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UTICAJ RAZLIČITIH USLOVA NEGE NA SVOJSTVA BETONA NA BAZI CEMENTA I VISOKOG SADRŽAJA LETEĆEG PEPELA

Rezime:

Istraživanje je imalo za cilj da se ispita uticaj različitih uslova nege na mehanička svojstva betona spravljenog sa visokim sadržajem letećeg pepela (HVFAC) u poređenju sa klasičnim betonom na bazi cementa (OPC). Primenjena su tri različita režima nege betona: nega u vodi, nega na vazduhu u laboratoriji i nega u standardnim laboratorijskim uslovima nakon premazivanja uzoraka sredstvom na bazi poliolefinske emulzije. Cilj je bio da se utvrdi uticaj ovakvih režima nege na razvoj čvrstoće pri pritisku i modula elastičnosti tokom vremena, kao i čvrstoća pri zatezanju (athezija) putem Pull-off metode i vodonepropustljivost betona. Uzorci negovani u vodi su imali najbolja mehanička svojstva, dok primena sredstva za negu nije imala značajniji uticaj na predmetna svojstva u poređenju sa uzorcima negovanim na vazduhu.

Ključne reči: OPC beton, HVFAC beton, uslovi nege, mehanička svojstva

THE INFLUENCE OF DIFFERENT CURING CONDITIONS ON CEMENT AND HIGH VOLUME FLY ASH CONCRETE PROPERTIES

Summary:

The research was conducted in order to evaluate the influence of different curing conditions on mechanical properties of high volume fly ash concrete (HVFAC) in comparison with the ordinary Portland cement concrete (OPC). Three different curing regimes were evaluated: standard water curing, standard laboratory air curing and curing in standard laboratory conditions using curing compound based on the polyolefin emulsion. The main objectives were to evaluate the influence of these curing regimes on the compressive strength and modulus of elasticity development over time, as well as the pull-off adhesion strength and water permeability of concrete. The samples cured in water had the highest mechanical properties, whereas the use of the curing compound did not significantly influence these properties compared with the samples cured in standard air conditions.

Key words: OPC concrete, HVFAC concrete, curing conditions, mechanical properties

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1. INTRODUCTION

In the modern age, a lot of human action is directed at the preservation of the environment. The construction industry is no exception to this trend. Relatively big effort is made in the identification of the negative effects that the use of different construction materials and processes have on the environment. The main focus of current research done in the material science field is oriented towards finding new alternatives to conventional construction materials by using waste and recycled materials. This is the reason why conventional cement concrete is being modified by the use of supplementary cementitious materials (mainly fly ash and slag) and recycled materials (mainly recycled concrete aggregate).

Since the 1930s, fly ash has been used as a partial replacement of clinker in Portland cement, or as an addition in concrete, mostly to limit the amount of early heat generation. The important benefit from the utilization of fly ash as a cement replacement is the reduction of carbon dioxide (CO_2) emissions from the Portland cement production. Approximately one ton of CO_2 is released for each ton of the Portland cement clinker [1]. A positive environmental effect of using fly ash in concrete is also obtained through the decrease of the amount of fly ash deposited in landfills and through the use of the waste material instead of natural resources for concrete production. It is for these reasons that today there is a general trend of replacing higher amounts of Portland cement in concrete.

In 1985, the Advanced Concrete Technology Group at CANMENT, Canada, started a project to develop structural high volume fly ash concrete (HVFAC) [2], [3]. HVFAC is usually defined as the concrete with more than 50% of fly ash in the total amount of cementitious materials. A large amount of research has been done regarding the physical and mechanical properties of HVFAC and in addition, work was also done on the evaluation of its material properties through the standards for cement concrete [4]. On the other hand, only a limited amount of research has been done so far regarding HVFAC structural properties.

Furthermore, the connection between HVFAC material properties testing and conditions in practical use must be evaluated for its safe application. One of the most important factors ensuring good performance of concrete is adequate curing. The mechanism of cement hydration and the influence of different curing types on physical and mechanical properties of conventional cement concrete are well known. However, the influence of different curing conditions on HVFAC has not been fully understood.

Pozzolanic material is usually defined as the material which will, in the presence of moisture, chemically react with calcium hydroxide $Ca(OH)_2$ at ordinary temperatures to form compounds possessing cementitious properties. At normal temperatures, the pozzolanic reaction is slower than the hydration of cement, so longer curing is needed for the full potential of fly ash to be reached [5]. It is generally recommended that HVFAC is moist cured for at least 7 days [6]. Adequate duration of moist curing helps the successful development of hydration and pozzolanic reaction, and increased curing temperatures can improve early age strengths [7]. However, results from the literature show that increased curing temperatures or steam curing, although helping the early age strength, can have adverse effect on the 28-day compressive strengths [8], [9]. In order to resolve the discrepancy of current results from literature, further studies are needed to determine the influence of different curing regimes on HVFAC properties.

This paper presents the research conducted in order to evaluate the influence of different curing conditions on HVFAC mechanical properties in comparison with the conventional cement concrete. Two types of concrete were made and tested: HVFAC and ordinary Portland cement concrete (OPC) designed to have the same workability and 28-day compressive strength for samples cured in water. Three curing conditions were chosen for the analysis: standard water curing (W), standard laboratory air curing (L) and curing in standard laboratory conditions using curing compound based on the polyolefin emulsion to coat the samples (C). The main objectives were to evaluate the influence of these curing regimes on the compressive strength and modulus of elasticity development over time as well as the pull-off adhesion strength and water permeability of both OPC and HVFAC samples.

2. MATERIALS AND CURING PROCEDURE

Both types of concrete were made with the same component materials (aggregate, cement and water) and the HVFAC mixture was designed to have 50% of fly ash in total cementitious materials mass.

All concrete mixtures were made using tap water and river aggregate obtained from "Elita-Cop" separated into three fractions (0/4 mm, 4/8 mm and 8/16 mm) using standard sieving method. Prior to sieving and mixing, the aggregate was dried in the oven until the constant mass was reached. The sieve analysis of used aggregate is presented in Figure 1. The density of used aggregate was 2673 kg/m^3, 2578 kg/m^3 and 2602 kg/m^3 for fractions 0/4 mm, 4/8 mm and 8/16 mm, respectively.

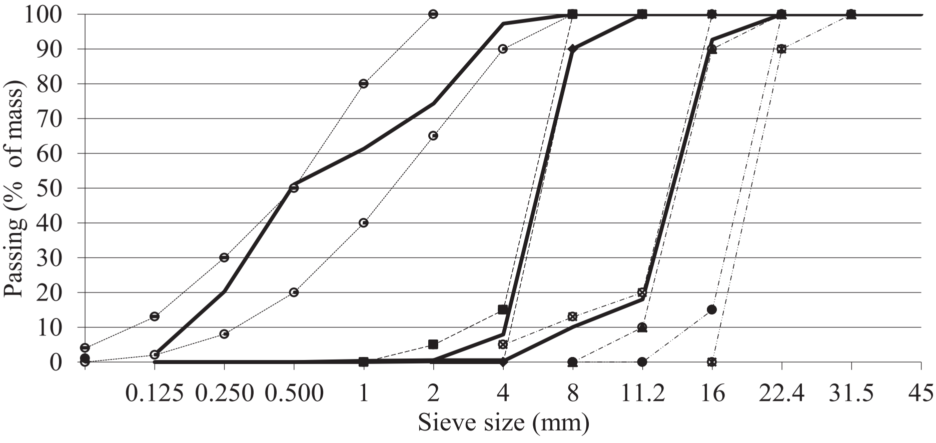

Figure 1 – Sieve analysis of aggregate

Portland composite cement CEM II (class PC 20M (S-L) 42.5R) produced by "Lafarge", Beočin was used for preparation of both concrete types. This type of cement contains additions (ground slag and limestone) up to 20% of the total mass, and there is no fly ash in the composition of cement. The specific gravity of cement was 3040 kg/m^3.

Fly ash was obtained from the "Nikola Tesla B" power plant in Obrenovac, Serbia. The average specific gravity of fly ash determined using the pycnometer method was 2075 kg/m^3.

The particle size distribution and chemical composition of fly ash are presented in Figure 2 and Table 1. In the last row of Table 1, the maximum allowed values of certain substances according to EN 450-1: 2012 [10] are presented. As it can be seen, the total quantity of SiO_2 + Al_2O_3 + Fe_2O_3 is higher than 70%. Figure 2 shows that the quantity of particles smaller than 45µm is higher than 12%. It can be concluded that the fly ash used in this research met the requirements of EN 450-1:2012 for the use of fly ash in concrete, and according to the ASTM-C618 [11] provisions could be classified as class F fly ash.

Table 1 – Chemical composition of fly ash (% of mass)

SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	P_2O_6	SO_3	MnO	LOI
64.14	19.22	4.35	0.16	8.32	0.01	0.36	0.66	0.17	0.86	0.03	4.68
-	-	-	-	-	max 4	max 5	-	max 5	max 3	-	max 6

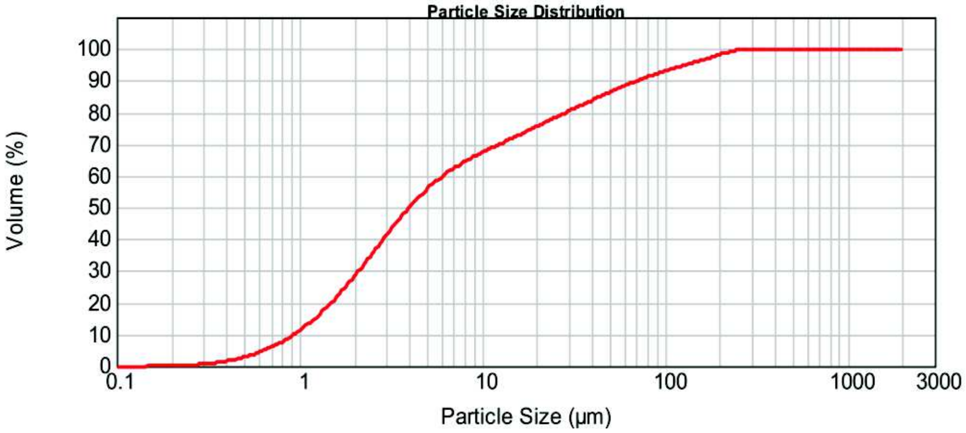

Figure 2 – Sieve analysis of fly ash

The concrete mix design was based on the absolute volume method. The mixing procedure began with mixing sand and coarse aggregate in a mixing pan for one min, then adding cement and fly ash and mixing for another minute. Water was added during the next 30 s, and the mixing continued for approximately 2.5 min. The mixture was used to cast 10 cm concrete cubes for compressive strength testing, 15·30 cm cylinders for testing the modulus of elasticity and 15 cm cubes for testing pull-off strength and water permeability. All samples were demoulded after 24 h. The values of the various properties reported in this paper represent the mean value of three measurements.

After mixing, all specimens were cast in steel moulds and the concrete was compacted using a vibrating table. The first group of specimens was demoulded after 24h and placed in water thank (W-samples). The second group (L-samples) was cured in standard laboratory air conditions (T=20±2°C, RH=60±5°C). Curing of the third group of samples was done using the curing compound based on the polyolefin emulsion (C-samples). Namely, immediately after casting into moulds, the uncovered concrete surface of the C-specimens was sprayed with the liquid curing compound for preventing water loss in concrete. After the demoulding, the same spraying procedure was applied to all remaining surfaces.

As the target values, workability class S2 and compressive strength class C25/30 (MB30) were adopted for both OPC and HVFAC mixtures. All concrete samples which were made from either one of the two mixtures were additionally divided into three categories according to the applied curing procedure: OPC-W, OPC-L, OPC-C, HVFAC-W, HVFAC-L and HVFAC-C. The concrete mix design of OPC and HVFAC mixtures are presented in Table 2.

Table 2 – Concrete mix design

Mixture	*W/CM* [-]*	*Water [kg/m^3]*	*Aggregate [kg/m^3]*			*Cement [kg/m^3]*	*Fly ash [kg/m^3]*
			(0/4 mm)	*(4/8 mm)*	*(8/16 mm)*		
OPC	*0.614*	*175*	*835*	*557*	*464*	*285*	*0*
HVFAC	*0.488*	*195*	*838*	*503*	*335*	*200*	*200*

* *Water-to-cementitious materials ratio*

3. RESULTS AND DISCUSION

3.1. WORKABILITY AND CONCRETE DENSITY

Concrete workability was tested using the Abrams cone method according to EN 12350-2: 2010 standard. The average value of measured slump values was 7.0 cm for the OPC mixture, and 9.6 cm for the HVFAC mixture. The obtained values for the OPC and HVFAC mixtures corresponded to different workability classes, S2 and S3 respectively. From the engineering point of view it can be considered that the workability of these two types of concrete was not significantly different.

Concrete bulk density was tested according to EN 12350-2: 2010 standard. The average density for the OPC mixture was 2353 kg/m^3, and for the HVFAC 2260 kg/m^3. This reduction in density occurred due to a significantly lower density of fly ash compared with the cement and the lower amount of aggregate that was used in the HVFAC mixture.

3.2. COMPRESSIVE STRENGTH

Compressive strength was determined at the ages of 1, 3, 7, 28 and 114 days. The test was conducted in accordance with EN 12390-1:2010 standard. Figure 3 shows the development of compressive strength of both OPC and HVFAC mixtures cured at different regimes. At the age of 28 days, the samples cured in water had compressive strength of 38.7 MPa and 40.8 MPa for the OPC and HVFAC mixtures, respectively. Both of these values corresponded to the designed concrete class C25/30.

As expected, OPC samples stored in water had the highest compressive strength during all 114 days of testing. Also, it can be seen that the application of curing compound based on the polyolefin emulsion did not result in the preservation of the concrete compressive strength compared with samples cured in water. Moreover, the L-samples and C-samples had lower 28-day compressive strength compared with the water cured samples, for 20% and 15%, respectively. The decrease was even more pronounced at the age of 114 days: 39% and 30%

for the L-samples and C-samples, respectively. The use of the curing compound did not significantly influence the compressive strength compared with the samples cured in air (L-samples).

HVFAC samples cured in water had the highest 28-day compressive strength, similar like in the case of the OPC samples. The L-samples and C-samples had lower 28-day compressive strength compared with the water cured samples, for 23% and 29%, respectively. These differences were also higher at the age of 114 days: 34% and 36% lower compressive strength for the L-samples and C-samples compared with the W-samples, respectively.

The influence of different curing conditions on the compressive strength analysed in this study was similar for both OPC and HVFAC mixtures. At the age of 28 days the difference between the decrease of compressive strength between the W-samples and L-samples was up to 5% for both OPC and HVFAC mixtures. This difference was even more pronounced for C-samples that had up to 15% higher decrease in strength for HVFAC mixtures compared with the OPC ones.

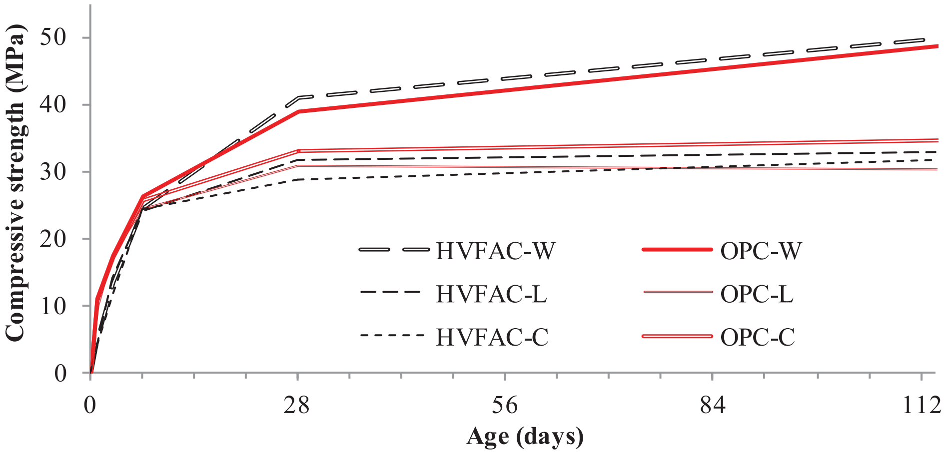

Figure 3 – Compressive strength development of differently cured OPC and HVFAC mixtures

The early age compressive strengths (before 7 days) of all OPC mixtures were higher compared with the HVFAC mixtures cured in the same way. This can be explained with the fact that the pozzolanic reaction needs time and takes place after the beginning of hydration, approximately at the age of 7–14 days or later [12], [13]. It can also be noticed that the influence of different curing conditions was less pronounced at early ages than in later ages, for both concrete types and especially for the OPC mixtures. This can be a consequence of the fact that all samples were stored in moulds for the first 24h and had enough water for early age strength development.

The compressive strength development over time was similar for corresponding OPC and HVFAC mixtures, as can be seen in Figure 3. This property of the selected OPC and HVFAC mixtures cannot be simply compared due to the different mix designs. However, it was expected that after 28 days the strength increase of OPC mixture should be lower than the HVFAC mixture; but, at that age a significant increase of strength was noticed for both OPC and HVFAC mixtures cured in water. A possible explanation can be found in the use of blended cement that has slag as a pozzolanic material. In samples that had enough water (W-samples) a significant strength increase can be explained with the pozzolanic reaction that has developed in both HVFAC and OPC concretes. The extent of the pozzolanic reaction in HVFAC depends on the available $Ca(OH)_2$ and water content. Therefore, a lower strength gain of HVFAC mixture can be explained with relatively high fly ash amount and limited Portland cement amount.

It can generally be concluded that the influence of different curing conditions on the compressive strength was more pronounced in HVFAC mixtures compared with the OPC ones. For more specific conclusions, additional research is needed.

3.3. MODULUS OF ELASTICITY

The modulus of elasticity was tested at 3, 7 and 28 days. The test was conducted in accordance with SRPS U.M1.025:1983 standard. Figure 4 shows the effect of different curing conditions on the modulus of elasticity. Similar like in the case of compressive strength, the W-samples had the highest values of the modulus of elasticity at the age of 28 days.

For the OPC mixtures, the L-samples and C-samples had lower 7-day modulus of elasticity compared with the W-samples, for 16% and 11%, respectively. These differences were slightly higher at the age of 28 days: 17% and 16% lower modulus of elasticity for the L-samples and C-samples compared with the W-samples was obtained, respectively.

This difference was similar for HVFAC L-samples and lower for the C-samples. The L-samples and C-samples had lower 7-day modulus of elasticity compared with the water cured samples, for 15% and 2%, respectively. At the age of 28 days, these differences were also slightly higher: 16% and 6% lower modulus of elasticity for the L-samples and C-samples compared with the W-samples were obtained, respectively.

HVFAC had slower increase of modulus of elasticity in the first seven days compared with OPC samples. After 7 days, the increase was more pronounced for HVFAC, especially for the L-samples and C-samples.

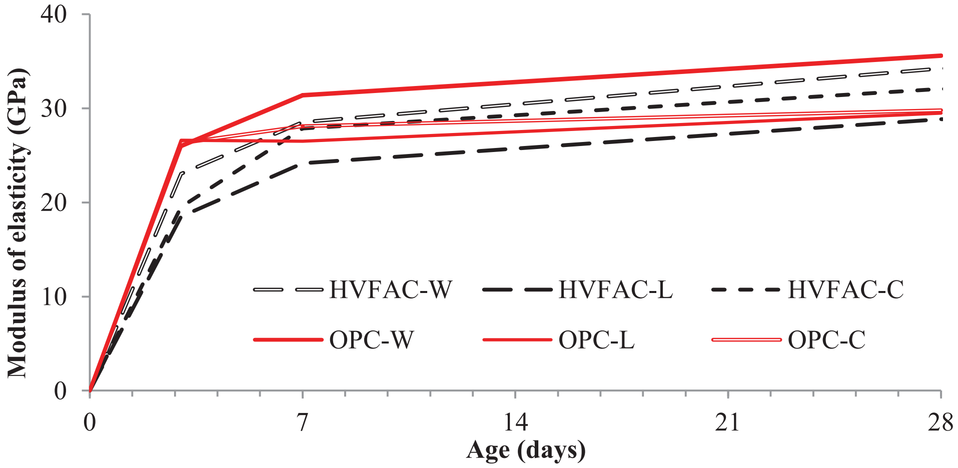

Figure 4 –Modulus of elasticity development of differently cured OPC and HVFAC mixtures

3.4. PULL-OFF TEST

For the purpose of defining the influence of different curing conditions on the concrete surface quality, the pull-off adhesion test was performed. The axial tensile force was applied until the fracture, using metal discs (50 mm in diameter and 30 mm thick), glued with an epoxy adhesive to the concrete surface. Testing was conducted in accordance with EN 1542:2010 standard, at the age of 28 days. The preparation of the samples consisted of drilling the 50 mm notch with a depth of 15±5 mm, and then cleaning the concrete surface before the metal disc gluing. Measured pull-off tensile strength values are given in Figure 5.

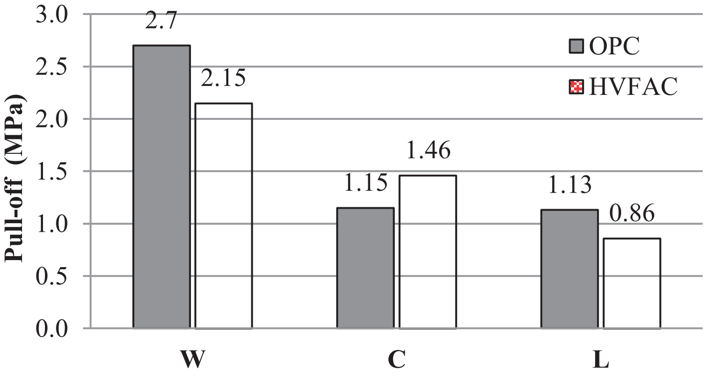

Figure 5 – Pull-off strength of OPC and HVFAC samples

It can be seen that for both types of concrete, the water-cured samples had significantly higher tensile strength compared with the L and C-samples. The tensile strength of OPC samples was 20% higher compared with the HVFAC samples even though the 28-day compressive strength was 5% lower for the OPC mixture.

Samples that were not cured in water had tensile strength lower than 1.5 MPa. No significant difference between the L and C-samples was noticed for both OPC and HVFAC mixtures.

3.5. WATER PERMEABILITY TEST

The testing of concrete water permeability was performed according to EN 12390-8: 2010 standard. Tested samples were exposed to water at a pressure of 500 kPa for 72 hours in the laboratory conditions (T=20±2°C and RH=60±5%). After being exposed to water pressure, the samples were broken and the maximum water penetration depth was measured. The obtained results are shown in Figure 6.

According to the presented results, it can be concluded that, in this particular case, the curing conditions had higher impact on the concrete water permeability than the used concrete type. HVFAC samples cured in water had lower water penetration than the OPC samples cured in the same way. According to SRPS U.M1.206:2013 standard, the OPC-W mixture corresponded to the waterproof class V-I, and the HVFAC-W to the waterproof class V-II. In the case of concrete specimens cured using the other two regimes, considerably higher water penetration depths were measured. Since the water penetration depths ranged from 9.2 cm to

13.4 cm, these concrete types cannot be classified as water-resistant concrete. The application of different curing conditions had a significant influence on the water permeability of both OPC and HVFAC mixtures.

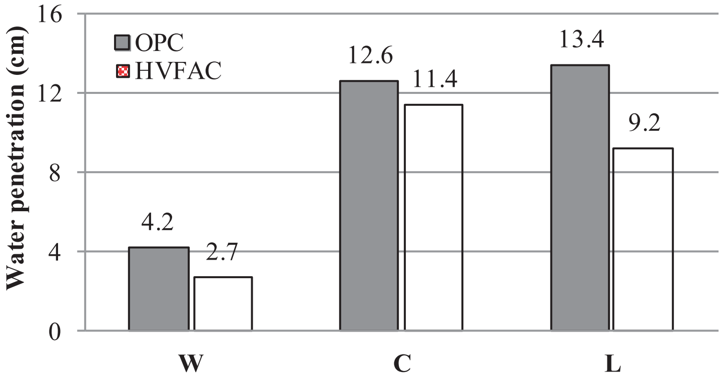

Figure 6 – Maximum depth of water penetration

4. CONCLUSION

In order to support the implementation and promotion of sustainable development and the importance of concrete curing conditions, different tests were conducted on the OPC and HVFAC mixtures. The main objectives were to evaluate the influence of three different curing regimes on the compressive strength and modulus of elasticity development over time as well as the pull-off adhesion strength and water permeability of both concrete types. Based on the presented results, the following conclusions can be made:

- Concrete samples cured in water had the highest compressive strength during all 114 days of testing and they were higher for up to 39% and 36% compared with other curing regimes for OPC and HVFAC, respectively.
- Compared with the water-cured samples, the modulus of elasticity was lower for L-samples and C-samples for both OPC and HVFAC mixture for up to 17%.
- For both types of concrete, the water-cured samples had significantly higher pull-off tensile strength compared with the L and C-samples. The tensile strength of the OPC samples was 20% higher compared with the HVFAC samples.
- The curing conditions had the most significant impact on the concrete water permeability. The OPC and HVFAC samples cured in water had the lowest water penetration, up to 30% of the specimen height. In the case of samples cured in other two ways, penetration depths ranged from 60% to 90% of the specimen height. HVFAC samples had up to 35% lower water penetration compared with the corresponding OPC samples.

Generally, the use of the curing compound did not significantly influence the concrete properties compared with the samples cured in standard air conditions.

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