum and 2×6 m for reference with 15 cm thickness. The status of concrete area is shown in Fig. 1.

Mixture Proportions

The aggregate used in concrete manufacturing is limestone-base crushed stone aggregate. Table 1 shows the mix proportions of the concrete used in the study. According to the analyses, its chloride and SO₃ contents are 0.0053 and 0.04%, respectively.

Ordinary Portland Cement (OPC) with specific gravity of 3110 kg m⁻³ and fineness of 294 m² kg⁻¹ was used. The 7 and 28 day mortar cube strengths were 43.9 and 56.1 MPa, respectively, initial setting time was 186 min and final setting time was 4 h and 37 min. The oxide compositions of OPC are given in Table 2.

Chemical characteristics of mixing water are shown in Table 3. The chemical additive is complied with ASTM C 494 (1999) type A and it increases viscosity.
Table 1: Mix proportions of the concrete (kg m⁻³)

<table>
<thead>
<tr>
<th>Aggregate (kg)</th>
<th>Cement (kg)</th>
<th>Water (l)</th>
<th>Plasticizer admixture (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-3 mm</td>
<td>360</td>
<td>335</td>
<td>425</td>
</tr>
<tr>
<td>8-16 mm</td>
<td>630</td>
<td></td>
<td>191</td>
</tr>
<tr>
<td>16-25 mm</td>
<td></td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

Table 2: Chemical composition of cement

<table>
<thead>
<tr>
<th>Chemical composition</th>
<th>CaO</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>MgO</th>
<th>SO₃</th>
<th>K₂O</th>
<th>Na₂O</th>
<th>Li</th>
<th>IR</th>
<th>S.CaO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>63.07</td>
<td>20.31</td>
<td>5.64</td>
<td>3.27</td>
<td>1.4</td>
<td>2.88</td>
<td>0.9</td>
<td>0.24</td>
<td>1.12</td>
<td>0.49</td>
<td>0.68</td>
</tr>
</tbody>
</table>

Table 3: Chemical characteristics of mixing water

<table>
<thead>
<tr>
<th>pH</th>
<th>Total hardness (Ft)</th>
<th>Ca²⁺</th>
<th>Mg²⁺</th>
<th>Cl⁻</th>
<th>SO₄</th>
<th>Na₂O</th>
<th>K₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.14</td>
<td>47.86</td>
<td>74.49</td>
<td>71.09</td>
<td>92.30</td>
<td>374.88</td>
<td>258.50</td>
<td>122.50</td>
</tr>
</tbody>
</table>

Fig. 1: Area drilled core samples for experimental investigations

Procedure

Vacuum dewatering was started after the concrete had been cast and placed and the surface had been leveled by screed vibrator. Vacuum was applied for 35 min for full-vacuum concrete (FVC) and 18 min for semi-vacuum concrete (SVC). Vacuum dewatering was not applied on reference concrete (RC) for making comparison. After the reference concrete (RC) had been cast and the surface had been leveled by screed vibrator and vacuum-dewatering process on FVC and SVC’s had been completed, finishing on surfaces was done by using finishing machinery.

Concrete was exposed to outdoor conditions having daily temperature average was +17°C for daytime and +3°C for nights for 5 days after it was cast. At the end of this period, core specimens with 75 mm diameter were taken at 10 cm intervals according to ASTM C 42 (1999) to be tested on 7 and 28th days and to be cured in an environment with 95% relative humidity.

Compressive strength values were determined on 7 and 28th days on the samples cured in water and 36th month on samples taken from the areas left to outside and also cured in water according to ASTM C 39 (2001) Loading rate was 1.30 kN sec⁻¹.

Indirect tensile strengths were obtained by performing splitting test carried out according to ASTM C 496 (1994, 1996) Loading rate was 0.5 kN sec⁻¹.

Carbonation depth test was performed on the samples exposed to outdoor conditions for 36 months with the size of 75x150 mm by measuring color change by spraying phenolphthalein 1% solution (dissolved in alcohol) to the surfaces of the pieces formed as a result of tensile strength test in splitting with 2 cm intervals and 0.01 precious with the help of a compass. The base indicator
sprayed on the surface of the concrete converts the color of the non-carbonated concrete with pH of 11-12.5 into dark pink. It does not cause a color change in the concrete, which its pH value reduced to 8-9 as a result of carbonation.

To determine the effect of vacuum application on chloride content, chloride determination test was done by taking dust samples from the depths of 0-10, 10-20 and 20-35 mm in concrete surface left to outdoor for 36 months for simulating real conditions according to ASTM C 1218 M-99 (1999).

RESULTS AND DISCUSSION

Densities were measured in fresh concrete as 2644 kg m\(^{-3}\) for FVC, 2591 kg m\(^{-3}\) for SVC and 2546 kg m\(^{-3}\) for RC. Considering densities obtained in fresh concrete and Table 4, it is seen that density of FVC is higher significantly and those of SVC and RC are almost equal.

**Compressive Strength**

Average compressive strength values of the samples stocked in curing pool of the laboratory are seen on Table 5 and graphics obtained by the curves are shown in Fig. 2.

As shown in Table 5, FVC samples show higher compressive strength. Especially, their strength for 36 month is superior against SVC samples significantly. In comparison with RC, an increase of 44% occurred. According to the same samples, a difference of −19% is seen between compressive strength values obtained in 28 days and 36-month-curing period. The same difference is seen as 56% with respect to FVC samples. These results are also consistent with literature (Malinowski and Wenander, 1975; Wenander, 1975; Wenander et al., 1975; Pickard, 1981; Şimşek, 2005).

<table>
<thead>
<tr>
<th>Concrete types</th>
<th>Core size (mm)</th>
<th>Water absorption capacity (%)</th>
<th>Unit weight (kg m(^{-3}))</th>
<th>Pore ratio</th>
<th>Dry density</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC</td>
<td>75-150</td>
<td>4.760</td>
<td>2478</td>
<td>10.310</td>
<td>2.555</td>
</tr>
<tr>
<td>SVC</td>
<td>75-150</td>
<td>3.045</td>
<td>2491</td>
<td>6.773</td>
<td>2.576</td>
</tr>
<tr>
<td>FVC</td>
<td>75-150</td>
<td>2.608</td>
<td>2598</td>
<td>5.862</td>
<td>2.627</td>
</tr>
</tbody>
</table>

Table 4: Some physical properties of the hardened concrete

Similar results were reported by previous studies (Pickard, 1981; Şimşek, 2005)

Table 5: Compressive strengths of the concrete core specimens

<table>
<thead>
<tr>
<th>Concrete type</th>
<th>7 day</th>
<th>28 day</th>
<th>36 month</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC</td>
<td>16.88</td>
<td>22.07</td>
<td>26.21</td>
</tr>
<tr>
<td>SVC</td>
<td>18.95</td>
<td>22.13</td>
<td>27.98</td>
</tr>
<tr>
<td>FVC</td>
<td>19.63</td>
<td>24.26</td>
<td>37.77</td>
</tr>
</tbody>
</table>

Fig. 2: Average compressive strengths of the samples stored in laboratory
Fig. 3: Compressive strength and density graphics for the samples left to be cured outside at the end of 36th month

Fig. 4: Indirect tensile strength of the concrete core specimens after 36-month cured

Compressive strength and density graphics for the samples left to be cured outside at the end of 36th month were shown in Fig. 3.

**Tensile Strength**

In comparison of FVC and SVC samples with the RC, increases of 9 and 10% are seen, respectively. Also, the increases in the samples cured outside are 12 and 17%, respectively in the same way (Fig. 4).

It can be observed from Fig. 4 that FVC samples developed higher indirect tensile strength than that of SVC and RC in both curing condition.

**Carbonation Depth**

Data regarding to carbonation depth and statistical data are shown in Table 6. The results obtained from FVC and SVC samples are better than that of RC samples. But, FVC samples are exhibited best results.
Table 6: Carbonation depth of concrete core specimens

<table>
<thead>
<tr>
<th>Process</th>
<th>Sample</th>
<th>Mean±SD*</th>
<th>95% confidence limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVC</td>
<td>99</td>
<td>0.506±0.246</td>
<td>0.2699 0.7522</td>
</tr>
<tr>
<td>SVC</td>
<td>101</td>
<td>0.791±0.206</td>
<td>0.7731 1.1851</td>
</tr>
<tr>
<td>RC</td>
<td>90</td>
<td>4.205±0.725</td>
<td>3.9783 4.4284</td>
</tr>
</tbody>
</table>

*SD: Standard Deviation

Table 7: ANOVA table for carbonation depth

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Sum of squares</th>
<th>df*</th>
<th>Mean of squares</th>
<th>F-ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between groups</td>
<td>753.427</td>
<td>2</td>
<td>376.714</td>
<td>360.054</td>
<td>0.000**</td>
</tr>
<tr>
<td>Within groups</td>
<td>380.324</td>
<td>287</td>
<td>1.255</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>1133.751</td>
<td>289</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*Degree of freedom; **p<0.05

Table 8: The multi-comparison analysis of means using the SNK of carbonation depth

<table>
<thead>
<tr>
<th>Concrete types</th>
<th>N</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVC</td>
<td>99</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SVC</td>
<td>101</td>
<td>-</td>
<td>0.9791</td>
<td>-</td>
</tr>
<tr>
<td>RC</td>
<td>90</td>
<td>-</td>
<td>-</td>
<td>4.2033</td>
</tr>
<tr>
<td>p</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 5: Relation between chloride content and depth on the concrete types

Variance solutions in which the effect of vacuum dewatering on carbonation depth was studied are given in Table 7.

As a result of variance analysis, it was found that a meaningful variance at a level of α = 0.05 between concrete types exists. The Student-Newman-Keuls test was used to compare all pairs of means following one-way ANOVA. As shown in Table 8, in Student-Newman-Keuls (SNK) multi-comparison tests, which were carried out for determining that which groups were varied, a meaningful variance at a level of α = 0.05 between all concrete samples exists.

According to this, carbonation occurred less 50% in FVC concrete samples compared with SVC samples. However, the actual improvement was seen as 88% less progress compared with RC.

Chloride Content

The obtained chloride content profile is given in Fig. 5. Regarding to chloride contents, the best result was obtained in FVC samples at a depth of 20-35 mm from the concrete surface. Any significant difference was not seen between concrete types at 10-20 mm depth interval.
CONCLUSIONS

In this study in which the effects of vacuum dewatering to concrete on strength and durability characteristics of the concrete were studied, the following conclusions were made:

- A tendency to increase in density exists depending on time of vacuum dewatering. Accordingly, more compact concretes with fewer pores may be obtained by especially full vacuum dewatering process.
- Vacuum dewatering process for 35 min provided 55% increase in compressive strength at the end of 36-month water cure period. In case of the concrete exposed to outdoor conditions, the increase in compressive strength was 23%.
- Considering comparison of tensile strength values, it was seen that increases of 9-17% were obtained depending on time of vacuum dewatering process.
- Carbonation depth and chloride content values, which were examined in this study under durability characteristics scope, are similar to strength values. It may be said that vacuum dewatering application may contribute to both characteristics of the concrete positively.

As a result, vacuum dewatering application makes possible to remove excess mixing water from the concrete and thus, concretes, which have desired durability and strength characteristics and have longer life, may be produced.

REFERENCES